RELION® PROTECTION AND CONTROL

630 series

Technical Manual

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This product complies with following directive and regulations.

Directives of the European parliament and of the council:

- Electromagnetic compatibility (EMC) Directive 2014/30/EU
- Low-voltage Directive 2014/35/EU
- RoHS Directive 2011/65/EU

UK legislations:

- Electromagnetic Compatibility Regulations 2016
- Electrical Equipment (Safety) Regulations 2016
- The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012

These conformities are the result of tests conducted by the third-party testing in accordance with the product standard EN / BS EN 60255-26 for the EMC directive / regulation, and with the product standards EN / BS EN 60255-1 and EN / BS EN 60255-27 for the low voltage directive / safety regulation.

The product is designed in accordance with the international standards of the IEC 60255 series.

Table of contents

Section 1 Introduction

1.1 This manual

The technical manual contains application and functionality descriptions and lists function blocks, logic diagrams, input and output signals, setting parameters and technical data sorted per function. The manual can be used as a technical reference during the engineering phase, installation and commissioning phase, and during normal service.

1.2 Intended audience

This manual addresses system engineers and installation and commissioning personnel, who use technical data during engineering, installation and commissioning, and in normal service.

The system engineer must have a thorough knowledge of protection systems, protection equipment, protection functions and the configured functional logic in the protection relays. The installation and commissioning personnel must have a basic knowledge in handling electronic equipment.

1.3 Product documentation

1.3.1 Product documentation set

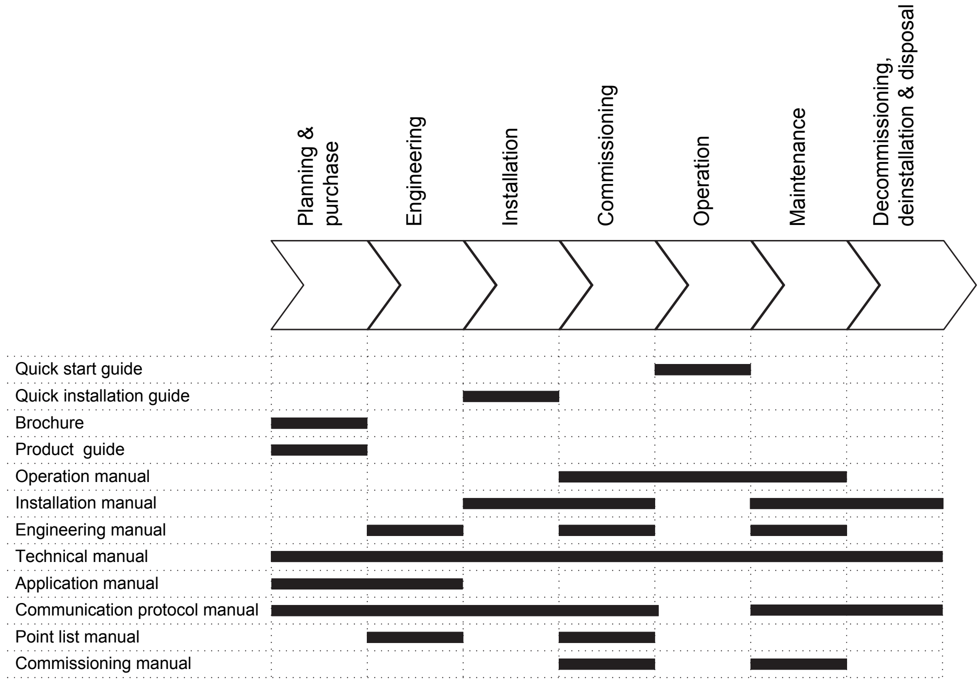


Figure 1: The intended use of documents during the product life cycle

Product series- and product-specific manuals can be downloaded from the ABB Web site www.abb.com/mediumvoltage.

1.3.2 Document revision history

Document revision/date	Product series version	History
A/2009-09-15	1.0	First release
B/2011-03-07	1.1	Content updated to correspond to the product series version
C/2011-05-18	1.1	Content updated
D/2012-09-18	1.2	Content updated to correspond to the product series version
E/2014-11-28	1.3	Content updated to correspond to the product series version
F/2019-02-25	1.3	Content updated
G/2022-03-28	1.3	Content updated

Download the latest documents from the ABB Web site abb.com/mediumvoltage.

1.3.3 Related documentation

Product series- and product-specific manuals can be downloaded from the ABB Web site abb.com/mediumvoltage.

1.4 Symbols and conventions

1.4.1 Symbols

The electrical warning icon indicates the presence of a hazard which could result in electrical shock.

The warning icon indicates the presence of a hazard which could result in personal injury.

The caution icon indicates important information or warning related to the concept discussed in the text. It might indicate the presence of a hazard which could result in corruption of software or damage to equipment or property.

The information icon alerts the reader of important facts and conditions.

The tip icon indicates advice on, for example, how to design your project or how to use a certain function.

Although warning hazards are related to personal injury, it is necessary to understand that under certain operational conditions, operation of damaged equipment may result in degraded process performance leading to personal injury or death. Therefore, comply fully with all warning and caution notices.

1.4.2 Document conventions

A particular convention may not be used in this manual.

- Abbreviations and acronyms are spelled out in the glossary. The glossary also contains definitions of important terms.
- Push button navigation in the LHMI menu structure is presented by using the push button icons.
  To navigate between the options, use and .
- Menu paths are presented in bold.
  Select **Main menu/Settings**.
- WHMI menu names are presented in bold.
  Click **Information** in the WHMI menu structure.
- LHMI messages are shown in Courier font.
  To save the changes in nonvolatile memory, select `Yes` and press .
- Parameter names are shown in italics.
  The function can be enabled and disabled with the *Operation* setting.
- The ^ character in front of an input or output signal name in the function block symbol given for a function, indicates that the user can set an own signal name in PCM600.
- The * character after an input or output signal name in the function block symbol given for a function, indicates that the signal must be connected to another function block in the application configuration to achieve a valid application configuration.

1.4.3 Functions, codes and symbols

Table 1: Functions included in the IEDs

Description	IEC 61850	IEC 60617	ANSI
Protection			
Three-phase non-directional overcurrent protection, low stage	PHLPTOC	3I>	51P-1
Three-phase non-directional overcurrent protection, high stage	PHHPTOC	3I>>	51P-2
Three-phase non-directional overcurrent protection, instantaneous stage	PHIPTOC	3I>>>	50P/51P
Voltage dependent overcurrent protection	PHPVOC	I(U)>	51V
Three-phase directional overcurrent protection, low stage	DPHLPDOC	3I> ->	67-1
Three-phase directional overcurrent protection, high stage	DPHHPDOC	3I>> ->	67-2
Distance protection	DSTPDIS	Z<	21, 21P, 21N
Automatic switch-onto-fault logic	CVRSOF	SOTF	SOTF
Fault locator	SCEFRFLO	FLOC	21FL
Autoreclosing	DARREC	O -> I	79
Non-directional earth-fault protection, low stage	EFLPTOC	I0>	51N-1

Table continues on next page

Description	IEC 61850	IEC 60617	ANSI
Non-directional earth-fault protection, high stage	EFHPTOC	I0>>	51N-2
Non-directional earth-fault protection, instantaneous stage	EFIPTOC	I0>>>	50N/51N
Directional earth-fault protection, low stage	DEFLPDEF	I0> ->	67N-1
Directional earth-fault protection, high stage	DEFHPDEF	I0>> ->	67N-2
Harmonics based earth-fault protection	HAEFPTOC	Io>HA	51NHA
Transient/intermittent earth-fault protection	INTRPTEF	I0> -> IEF	67NIEF
Admittance-based earth-fault protection	EFPADM	Yo> ->	21YN
Multi-frequency admittance-based earth-fault protection	MFADPSDE	I0> ->Y	67YN
Wattmetric earth-fault protection	WPWDE	Po> ->	32N
Stabilised restricted earth-fault protection	LREFPNDF	dI0Lo>	87NL
Third harmonic based stator earth fault protection	H3EFPSEF	dUo(3H)>/ Uo(3H)<	27/59THD
High-impedance based restricted earth-fault protection	HREFPDIF	dI0Hi>	87NH
Rotor earth-fault protection	MREFPTOC	Io>R	64R
Phase discontinuity protection	PDNSPTOC	I2/I1>	46PD
Negative-sequence overcurrent protection	NSPTOC	I2>	46
Negative-sequence overcurrent protection for machines	MNSPTOC	I2>G/M	46G/46M
Phase-reversal protection	PREVPTOC	I2>>	46R
Three-phase thermal overload protection for feeder	T1PTTR	3Ith>F	49F
Three-phase thermal overload protection, two time constants	T2PTTR	3Ith>T/G	49T/G
Three-phase thermal overload protection for motors	MPTTR	3Ith>M	49M
Motor startup supervision	STTPMSU	Is2t n<	48,66,14,51LR
Motor load jam protection	JAMPTOC	Ist>	51LR
Emergency start	ESMGAPC	ESTART	ESTART
Loss of load supervision	LOFLPTUC	3I<	37
Three-phase current inrush detection	INRPHAR	3I2f>	68
Transformer differential protection for two-winding transformers	TR2PTDF	3dI>T	87T
High-impedance or flux-balance based differential protection for machines	MHZPDIF	3dIHi>G/M	87GH/87MH

Table continues on next page

Description	IEC 61850	IEC 60617	ANSI
Stabilized differential protection for machines	MPDIF	3dI>G/M	87G/87M
Three-phase overvoltage protection	PHPTOV	3U>	59
Three-phase undervoltage protection	PHPTUV	3U<	27
Positive-sequence overvoltage protection	PSPTOV	U1>	47O+
Positive-sequence undervoltage protection	PSPTUV	U1<	47U+
Negative-sequence overvoltage protection	NSPTOV	U2>	47O-
Residual overvoltage protection	ROVPTOV	U0>	59G
Directional reactive power undervoltage protection	DQPTUV	Q>-->,3U<	32Q,27
Reverse power/directional overpower protection	DOPPDPR	P>	32R/32O
Underpower protection	DUPPDPR	P<	32U
Frequency gradient protection	DAPFRC	df/dt>	81R
Overfrequency protection	DAPTOF	f>	81O
Underfrequency protection	DAPTUF	f<	81U
Load shedding	LSHDPFRQ	UFLS/R	81LSH
Low voltage ride through protection function	LVRTPTUV	U<RT	27RT
Overexcitation protection	OEPVPH	U/f>	24
Voltage vector shift protection	VVSPPAM	VS	78V
Three-phase underexcitation protection	UEXPDIS	X<	40
Three-phase underimpedance protection	UZPDIS	Z< GT	21GT
Circuit breaker failure protection	CCBRBRF	3I>/I0>BF	51BF/51NBF
Tripping logic	TRPPTRC	I -> O	94
Multipurpose analog protection	MAPGAPC	MAP	MAP
Protection-related functions			
Local acceleration logic	DSTPLAL	LAL	LAL
Communication logic for residual overcurrent	RESCPSCH	CLN	85N
Scheme communication logic	DSOCPSCH	CL	85
Current reversal and WEI logic	CRWPSCH	CLCRW	85CRW
Current reversal and WEI logic for residual overcurrent	RCRWPSCH	CLCRWN	85NCRW
Control			
Bay control	QCCBAY	CBAY	CBAY
Interlocking interface	SCILO	3	3
Table continues on next page			

Description	IEC 61850	IEC 60617	ANSI
Circuit breaker/disconnector control	GNRLCSWI	I <-> O CB/DC	I <-> O CB/DC
Circuit breaker	DAXCBR	I <-> O CB	I <-> O CB
Disconnector	DAXSWI	I <-> O DC	I <-> O DC
Local/remote switch interface	LOCREM	R/L	R/L
Synchrocheck	SYNCRSYN	SYNC	25
Tap changer control with voltage regulator	OLATCC	COLTC	90V
Generic process I/O			
Single point control (8 signals)	SPC8GGIO	-	-
Double point indication	DPGGIO	-	-
Single point indication	SPGGIO	-	-
Generic measured value	MVGGIO	-	-
Logic Rotating Switch for function selection and LHMI presentation	SLGGIO	-	-
Selector mini switch	VSGGIO	-	-
Pulse counter for energy metering	PCGGIO	-	-
Event counter	CNTGGIO	-	-
Supervision and monitoring			
Runtime counter for machines and devices	MDSOPT	OPTS	OPTM
Circuit breaker condition monitoring	SSCBR	CBCM	CBCM
Fuse failure supervision	SEQRFUF	FUSEF	60
Current circuit supervision	CCRDIF	MCS 3I	MCS 3I
Trip-circuit supervision	TCSSCBR	TCS	TCM
Station battery supervision	SPVNZBAT	U<>	U<>
Energy monitoring	EPDMMTR	E	E
Measured value limit supervision	MVEXP	-	-
Hot-spot and insulation ageing rate monitoring for transformers	HSARSPTR	3Ihp>T	26/49HS
Tap position indication	TPOSSLTC	TPOSM	84M
Power quality			
Voltage variation	PHQVVR	PQMU	PQMV
Voltage unbalance	VSQVUB	PQMUBU	PQMUBV
Current harmonics	CMHAI	PQM3I	PQM3I
Voltage harmonics (phase-to-phase)	VPPMHAI	PQM3Upp	PQM3Vpp
Voltage harmonics (phase-to-earth)	VPHMHAI	PQM3Upe	PQM3Vpg
Measurement			
Three-phase current measurement	CMMXU	3I	3I
Table continues on next page			

Description	IEC 61850	IEC 60617	ANSI
Three-phase voltage measurement (phase-to-earth)	VPHMMXU	3Upe	3Upe
Three-phase voltage measurement (phase-to-phase)	VPPMMXU	3Upp	3Upp
Residual current measurement	RESCMMXU	I0	I0
Residual voltage measurement	RESVMMXU	U0	U0
Power monitoring with P, Q, S, power factor, frequency	PWRMMXU	PQf	PQf
Sequence current measurement	CSMSQI	I1, I2	I1, I2
Sequence voltage measurement	VSMSQI	U1, U2	V1, V2
Analog channels 1-10 (samples)	A1RADR	ACH1	ACH1
Analog channels 11-20 (samples)	A2RADR	ACH2	ACH2
Analog channels 21-30 (calc. val.)	A3RADR	ACH3	ACH3
Analog channels 31-40 (calc. val.)	A4RADR	ACH4	ACH4
Binary channels 1-16	B1RBDR	BCH1	BCH1
Binary channels 17 -32	B2RBDR	BCH2	BCH2
Binary channels 33 -48	B3RBDR	BCH3	BCH3
Binary channels 49 -64	B4RBDR	BCH4	BCH4
Station communication (GOOSE)			
Binary receive	GOOSEBINRCV	-	-
Double point receive	GOOSEDPRCV	-	-
Interlock receive	GOOSEINTLKRCV	-	-
Integer receive	GOOSEINTRCV	-	-
Measured value receive	GOOSEMVRCV	-	-
Single point receive	GOOSESPRCV	-	-

Section 2 630 series overview

2.1 Overview

630 series consists of IEDs for protection, control, measurement and supervision of utility and industrial distribution substations, medium and large asynchronous motors in industrial power systems, and transformers in utility and industry power distribution networks.

630 series is a part of ABB's Relion® product family. The 630 protection and control product series is characterized by functional scalability and flexible configurability. It also features necessary control functions for bay control in different applications.

The supported communication protocols including IEC 61850 offer seamless connectivity to various station automation and SCADA systems.

2.1.1 Product series version history

Product series version	Product series history
1.0	First release
1.1	• Support for IEC 60870-5-103 communication protocol • Analog GOOSE • RTD module • New analog input modules • Additional arithmetic and logic function support • Admittance-based earth-fault protection • Wattmetric earth-fault protection • Power quality functions • Stabilized three-phase differential protection for motors and generators • High-impedance/flux-balance-based differential protection for motors and generators • Synchronized motor protections • Voltage control of transformers (single and parallel) • Three-phase underimpedance protection • Overexcitation protection
1.2	• REG630 generator protection and control • Voltage-dependent overcurrent protection • Underpower protection • Third harmonic-based stator earth-fault protection

1.3	• Harmonics based earth-fault protection
	• Directional reactive power undervoltage protection
	• Multi-frequency admittance-based earth-fault protection
	• Runtime counter for machines and devices
	• AND and OR gates with 20 inputs
	• Voltage vector shift protection
	• Low voltage ride through protection
	• Comparison functions
	    • Equality check for integer and real signals
	    • Greater than or equal check for integer and real signals
	    • Greater than check for integer and real signals
	    • Less than or equal check for integer and real signals
	    • Less than check for integer and real signals
	    • Not equal check for integer and real signals
	• Hot-spot and insulation ageing rate monitoring for transformers

2.1.2 PCM600 and IED connectivity package version

- Protection and Control IED Manager PCM600 Ver. 2.5 or later
- ABB REF630 Connectivity Package Ver. 1.3 or later
- ABB REG630 Connectivity Package Ver. 1.3 or later
- ABB REM630 Connectivity Package Ver. 1.3 or later
- ABB RET630 Connectivity Package Ver. 1.3 or later

Download connectivity packages from the ABB Web site abb.com/mediumvoltage or directly with Update Manager in PCM600.

2.2 Local HMI

The LHMI is used for setting, monitoring and controlling the protection relay. The LHMI comprises the display, buttons, LED indicators and communication port.

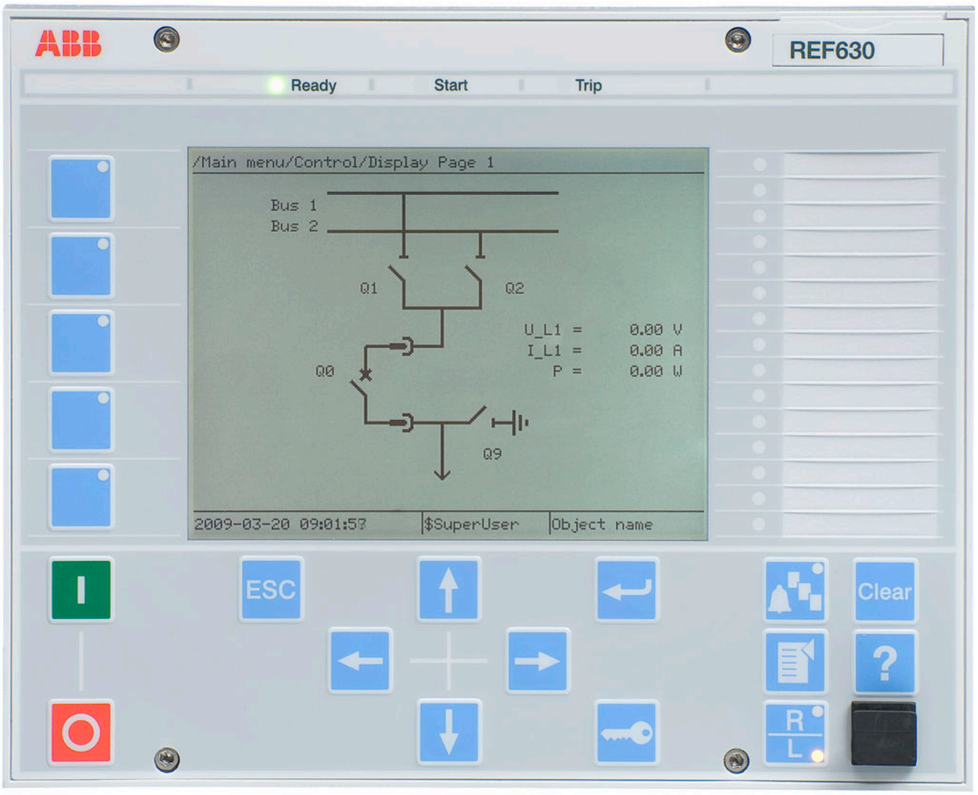


Figure 2: Example of the LHMI

2.2.1 Display

The LHMI includes a graphical monochrome display with a resolution of 320 x 240 pixels. The character size can vary. The amount of characters and rows fitting the view depends on the character size and the view that is shown.

The display view is divided into four basic areas.

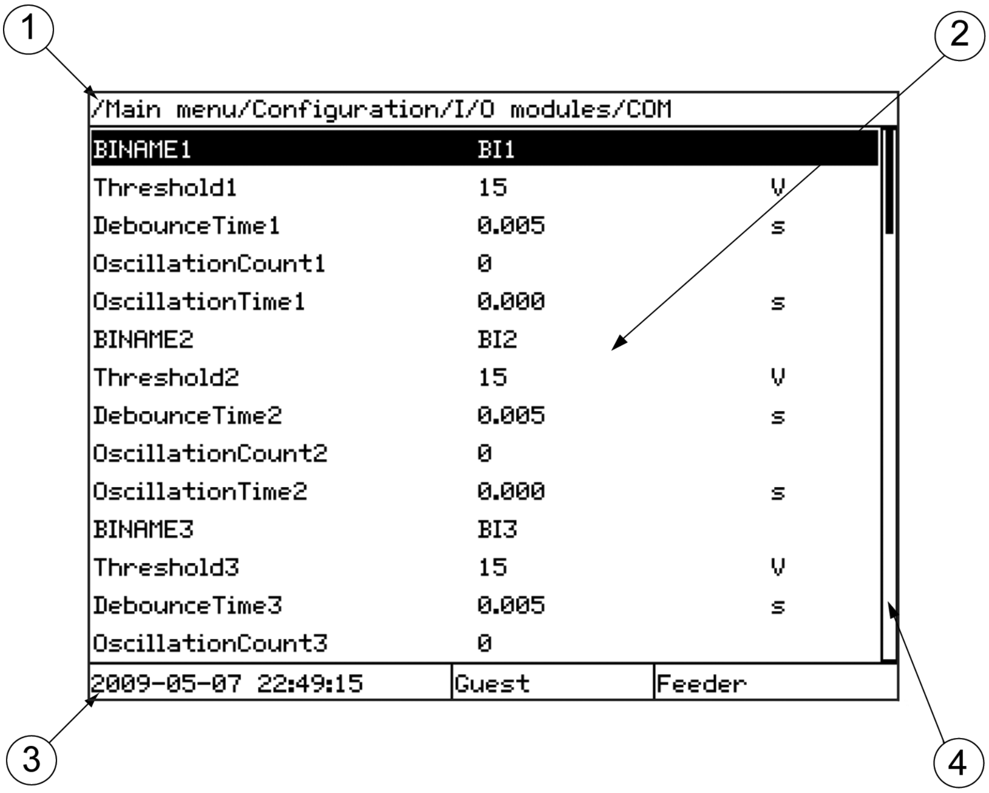


Figure 3: Display layout

1 Path

2 Content

3 Status

4 Scroll bar (appears when needed)

The function button panel shows on request what actions are possible with the function buttons. Each function button has a LED indication that can be used as a feedback signal for the function button control action. The LED is connected to the required signal with PCM600.

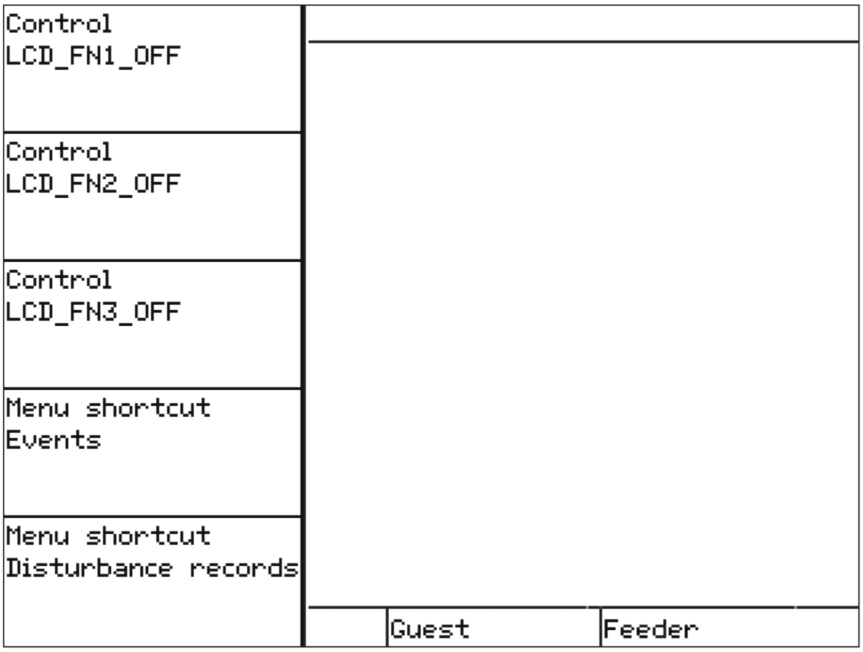


Figure 4: Function button panel

The alarm LED panel shows on request the alarm text labels for the alarm LEDs.

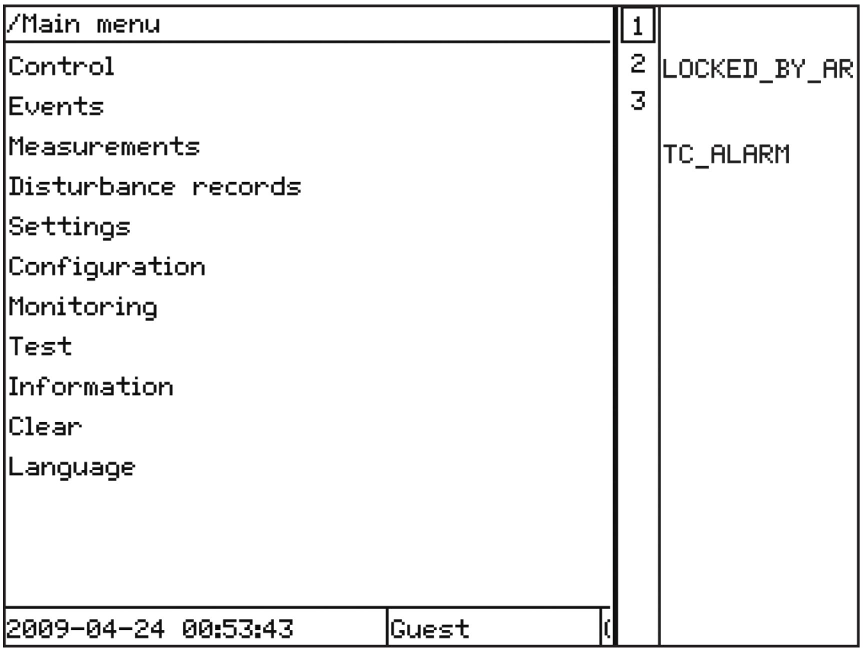


Figure 5: Alarm LED panel

The function button and alarm LED panels are not visible at the same time. Each panel is shown by pressing one of the function buttons or the Multipage button. Pressing the ESC button clears the panel from the display. Both the panels have dynamic width that depends on the label string length that the panel contains.

2.2.2 LEDs

The LHMI includes three protection status LEDs above the display: Ready, Start and Trip.

There are 15 programmable alarm LEDs on the front of the LHMI. Each LED can indicate three states with the colors: green, yellow and red. The alarm texts related to each three-color LED are divided into three pages. Altogether, the 15 physical three-color LEDs can indicate 45 different alarms. The LEDs can be configured with PCM600 and the operation mode can be selected with the LHMI, WHMI or PCM600.

2.2.3 Keypad

The LHMI keypad contains push-buttons which are used to navigate in different views or menus. With the push-buttons you can control objects in the single-line diagram, for example, circuit breakers or disconnectors The push-buttons are also used to acknowledge alarms, reset indications, provide help and switch between local and remote control mode.

The keypad also contains programmable push-buttons that can be configured either as menu shortcut or control buttons.

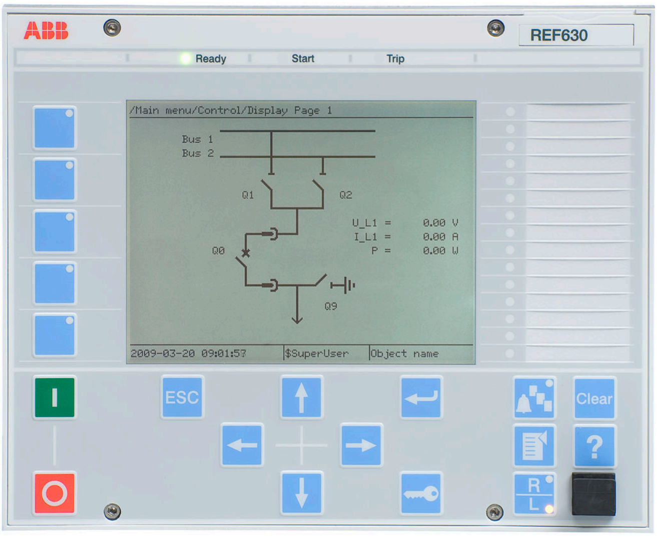


Figure 6: LHMI keypad with object control, navigation and command push-buttons and RJ-45 communication port

2.3 Web HMI

The WHMI enables the user to access the protection relay via a Web browser. The supported Web browser versions are Internet Explorer 8.0, 9.0 and 10.0.

WHMI is disabled by default. To enable the WHMI, select **Main menu/Configuration/HMI/Web HMI/Operation** via the LHMI.

WHMI offers several functions.

- Alarm indications and event lists
- System supervision
- Parameter settings
- Measurement display
- Disturbance records
- Phasor diagram

Viewing phasor diagram with WHMI requires downloading a SVG Viewer plugin.

The menu tree structure on the WHMI is almost identical to the one on the LHMI.

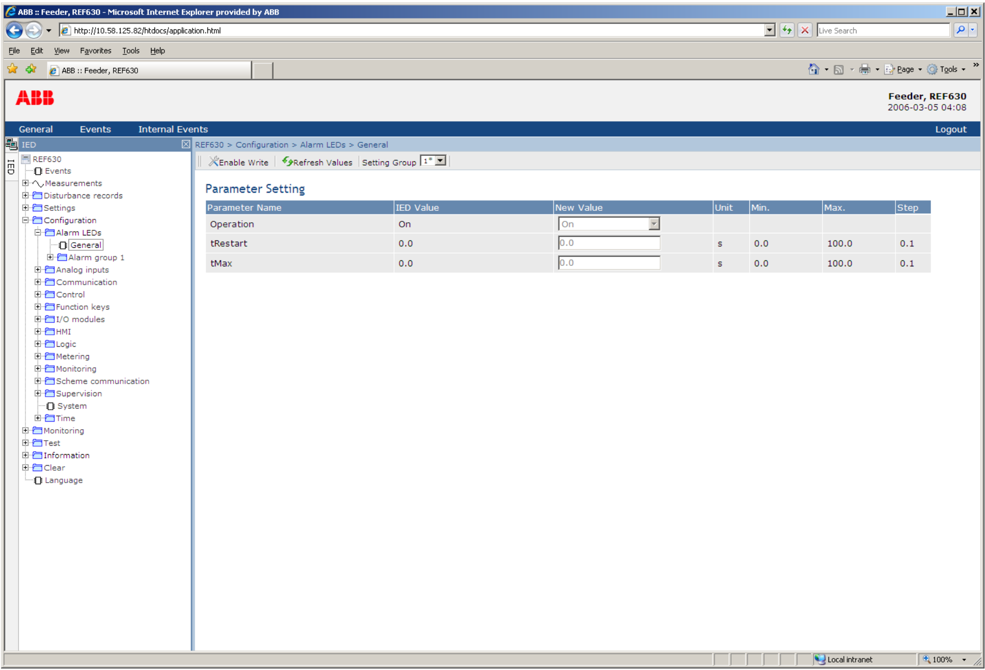


Figure 7: Example view of the WHMI

The WHMI can be accessed locally and remotely.

- Locally by connecting the user's computer to the protection relay via the front communication port.
- Remotely over LAN/WAN.

2.4 Authorization

At delivery, logging on to the IED is not required to be able to use the LHMI. The IED user has full access to the IED as a SuperUser until users and passwords are created with PCM600 and written into the IED.

The available user categories are predefined for LHMI and WHMI, each with different rights.

Table 2: Available user categories

User category	User rights
SystemOperator	Control from LHMI, no bypass
ProtectionEngineer	All settings
DesignEngineer	Application configuration
UserAdministrator	User and password administration

All changes in user management settings cause the IED to reboot.

2.5 Communication

The protection relay supports communication protocols IEC 61850-8-1, IEC 60870-5-103 and DNP3 over TCP/IP.

All operational information and controls are available through these protocols. However, some communication functionality, for example, horizontal communication (GOOSE) between the protection relays, is only enabled by the IEC 61850-8-1 communication protocol.

Disturbance files are accessed using the IEC 61850 or IEC 60870-5-103 protocols. Disturbance files are also available to any Ethernet based application in the standard COMTRADE format. The protection relay can send binary signals to other protection relays (so called horizontal communication) using the IEC 61850-8-1 GOOSE (Generic Object Oriented Substation Event) profile. Binary GOOSE messaging can, for example, be employed for protection and interlocking-based protection schemes. The protection relay meets the GOOSE performance requirements for tripping applications in distribution substations, as defined by the IEC 61850 standard. Further, the protection relay supports the sending and receiving of analog values using GOOSE messaging. Analog GOOSE messaging enables fast transfer of analog measurement values over the station bus, thus facilitating for example sharing of RTD input values, such as surrounding temperature values, to other relay applications. The protection relay interoperates with other IEC 61850 compliant devices, tools and systems and simultaneously reports events to five different clients on the IEC 61850 station bus. For a system using DNP3 over TCP/IP, events can be sent to four different masters. For systems using IEC 60870-5-103, the protection relay can be connected to one master in a station bus with star-topology.

All communication connectors, except for the front port connector, are placed on integrated communication modules. The protection relay is connected to Ethernet-based communication systems via the RJ-45 connector (10/100BASE-TX) or the fibre-optic multimode LC connector (100BASE-FX).

IEC 60870-5-103 is available from optical serial port where it is possible to use serial glass fibre (ST connector) or serial plastic fibre (snap-in connector).

The protection relay supports the following time synchronization methods with a timestamping resolution of 1 ms.

Ethernet communication based

- SNTP (simple network time protocol)
- DNP3

With special time synchronization wiring

- IRIG-B

IEC 60870-5-103 serial communication has a time-stamping resolution of 10 ms.

Section 3 Basic functions

3.1 General parameters

Table 3: Battery voltage setting available for each BIO and COM board.

Name	Values (Range)	Unit	Step	Default	Description
BatteryVoltage	24 - 250	V	1	110	Station battery voltage

Table 4: Binary input settings available for all binary inputs in BIO and COM boards.

Name	Values (Range)	Unit	Step	Default	Description
Threshold1	6 - 900	%UB	1	65	Threshold in percentage of station battery voltage for input 1
DebounceTime1	0.01 - 0.100	s	0.001	0.01	Debounce time for input 1
OscillationCount1	0 - 255	-	1	0	Oscillation count for input 1
OscillationTime1	0.000 - 600.000	s	0.001	0.000	Oscillation time for input 1

Binary input settings are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

Table 5: RTD01_4AO output channel settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
MinMaxRange1	0..20 mA 4..20 mA User Defined	-	-	4..20 mA	Min Max range of transducer value for analog output 1
MinPrimValue1	-1000000000.000 - 1000000000.000	-	0.001	4.000	Minimum primary value for analog output 1
MaxPrimValue1	-1000000000.000 - 1000000000.000	-	0.001	20.000	Maximum primary value for analog output 1

RTD output channel settings are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

Table 6: RTD01_4AO output channel settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
UDefMinRangeCh1	-20.00 - 20.00	mA	0.01	4.00	User defined minimum range for analog output 1
UDefMaxRangeCh1	-20.00 - 20.00	mA	0.01	20.00	User defined maximum range for analog output 1
EnableDeadBand1	Off On	-	-	Off	Enable dead band for analog output 1
DeadBandValue1	0.10 - 10.00	%	0.01	0.10	Dead band value for analog output 1

RTD output channel settings are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

Table 7: RTD01_8AI input channel settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
InputMode1	Off Voltage Current Temp(RTD) 2Wire Temp(RTD) 3Wire Resistance 2 Wire Resistance 3 Wire	-	-	Off	Signal mode for analog input 1
InputType1	PT100 PT250 NI100 NI120 CU10	-	-	PT100	Temperature sensor type for analog input 1
MinMaxRange1	0..1(mA or V) 0..5(mA or V) 1..5(mA or V) 0..10(mA or V) -5..5(mA or V) -10..10(mA or V) 2..10 V 0..20 mA 4..20 mA -1..1 mA -2.5..2.5 mA -20..20 mA 0..100 Ohm 0..200 Ohm 0..500 Ohm 0..1000 Ohm 0..2000 Ohm 0..5000 Ohm 0.10000 Ohm User Defined	-	-	4..20 mA	Min Max range of transducer value for analog input 1
MinPrimValue1	-1000000000.000 - 1000000000.000	-	0.001	4.000	Minimum primary value for analog input 1
MaxPrimValue1	-1000000000.000 - 1000000000.000	-	0.001	20.000	Maximum primary value for analog input 1

RTD input channel settings are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

Table 8: RTD01_8AI input channel settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
FilterTime1	0.4 s 1 s 2 s 3 s 4 s 5 s	-	-	5 s	Filter co-efficient time for analog input 1
EnableDeadBand1	Off On	-	-	Off	Enable dead band for analog input 1
DeadBandValue1	0.10 - 10.00	%	0.01	0.10	Dead band value for analog input 1
UDefMinRange1	-25.00 - 20000.00	-	0.01	4.00	User defined minimum range of transducer value for analog input 1
UDefMaxRange1	-25.00 - 20000.00	-	0.01	20.00	User defined maximum range of transducer value for analog input 1
TolrncLLimitCh1	-4.0 - 0.0	%	0.1	0	Low tolerance limit for analog input 1
TolrncHLimitCh1	0.0 - 4.0	%	0.1	0	High tolerance limit for analog input 1
UDefUnitCh1	None Current Voltage Resistance Celsius temp	-	-	None	User defined unit for analog input 1

RTD input channel settings are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

Table 9: TRM CT input channel settings

Name	Values (Range)	Unit	Step	Default	Description
ReversePolarity1	Yes No	-	-	No	Reverse polarity of the current in channel 1
CTsec1	0.1 - 10.0	A	0.1	1	Rated CT secondary current
CTprim1	1 - 99999	A	1	400	Rated CT primary current

TRM CT input channel settings are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

Table 10: TRM VT input channel settings

Name	Values (Range)	Unit	Step	Default	Description
VTsec6	0.001 - 999.999	V	0.001	110	Rated VT secondary voltage
VTprim6	0.001 - 9999.999	kV	0.001	20	Rated VT primary voltage

TRM VT input channel settings are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

3.2 Binary input

3.2.1 Binary input design

The design of all binary inputs enables burning off the oxide of the relay contact connected to the input. This is achieved with a high peak inrush current while maintaining a low steady-state current. The design is used to make a reliable contact with the external output contact. The short current pulse is intended for removing any possible oxidation from the contact surface of the connected contact.

Use only DC power for the binary inputs. Use of AC power, including full- or half-wave rectified AC power, may cause damage to the binary input modules.

3.2.2 Binary input debounce filter

The debounce filter eliminates bounces and short disturbances on a binary input.

A time counter is used for filtering. The time counter is increased once in a millisecond when a binary input is high, or decreased when a binary input is low. A new debounced binary input signal is forwarded when the time counter reaches the set *DebounceTime* value and the debounced input value is high or when the time counter reaches 0 and the debounced input value is low. The default setting of *DebounceTime* is 10 ms.

The binary input ON-event gets the time stamp of the first rising edge, after which the counter does not reach 0 again. The same happens when the signal goes down to 0 again.

Each binary input has a filter time parameter *DebounceTimex*, where x is the number of the binary input of the module in question (for example *DebounceTime1*).

3.2.3 Oscillation filter

Binary input lines can be very long in substations and there are electromagnetic fields from, for example, nearby breakers. Floating input lines can result in binary inputs' activity. These events are unwanted traffic in the system. An oscillation filter is used to reduce the load from the system when a binary input starts oscillating.

Each debounced input signal change increments an oscillation counter. Every time the oscillation time counter reaches the set *OscillationTime*, the oscillation counter is checked and both the time counter and the oscillation counter are reset. If the counter value is above the set *OscillationCount* value the signal is declared as oscillating. If the value is below the set *OscillationCount* value, the signal is declared as valid again. During counting of the oscillation time the status of the signal remains unchanged, leading to a fixed delay in the status update, even if the signal has attained normal status again.

Each binary input has an oscillation count parameter *OscillationCountx* and an oscillation time parameter *OscillationTimex*, where x is the number of the binary input of the module in question.

3.3 RTD module

The RTD module is a multipurpose input and analog output hardware with eight multipurpose inputs and four mA outputs. Each of the multipurpose inputs (referred as RTD inputs) is designed to support RTD temperature sensor, current, voltage or resistance type of inputs. Each of the input channels can be configured as any one of these input types. Each input can be linearly scaled for various applications, for example, transformer tap changer position indication. Each input has an independent limit value supervision and a dead band supervision function along with error signal indication.

3.3.1 Multipurpose analog inputs

3.3.1.1 Functionality

All the inputs of the RTD module are independent channels with individual protection, reference and isolation, making them galvanically isolated from the rest of the module. However, the RTD inputs share a common ground. The RTD inputs are designed to support four different types of inputs.

- Temperature (RTD), supports both 2-wire and 3-wire connections (-100.0°C... +200.0°C).
- Current (-20...+20 mA).
- Voltage (-10...+10 V).
- Resistance, supports both 2-wire and 3-wire connections (0 Ω...10000 Ω).

The input channels can be configured as any one of the input types mentioned above.

3.3.1.2 Operation principle

Selection of input signal type

The RTD module has eight RTD input channels and carries scaled primary values, quality and a time stamp. Each input channel has an associated error status channel (AIx_ERR, where x is the input channel number) and one global error status input (AI_ERROR). Each input channel can be configured for a particular type of input signal like current, voltage, temperature or resistance using the setting *InputMode*. The setting allows the Monitoring tool and LHMI to show appropriate quantity and units. The default value is "Off".

When the *InputMode* setting is in one of the RTD modes (2-wire or 3-wire) the type of temperature sensor can be selected using the setting parameter *InputType*. The types of sensors available for the input module and the default selection are as shown in the RTD module input channel settings table.

The error status associated with each input channel (AIx_ERR) is updated based on the individual channel supervision and range check. This is done by checking the status of the input values and quality bit received from the RTD hardware module. The error status has a value of 0 for Input Valid, and a value of 1 for Data Quality Invalid/ out of range input values. The global error status for the input channels (AI_ERROR) indicates failure of the input module.

The module has an additional eight service channels which provides non-scaled secondary values (sensor values) along with the default units for the monitoring purpose.

Selection of output value format

Primary scaled values

The RTD input component provides primary scaled values to the application functions, which are also shown in the LHMI and Signal Monitoring tool with units. The appropriate unit for an input channel is set by using the setting *UDefUnitCh*. The available settings and the default value are as shown in RTD module input channel settings table.

Secondary (Service) values

The input module provides secondary (service) values along with units for the purpose of monitoring from the LHMI and Signal Monitoring tool.

User defined names

Each input channel can be assigned a user defined name using the Application Configuration tool.

Input linear scaling

The scaling of current, voltage and resistance signals is based on the settings *MinMaxRange*, *MinPrimValue* and *MaxPrimValue*. *MinMaxRange* setting represents transducer ranges where as *MinPrimValue* and *MaxPrimValue* settings represent the range of primary values.

MinPrimValue and *MaxPrimValue* is the range of primary values used as scaling parameters.

The calculations of scaling values are shown in below.

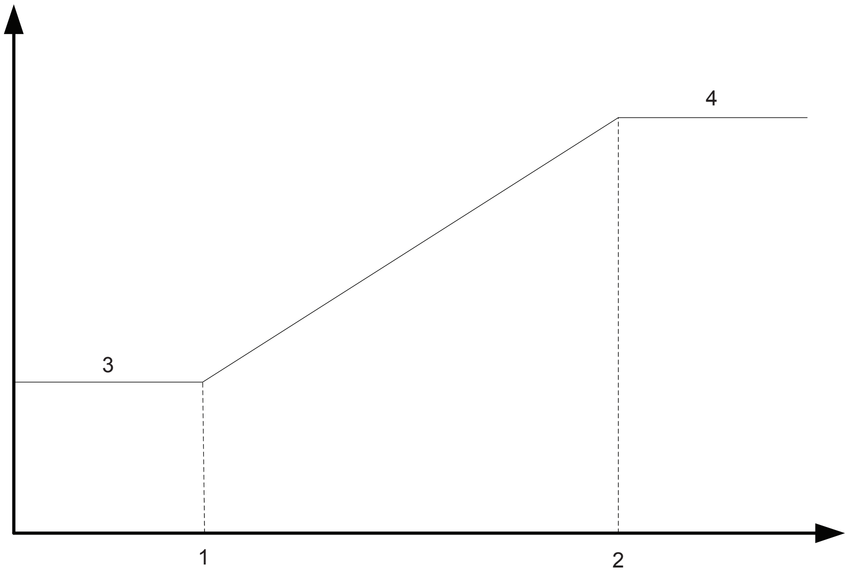


Figure 8: Scaling factor calculation

1 *MinRange* (Secondary values)
2 *MaxRange* (Secondary values)
3 *MinPrimValue* (Primary values)
4 *MaxPrimValue* (Primary values)

The above four values are setting parameters.

Other assumptions considered:

1. Outputs vary in linear proportion to input values.
2. Sensor error binary output is signaled if input values are out of range of *MaxRange* and *MinRange*.

Requirements for current (mA), typical values.

- *MinMaxRange*=0-20 mA, then let

    - *MinRange*=0 mA
    - *MaxRange*=20 mA
- *MinPrimValue*=0 A
- *MaxPrimValue*=1000 A

Let X=(*MaxPrimValue*-*MinPrimValue*)/(*MaxRange*-*MinRange*)

Then

Output=*MinPrimValue*+X·(Input-*MinRange*)

Example:

X=(1000000-0)/(20-0)=50000

If Input is 5 mA, Output=0+50000·(5-0)=250000 mA=250 A

Output=250 A when Input is 5 mA.

Requirements for voltage(V), typical values.

- *MinMaxRange*=0-10 V, then let
    - *MinRange*=0 V
    - *MaxRange*=10 V
- *MinPrimValue*=0 V
- *MaxPrimValue*=11000 V

Let X=(*MaxPrimValue*-*MinPrimValue*)/(*MaxRange*-*MinRange*)

Example:

X=(11000-0/(10-0)=1100

If Input is 6.3 V, Output=0+1100·(6.3-0)=6930 V=6.93 kV

Output=6.93 kV when Input is 6.3 V.

The *MinMaxRange* setting provides input range for different type of inputs. These are standard values applicable to the input sensors. A user defined value can be used when input range does not have any of the defined values.

The "User Defined" option provides the flexibility to adapt to different types of input ranges. When "User Defined" option is selected, it is necessary to set the *UDefMinRange* and *UDefMaxRange* values which are used for scaling factor computation.

The scaling functionality is not applicable when the input channel is configured in temperature modes (RTD 2-wire and RTD 3-wire).

Dead band supervision

The dead band handling deals with primary values in the input system components. The functionality decides percentage change in the input values that needs to be reported to the application. That is, if the percentage change between the current measured input values and the last reported values is greater than the setting *DeadBandValue* (in %) of the Primary measured range, the current measurement is reported to the application. Otherwise, the last reported measurement value is continued to be made available for the application.

The Primary measured range is the difference between the settings *Max value* and *Min value*.

$$\left[ABS\left(new\,value - last\,reported\,value\right) > \left(\%\,of\;\;DeadBandValue \cdot Primary\,measured\,range\right)\right]$$
$$Primary\,measured\,range = ABS\left(MaxValue - MinValue\right)$$

(Equation 1)

The range of the setting *DeadBandValue* and its default value are as shown in the RTD module input channel settings table.

The dead band handling feature can be enabled using the setting *EnableDeadBand*. If the feature is disabled, the input channel values are updated to application components at the same rate as the RTD hardware input update frequency.

Channel supervision

If the measured values at any of the input channel falls below the setting *TolrncLLimitCh* or rises above the setting *TolrncHLimitCh* for the selected input signal range (*MinMaxRange* or user defined range parameters), either the transducer or the wiring is considered to be faulty or the values are considered as out of range and the channel-specific invalid signal is activated. The invalid signal is deactivated when the transducer signal is received within the valid range. The range of the settings *TolrncLLimitCh* and *TolrncHLimitCh* is as shown in the RTD module input channel settings table.

As an example, when a channel *MinMaxRange* parameter is configured as "4-20 mA" and set *TolrncLLimitCh* and *TolrncHLimitCh* are -1% and +1% respectively, the active input is marked faulty/invalid if the measured value is below 3.84 mA or above 20.16 mA.

The operating ranges for the different type of inputs are as shown in the RTD module input channel settings table. If the measured values are out of the specified range, the RTD module freezes the value to the boundary values as specified in and set the invalid flag.

The invalid flag set and reported by the RTD hardware is updated to applications components accordingly.

Since *MinMaxRange* value is not valid for Temperature Input mode, the tolerance range check is performed for the fixed range of values -40 to +200 °C. When a channel is configured for measuring resistance 2-wire and resistance 3-wire the tolerance is considered for values between 0 to 10000 ohms.

Self supervision

The input samples from the RTD channel are validated by using an internally set reference voltage. If the measured voltage deviates by 1.5% of the measurement range of the input, the sample is discarded. If the faulty condition persists longer than the setting *FilterTime*, the channel specific error signal `AIx_ERR` and the global error signal `AI_ERROR` are set to TRUE to indicate a hardware fault. This would also serve as a self supervision for the input channels. As the measured value settles down to acceptable levels, the error signals are cleared. Refer to the RTD module input channel settings table for various values that *FilterTime* can be set to along with its default value.

3.3.1.3 RTD input connection

All eight RTD inputs are treated as analog input channels. RTD inputs can be used with 2-wire or 3-wire connection with common ground. When using the 3-wire connection, it is important that all three wires connecting the sensor are symmetrical, that is, the wires are of same type and length. Consequently, the wire resistance is automatically compensated.

3-wire connection RTD/resistance

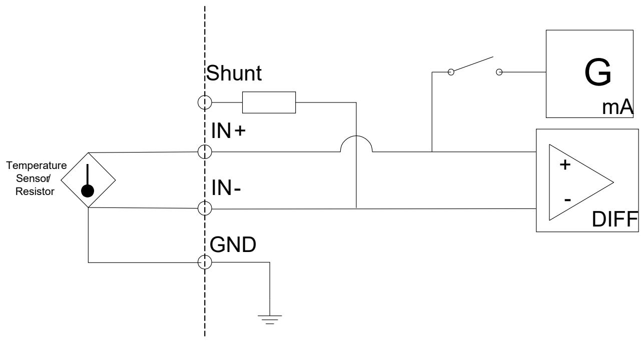


Figure 9: Physical connection diagram for 3-wire RTD source

2-wire connection RTD/resistance

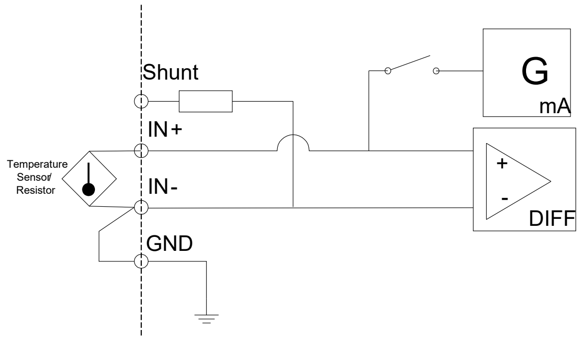


Figure 10: Physical connection diagram for 2-wire RTD source

Current transducer connection

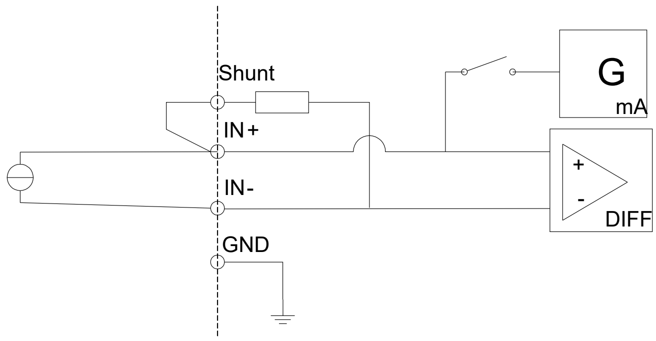


Figure 11: Physical connection diagram for current source

Current connection with grounding

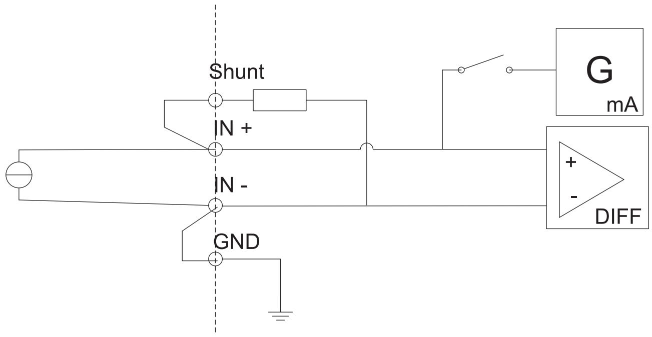


Figure 12: Physical connection diagram for current source with grounding

This mA input connection can be used when only floating or isolated mA sources are connected.

Voltage transducer connection

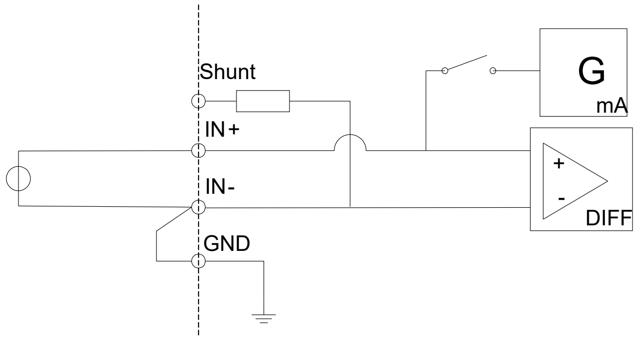


Figure 13: Physical connection diagram for voltage source

3.3.2 mA outputs

3.3.2.1 Functionality

All the outputs channels support mA output in the scalable range -20 mA to +20 mA.

3.3.2.2 Operation princible

Four analog output channels are available which can be individually configured, scaled or blocked by the user. The output components give the analog output status readback value for the respective channels. These status values are also considered as service values. Each output channel has associated readback analog output out-of-range (too high impedance) error status channel (`AOx_ERR`). The Global Error status for the output channels (`AO_ERROR`) indicates the failure of the output module and the fail status information of the output channels.

3.3.2.3 Scaling output values

The scaling of the output values is achieved using the settings *MinMaxRange*, *MinPrimValue* and *MaxPrimValue*. The settings *MinPrimValue* and *MaxPrimValue* represent the range of primary values from the application for scaling the output.

Setting *MinMaxRange* is used to scale the output mA values.

If *MinMaxRange* is set to "User Defined", the *UDefMinRangeCh* and *UDefMaxRangeCh* values are used for computing the scaling factor. These allow the flexible output range to be set anywhere between -20 mA...+20 mA.

The range of values for the setting and its default value are as shown in the RTD module input channel settings table.

Example: Let the scaling parameters be set to a primary range of 0 to 1000 A and secondary sensor range setting to ""4...20 mA"". Then a 100 A output from the application results in an output of 5.6 mA on the RTD module output side.

When using output forcing, the primary value scaling is fixed to 1000:1. If forcing is set to 5 A, it results in 5 mA to the mA output channel.

3.3.2.4 Dead band supervision

The dead band handling deals with primary values in the output components. This decides the percentage change in the output values that needs to be reported to the application. That is, the Primary values from the application are compared with the last reported value. If the difference exceeds the setting *DeadBandValue* (in %) of the primary measured range, the actual value is passed to the RTD output hardware.

The Primary measured range is the difference between the settings Max value and Min value.

$$\left[ABS\left(new\,value - last\ reported\ value\right) > \left(\%\ of\ DeadBandValue \cdot Primary\ measured\ range\right)\right]$$
$$Primary\ measured\ range = ABS\left(MaxValue - MinValue\right)$$

(Equation 2)

The range of the setting *DeadBandValue* and its default value are as shown in the RTD module input channel settings table.

The dead band handling feature can be enabled using the setting *EnableDeadBand*. If the feature is disabled, the output values are updated to application components at same rate as RTD hard ware analog output update frequency.

3.3.2.5 Supervision of analog outputs

The RTD module hardware supports the sending of the read back value with a determined repetition time and this is sent it to the application to monitor the status of mA output channel. The supervision of mA output is supported in the hardware and any fault detection can be reported to the application.

3.3.2.6 Forcing Support

Forcing of the RTD module output mA values is supported in the RTD output component. This is possible only when the IED is in the test mode. When values are forced from the LHMI, the values are treated as primary values which are scaled down to secondary currents using the output scaling parameters. The module ensures that the secondary output current values passed to the RTD hardware are within the range of -20...20 mA.

When using output forcing the primary value scaling is fixed to 1000:1. If forcing is set to 5 A, it results in 5 mA to the mA output channel.

Forcing feature can be tested only for configured output channels. When mA current values are forced to non-configured output channels, values are not passed to mA output channel HW circuitry.

3.3.2.7 Blocking

There is option to block the operation of output channels globally through the input `BLOCK` or block each individual channels using the inputs `AO1_BLK`, `AO2_BLK`, `AO3_BLK` and `AO4_BLK`.

Blocking signals are available as individual hardware channels and can be selected in PCM600 using the Application Configuration tool (ACT) from **Object types/ Hardware IO/ Binary Outputs**.

3.3.2.8 User defined names

User defined names for the individual output channels can be assigned through the Application Configuration tool.

3.4 User authentication

3.4.1 Functionality

To safeguard the interests of our customers, both the IED and the tools that are accessing the IED are protected by means of authorization handling. The authorization handling of the IED and PCM600 is implemented at both access points to the IED.

- Local, through the LHMI
- Remote, through the communication ports

3.4.2 Operation principle

Different levels (or types) of users can access or operate different areas of the IED and tools' functionality.

Table 11: Predefined user types

User type	Access rights
SystemOperator	Control from LHMI, no bypass, protection function activation and deactivation
ProtectionEngineer	All settings
DesignEngineer	Application configuration (including SMT, GDE and CMT)
UserAdministrator	User and password administration for the IED

The IED users can be created, deleted and edited only with the IED User Management within PCM600. The user can only LogOn or LogOff on the LHMI on the IED. There are no users, groups or functions that can be defined on LHMI.

Use only characters A - Z, a - z and 0 - 9 in user names and passwords.

Include at least one user in the UserAdministrator group to be able to write users created in PCM600 to the IED.

3.4.2.1 Authorization handling in the IED

At delivery the default user is the SuperUser. No Log on is required to operate the IED until a user has been created with the IED User Management.

Once a user is created and written to the IED, the user can perform a Log on using the password assigned in the tool. The default user is Guest.

If there is no user created, an attempt to log on displays a message box “No user defined!”.

If one user leaves the IED without logging off, the IED returns to Guest state, in which only reading is possible, after the timeout (set in **Main menu/ Configuration/HMI/LHMI/Display Timeout**) elapses. By factory default, the display timeout is set to 60 minutes.

If one or more users are created with the IED User Management and written to the IED, the Log on window opens if a user attempts a Log on by pressing the Key push-button or if the user attempts to perform an operation that is password protected.

See the operation manual for more information on the logon procedure.

After a successful Log on, the LHMI returns to the actual setting folder if, for example, a password protected setting needs to be changed. If the Log on has failed, an "Error Access Denied" message opens. If the user enters an incorrect password three times, the user is blocked for ten minutes before a new attempt to log in can be performed. The user is blocked from logging in from the LHMI, WHMI and PCM600. However, other users are allowed to log in during this period.

3.4.3 Authority status ATHSTAT

3.4.3.1 Function block

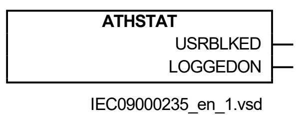


Figure 14: Function block

3.4.3.2 Functionality

Authority status (ATHSTAT) function is an indication function block for user logon activity.

3.4.3.3 Operation principle

Authority status (ATHSTAT) function informs about two events related to the IED and the user authorization.

- The fact that at least one user has tried to log on wrongly into the IED and it was blocked (the output USRBLKED)
- The fact that at least one user is logged on (the output LOGGEDON)

Whenever one of the two events occurs, the corresponding output (USRBLKED or LOGGEDON) is activated.

3.4.3.4 Signals

Table 12: ATHSTAT Output signals

Name	Type	Description
USRBLKED	BOOLEAN	At least one user is blocked by invalid password
LOGGEDON	BOOLEAN	At least one user is logged on

3.4.3.5 Settings

The function does not have any parameters available in LHMI or PCM600.

3.5 Local human-machine interface LHMI

3.5.1 Local HMI screen behaviour

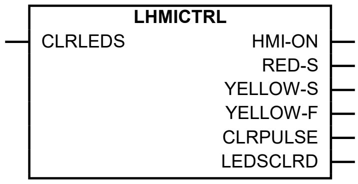
3.5.1.1 Settings

Table 13: SCREEN Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
DisplayTimeout	10 - 120	Min	10	60	Local HMI display timeout
ContrastLevel	-100 - 100	%	10	0	Contrast level for display
DefaultScreen	Main menu Control Events Measurements Disturbance records Monitoring	-	-	Main menu	Default screen
EvListSrtOrder	Latest on top Oldest on top	-	-	Latest on top	Sort order of event list
AutoIndicationDRP	Off On	-	-	Off	Automatic indication of disturbance report
SubstIndSLD	No Yes	-	-	No	Substitute indication on single line diagram
InterlockIndSLD	No Yes	-	-	No	Interlock indication on single line diagram
BypassCommands	No Yes	-	-	No	Enable bypass of commands

3.5.2 Local HMI signals

3.5.2.1 Function block



IEC09000320-1-en.vsd

Figure 15: LHMICTRL function block

3.5.2.2 Signals

Table 14: LHMICTRL Input signals

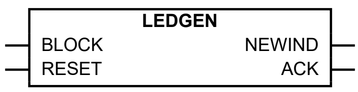
Name	Type	Default	Description
CLRLEDS	BOOLEAN	0	Input to clear the LCD-HMI LEDs

Table 15: LHMICTRL Output signals

Name	Type	Description
HMI-ON	BOOLEAN	Backlight of the LCD display is active
RED-S	BOOLEAN	Red LED on the LCD-HMI is steady
YELLOW-S	BOOLEAN	Yellow LED on the LCD-HMI is steady
YELLOW-F	BOOLEAN	Yellow LED on the LCD-HMI is flashing
CLRPULSE	BOOLEAN	A pulse is provided when the LEDs on the LCD-HMI are cleared
LEDSCLRD	BOOLEAN	Active when the LEDs on the LCD-HMI are not active

3.5.3 Basic part for the LED indication module

3.5.3.1 Function block



IEC09000321-1-en.vsd

Figure 16: LEDGEN function block

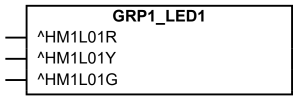


Figure 17: GRP1_LED1 function block

The GRP1_LED1 function block is an example, all 15 LED in each of group 1 - 3 has a similar function block.

3.5.3.2 Functionality

The function blocks LEDGEN and GRP1_LEDx, GRP2_LEDx and GRP3_LEDx (x=1-15) controls and supplies information about the status of the indication LEDs. The input and output signals of the function blocks are configured with PCM600. The input signal for each LED is selected individually using Signal Matrix or Application Configuration. Each LED is controlled by a GRP1_LEDx function block, that controls the color and the operating mode.

Each indication LED on LHMI can be set individually to operate in six different sequences; two as follow type and four as latch type. Two of the latching sequence types are intended to be used as a protection indication system, either in collecting or restarting mode, with reset functionality. The other two are intended to be used as signalling system in collecting mode with acknowledgment functionality.

3.5.3.3 Operation principle

Status LEDs

There are three status LEDs above the display in the front of the IED: green, yellow and red.

The green LED has a fixed function, while the yellow and red LEDs are user configured. The yellow LED can be used to indicate that a disturbance report is created (steady) or that the IED is in test mode (flashing). The red LED can be used to indicate a trip command.

Indication LEDs

Operating modes

Collecting mode

- LEDs which are used in the collecting mode of operation are accumulated continuously until the unit is acknowledged manually. This mode is suitable when the LEDs are used as a simplified alarm system.

Re-starting mode

- In the re-starting mode of operation each new start resets all previous active LEDs and activates only those which appear during one disturbance. Only LEDs defined for re-starting mode with the latched sequence type 6 (LatchedReset-S) initiate a reset and a restart at a new disturbance. A disturbance is defined to end a settable time after the reset of the activated input signals or when the maximum time limit has elapsed.

Acknowledgment/reset

- From LHMI
    - The active indications can be acknowledged/reset manually. Manual acknowledgment and manual reset have the same meaning and is a common signal for all the operating sequences and LEDs. The function is positive-edge triggered, not level triggered. Acknowledge/reset via the Clear button and menus on the LHMI.
- From function input
    - The active indications can also be acknowledged/reset from an input, ACK_RST, to the function. This input can, for example, be configured to a binary input operated from an external push button. The function is positive-edge triggered, not level triggered. This means that even if the button is continuously pressed, the acknowledgment/reset only affects indications active at the moment when the button is first pressed.
- Automatic reset
    - Only indications defined for re-starting mode with the latched sequence type 6 (LatchedReset-S)The can be automatically reset. When the LEDs have automatically been reset, still persisting indications are indicated with a steady light.

Operating sequence

The sequences can be of type Follow or Latched. For the Follow type, the LED follow the input signal completely. For the Latched type, each LED latches to the corresponding input signal until it is reset.

The figures below show the function of available sequences selectable for each LED separately. For sequence 1 and 2 (Follow type), the acknowledgment/reset function is not applicable. Sequence 3 and 4 (Latched type with acknowledgement) are only working in collecting mode. Sequence 5 is working according to Latched type and collecting mode while sequence 6 is working according to Latched type and restarting mode. The letters S and F in the sequence names have the meaning S = Steady and F = Flash.

At the activation of the input signal, the indication obtains corresponding color corresponding to the activated input and operates according to the selected sequence diagrams.

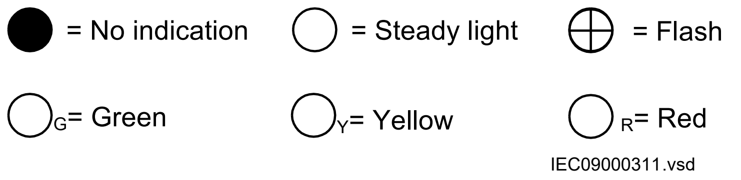


Figure 18: Symbols used in the sequence diagrams

Sequence 1 (Follow-S)

This sequence follows all the time, with a steady light, the corresponding input signals. It does not react on acknowledgment or reset. Every LED is independent of the other LEDs in its operation.

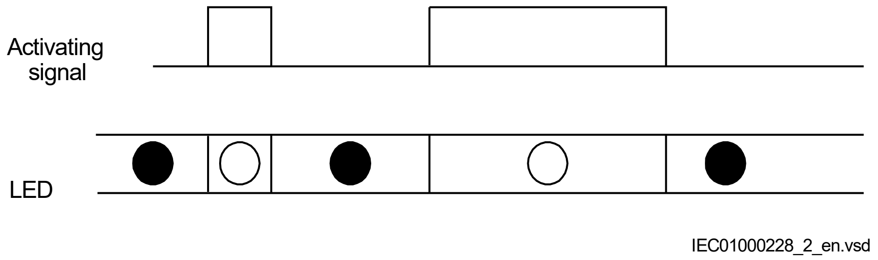


Figure 19: Operating sequence 1 (Follow-S)

If inputs for two or more colors are active at the same time to one LED the priority is as described above. An example of the operation when two colors are activated in parallel is shown in Figure 20.

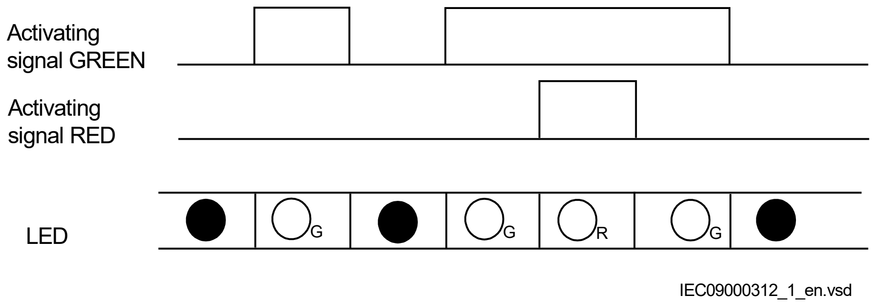


Figure 20: Operating sequence 1, two colors

Sequence 2 (Follow-F)

This sequence is the same as sequence 1, Follow-S, but the LEDs are flashing instead of showing steady light.

Sequence 3 (LatchedAck-F-S)

This sequence has a latched function and works in collecting mode. Every LED is independent of the other LEDs in its operation. At the activation of the input signal, the indication starts flashing. After acknowledgment the indication disappears if the signal is not present any more. If the signal is still present after acknowledgment it gets a steady light.

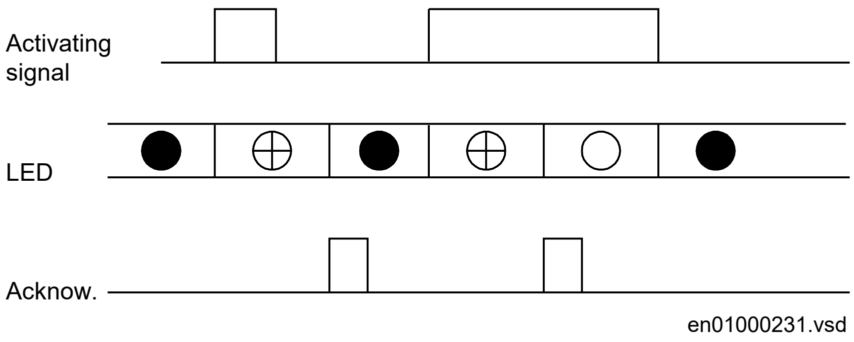


Figure 21: Operating sequence 3 (LatchedAck-F-S)

When a LED is acknowledged, all indications that appear before the indication with higher priority has been reset, are acknowledged, independent of if the low priority indication appeared before or after acknowledgment. In Figure 22 it is shown the sequence when a signal of lower priority becomes activated after acknowledgment has been performed on a higher priority signal. The low priority signal is shown as acknowledged when the high priority signal resets.

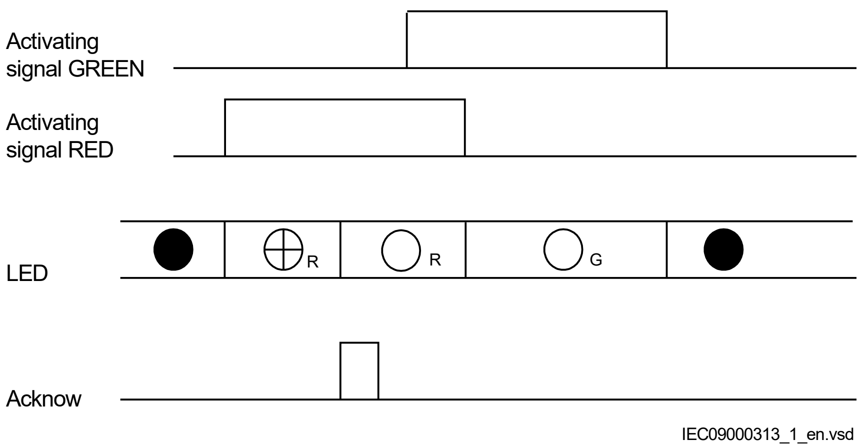


Figure 22: Operating sequence 3, 2 colors involved

If all three signals are activated the order of priority is still maintained. Acknowledgment of indications with higher priority acknowledges also low priority indications, which are not visible according to Figure 23.

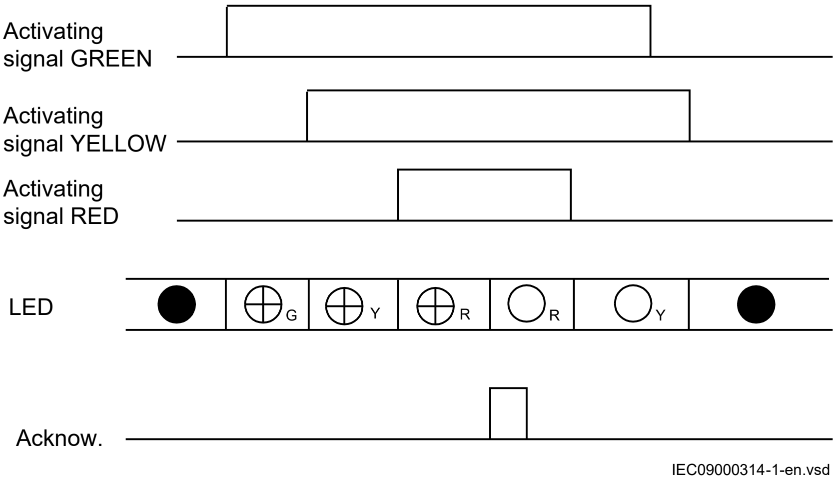


Figure 23: Operating sequence 3, three colors involved, alternative 1

If an indication with higher priority appears after acknowledgment of a lower priority indication the high priority indication is shown as not acknowledged according to Figure 24.

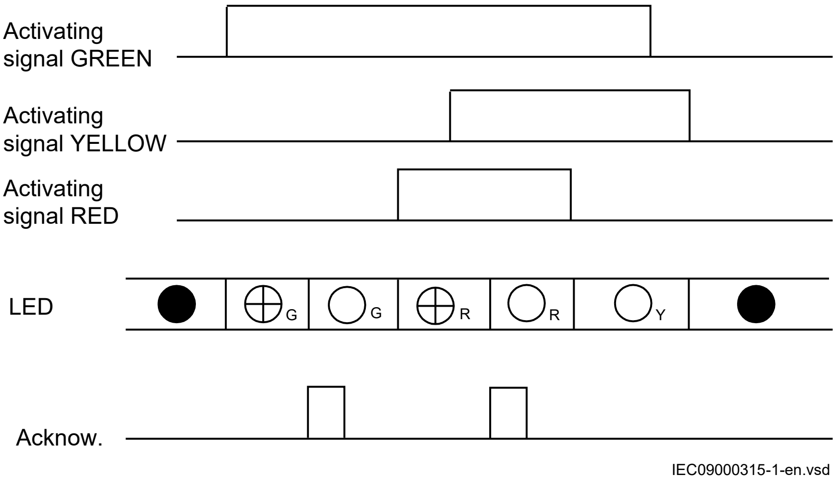


Figure 24: Operating sequence 3, three colors involved, alternative 2

Sequence 4 (LatchedAck-S-F)

This sequence has the same functionality as sequence 3, but steady and flashing light have been alternated.

Sequence 5 (LatchedColl-S)

This sequence has a latched function and works in collecting mode. At the activation of the input signal, the indication lights up with a steady light. The difference to sequence 3 and 4 is that the indications that are still activated are not affected by the reset, that is, immediately after the positive edge of the reset is executed, a new reading and storing of active signals is performed. Every LED is independent of the other LEDs in its operation.

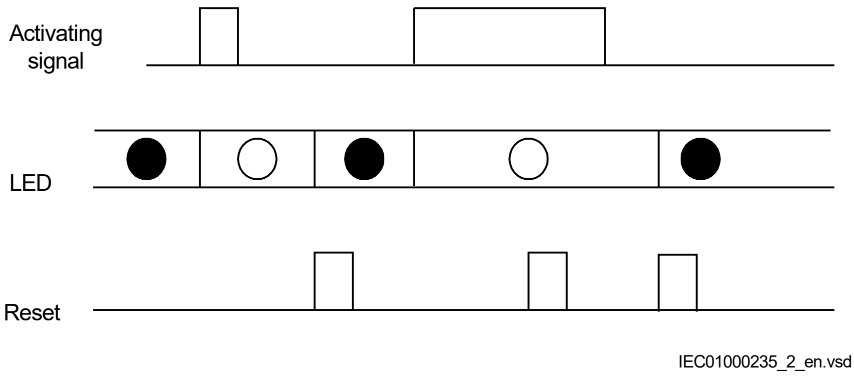


Figure 25: Operating sequence 5 (LatchedColl-S)

That means if an indication with higher priority has reset while an indication with lower priority still is active at the time of reset, the LED changes color according to Figure 26.

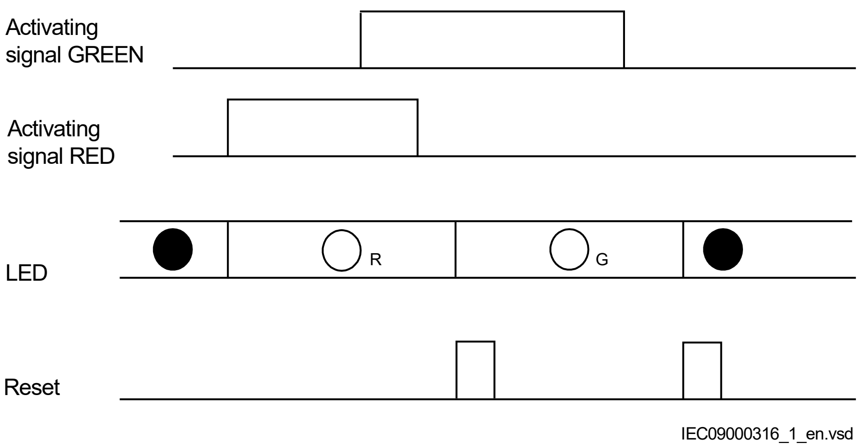


Figure 26: Operating sequence 5, two colors

Sequence 6 (LatchedReset-S)

In this mode all activated LEDs, which are set to sequence 6 (LatchedReset-S), are automatically reset at a new disturbance when activating any input signal for other LEDs set to sequence 6 (LatchedReset-S). Also, in this case indications that are still activated are not affected by manual reset, that is, immediately after the positive edge of that the manual reset has been executed a new reading and storing of active signals is performed. LEDs set for sequence 6 are completely independent in its operation of LEDs set for other sequences.

Figure 27 shows the timing diagram for two indications within one disturbance.

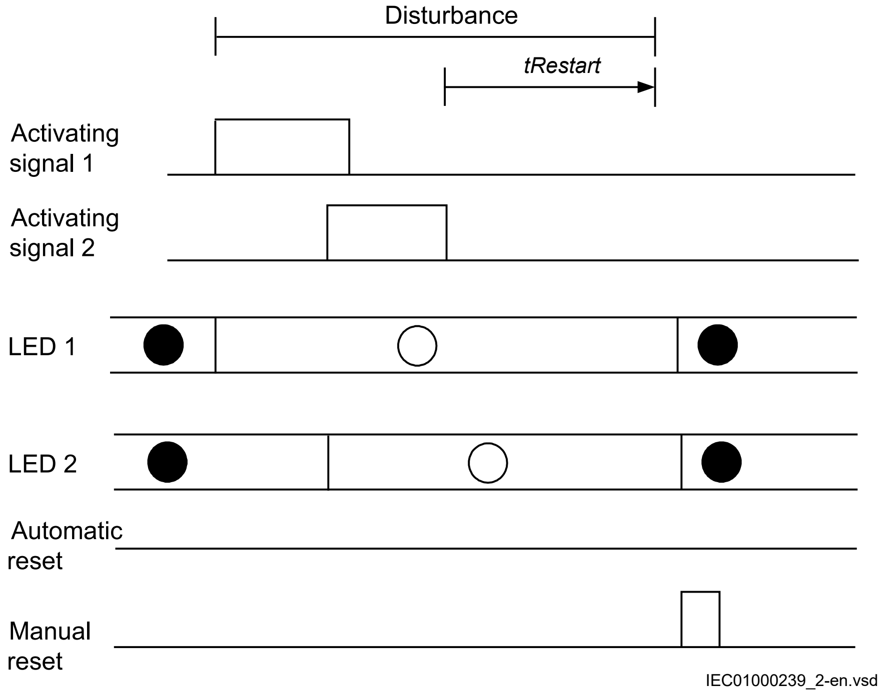


Figure 27: Operating sequence 6 (LatchedReset-S), two indications within same disturbance

Figure 28 shows the timing diagram for a new indication after *tRestart* time has elapsed.

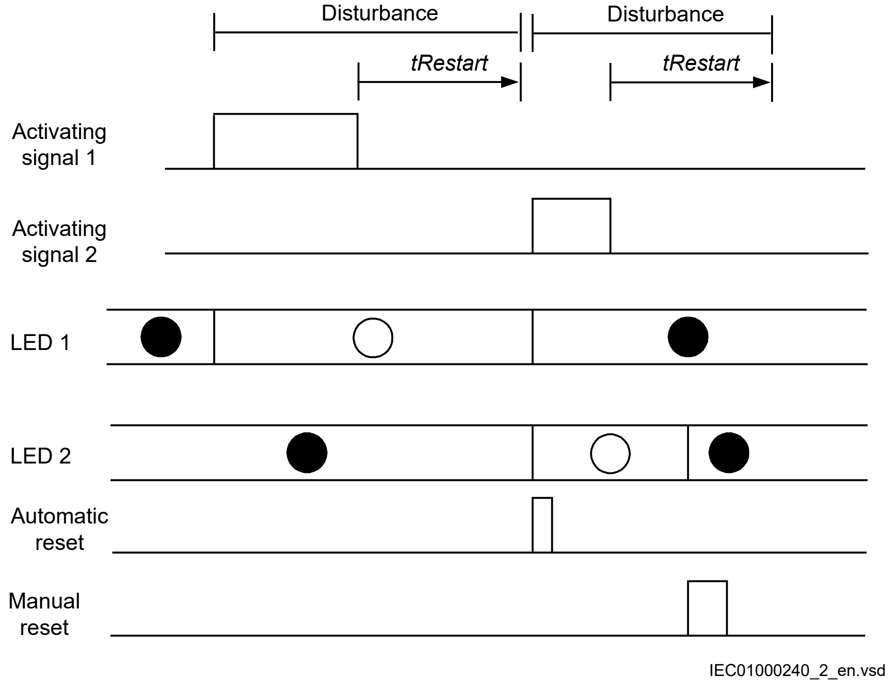


Figure 28: Operating sequence 6 (LatchedReset-S), two different disturbances

Figure 29 shows the timing diagram when a new indication appears after the first one has reset but before *tRestart* has elapsed.

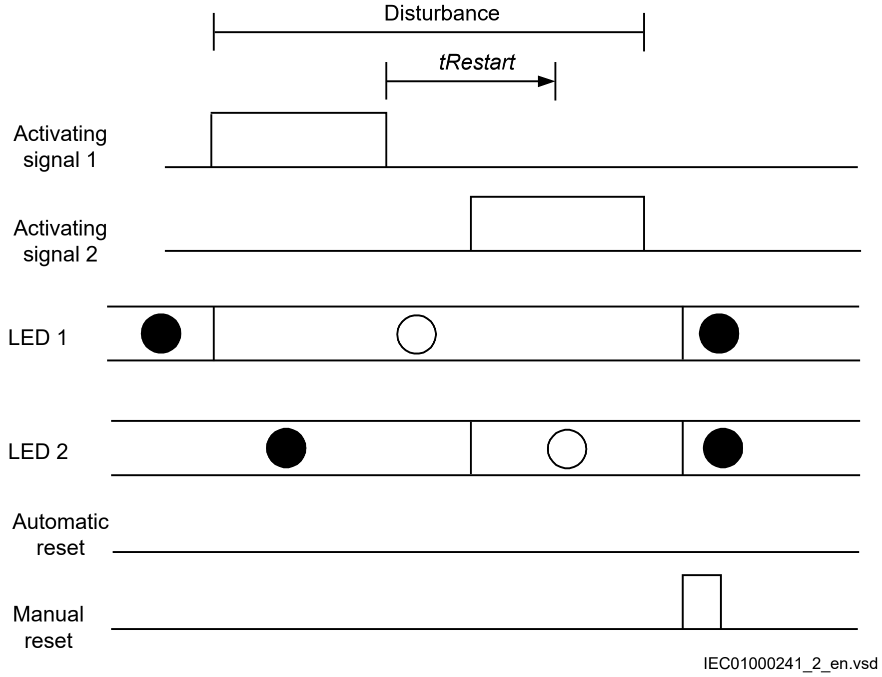


Figure 29: Operating sequence 6 (LatchedReset-S), two indications within same disturbance but with reset of activating signal between

Figure 30 shows the timing diagram for manual reset.

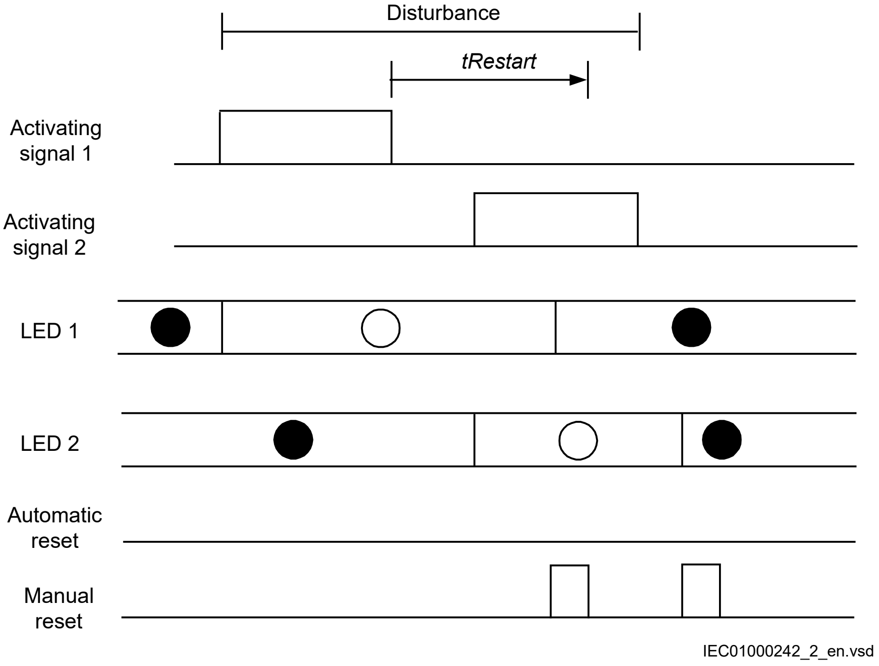


Figure 30: Operating sequence 6 (LatchedReset-S), manual reset

3.5.3.4 Signals

Table 16: LEDGEN Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Input to block the operation of the LEDs
RESET	BOOLEAN	0	Input to acknowledge/reset the indication LEDs

Table 17: GRP1_LED1 Input signals

Name	Type	Default	Description
HM1L01R	BOOLEAN	0	Red indication of LED1, local HMI alarm group 1
HM1L01Y	BOOLEAN	0	Yellow indication of LED1, local HMI alarm group 1
HM1L01G	BOOLEAN	0	Green indication of LED1, local HMI alarm group 1

Table 18: LEDGEN Output signals

Name	Type	Description
NEWIND	BOOLEAN	New indication signal if any LED indication input is set
ACK	BOOLEAN	A pulse is provided when the LEDs are acknowledged

3.5.3.5 Settings

Table 19: LEDGEN Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On
tRestart	0.0 - 100.0	s	0.1	0.0	Defines the disturbance length
tMax	0.0 - 100.0	s	0.1	0.0	Maximum time for the definition of a disturbance

Table 20: GRP1_LED1 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
SequenceType	Follow-S Follow-F LatchedAck-F-S LatchedAck-S-F LatchedColl-S LatchedReset-S	-	-	Follow-S	Sequence type for LED 1, local HMI alarm group 1
LabelOff	0 - 18	-	1	G1L01_OFF	Label string shown when LED 1, alarm group 1 is off
LabelRed	0 - 18	-	1	G1L01_RED	Label string shown when LED 1, alarm group 1 is red
LabelYellow	0 - 18	-	1	G1L01_YELLOW	Label string shown when LED 1, alarm group 1 is yellow
LabelGreen	0 - 18	-	1	G1L01_GREEN	Label string shown when LED 1, alarm group 1 is green

3.5.4 Display part for HMI function keys control module

3.5.4.1 Function block

Figure 31: Function block

3.5.4.2 Functionality

LHMI has five function buttons, directly to the left of the display, that can be configured either as menu shortcut or control buttons. Each button has an indication LED that can be configured in the application configuration.

When used as a menu shortcut, a function button provides a fast way to navigate between default nodes in the menu tree. When used as a control, the button can control a binary signal.

3.5.4.3 Operation principle

Each output on the FNKEYMD1 - FNKEYMD5 function blocks can be controlled from the LHMI function keys. By pressing a function button on the LHMI, the output status of the actual function block changes. These binary outputs can in turn be used to control other function blocks, for example, switch control blocks, binary I/O outputs etc.

FNKEYMD1 - FNKEYMD5 function block also has a number of settings and parameters that control the behavior of the function block. These settings and parameters are normally set using the Parameter Setting tool.

Operating sequence

The operation mode is set individually for each output, either OFF, TOGGLE or PULSED.

Mode 0 (OFF)

This mode always gives the output the value 0 (FALSE). Changes on the IO attribute are ignored.

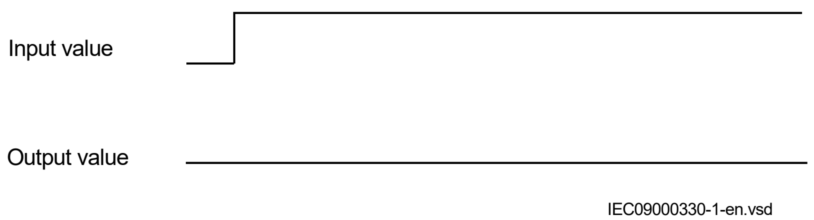


Figure 32: Sequence diagram for Mode 0

Mode 1 (TOGGLE)

In this mode the output toggles each time the function block detects that the input has been written. Note that the input attribute is reset each time the function block executes. The function block execution is marked with a dotted line below.

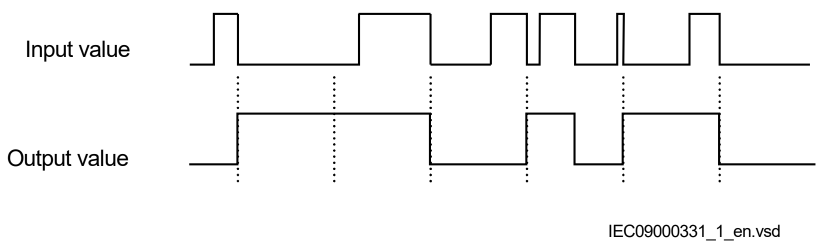


Figure 33: Sequence diagram for Mode 1

Mode 2 (PULSED)

In this mode the output is high for as long as the setting *pulse time*. After this time the output returns to “0”. The input attribute is reset when the function block detects it being high and there is no output pulse.

Note that the third positive edge on the input attribute does not cause a pulse, since the edge was applied during pulse output. A new pulse can only begin when the output is zero; else the trigger edge is lost.

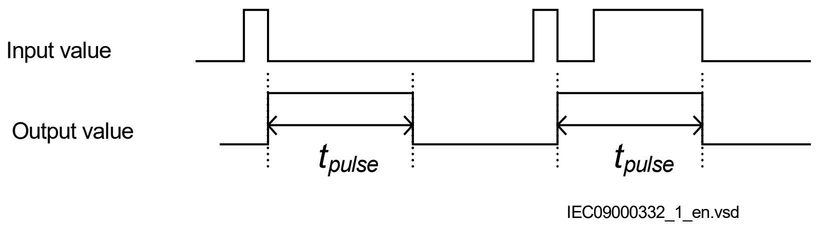


Figure 34: Sequence diagram for Mode 2

Input function

All the inputs work in the same way. When the LHMI is configured so that a certain function button is of type CONTROL, the corresponding input on this function block becomes active, and lights up the yellow function button LED when high. This functionality is active even if the function block operation setting is set to off.

3.5.4.4 Signals

Table 21: FNKEYMD1 Input signals

Name	Type	Default	Description
LEDCTL1	BOOLEAN	0	LED control input for function key

Table 22: FNKEYMD1 Output signals

Name	Type	Description
FKEYOUT1	BOOLEAN	Output controlled by function key

3.5.4.5 Settings

Table 23: FNKEYMD1 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Mode	Off Toggle Pulsed	-	-	Off	Output operation mode
PulseTime	0.001 - 60.000	s	0.001	0.200	Pulse time for output controlled by LCDFn1
LabelOn	0 - 18	-	1	LCD_FN1_ON	Label for LED on state
LabelOff	0 - 18	-	1	LCD_FN1_OFF	Label for LED off state

Table 24: FNKEYTY1 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Type	Off Menu shortcut Control	-	-	Off	Function key type
MenuShortcut	Main menu Control Events Measurements Disturbance records Monitoring	-	-	Main menu	

3.6 IED identifiers TERMINALID

3.6.1 Functionality

IED identifiers (TERMINALID) function allows the user to identify the individual IED in the system, not only in the substation, but in a whole region or a country.

Use only characters A-Z, a-z and 0-9 in station, object and unit names.

3.6.2 Application

3.6.2.1 Customer-specific settings

The customer-specific settings are used to give the IED a unique name and address. The settings are used by a central control system to communicate with the IED. The customer-specific identifiers are found in the LHMI or WHMI in **Configuration/System**.

The settings can also be made from PCM600.

Use only characters A - Z, a - z and 0 - 9 in station, unit and object names.

3.6.3 Settings

Table 25: TERMINALID Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
StationName	0 - 18	-	1	Station name	Station name
StationNumber	0 - 99999	-	1	0	Station number
ObjectName	0 - 18	-	1	Object name	Object name
ObjectNumber	0 - 99999	-	1	0	Object number
UnitName	0 - 18	-	1	Unit name	Unit name
UnitNumber	0 - 99999	-	1	0	Unit number
IEDMainFunType	0 - 255	-	1	0	IED main function type for IEC60870-5-103
TechnicalKey	0 - 18	-	1	AA0J0Q0A0	Technical key

3.7 Product information

3.7.1 Functionality

The Product identifiers function identifies the IED. The function has seven presets, settings that are unchangeable but important.

- IEDProdType
- ProductVer
- ProductDef
- SerialNo
- OrderingNo
- ProductionDate

The settings are visible on the LHMI or WHMI, under **Information/Product identifiers**.

They are very helpful in case of support process (such as repair or maintenance).

3.7.2 Application

3.7.2.1 Factory defined settings

The factory defined settings are useful for identifying a specific version and helpful when maintaining, repairing, interchanging IEDs between different substation automation systems and upgrading. The factory-made settings can not be changed by the customer. They can only be viewed. The settings are found in the LHMI or WHMI in**Information/Product identifiers**.

- IEDProdType

    - Describes the type of the IED. Example: REF630
- ProductDef
    - Describes the release number from the production. Example: 1.1.0.A1
- ProductVer
    - Describes the product version. Example: 1.1.0
- SerialNo
- OrderingNo
- ProductionDate

3.7.3 Settings

The function does not have any parameters available in LHMI or PCM600.

3.8 Primary system values PRIMVAL

3.8.1 Functionality

The rated system frequency and phasor rotation are set in **Main menu/ Configuration/System** in the LHMI and PCM600.

3.8.2 Application

The rated system frequency is set in **Main menu/Configuration/System** in the LHMI and PCM600.

3.8.3 Settings

Table 26: PRIMVAL Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Frequency	50.0 - 60.0	Hz	10.0	50.0	Rated system frequency
PhaseRotation	Normal=L1L2L3 Inverse=L3L2L1	-	-	Normal=L1L2L3	System phase rotation

3.9 Global phase base values BASEPH

3.9.1 Functionality

Almost all the current, voltage and power setting values are given in per unit (p.u.) values. The p.u. values are relational values to certain base values (given in A, kV, kVA). The base values are separate setting parameters for an IED. The base values are set independently of the used measurement device primary ratings. This allows for the settings to be given in relation to the nominal current and voltage values of the protected object, for example, if the measurement devices are oversized and their primary ratings are higher than the nominal values of the protected object.

The phase-to-earth or phase-to-phase base values are defined in BASEPH. The global settings related to BASEPH are located in **Configuration/Analog inputs/ Base values/Phase Grp 1…3** in LHMI and **Configuration/Analog inputs/Base values/BASEPH :1…3** in PST.

The BASEPH (Phase Grp) is called phase-to-earth or phase-to-phase base value group.

There are three groups (instances) of BASEPH (Phase Grp). As a default, all the applicable functions in the IED are set to use the same group of the base values. However, in each applicable function there is a selection (Base value Sel phase advanced settings) where one of the three possible groups can be selected individually for the function in question.

For example, all PHxPTOC functions use the first group Base value Sel phase = "Phase Grp 1" as a default but two other groups "Phase Grp 2" are "Phase Grp 3" are possible to select.

3.9.2 Settings

Table 27: BASEPH Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Voltage base Val PP	0.01 - 440.00	kV	0.01	20.00	Voltage base value, phase-to-phase
Current base Val Ph	1 - 9999	A	1	400	Current base value, phase
S base value 3Ph	0.05 - 1800000.00	kVA	0.05	13856.00	Three-phase power base value

3.9.3 The principles for voltage settings given in pu

The voltage base value in BASEPH is the phase-to-phase voltage. This means that in voltage settings related to phase-to-phase voltage, 1.0 p.u. corresponds to 20.00 kV (assuming the default value for the Voltage base Val PP setting). An example of this kind of setting is DSTPDIS PP V Ph Sel GFC (the default value 0.8 pu corresponds to 0.8 x 20 kV = 16 kV).

For the voltage settings that are related to the phase-to-earth voltage, the functions contain internal scaling factor (0.5774). Therefore for the voltage settings related to the phase-to-earth voltage, 1.0 results in a nominal phase-to-earth voltage of 11.55 kV, assuming the default value 20.00 kV for the Voltage base Val PP setting. An example of this kind of setting is PSPTOV Start value (the default value 1.1 pu corresponds to 1.1 x 0.5774 x 20 kV ≈12.7 kV).

There are few functions for which the internal scaling is not done. In these functions it can be selected whether phase-to-phase voltages or phase-to-earth voltages are used, for example, the Voltage selection setting in PHPTOV. This also means that the voltage settings in these functions can be either related to the phase-to-phase voltage or to the phase-to-earth voltage depending on the selection. In functions, for example, PHPTOV, PHPTUV and SYNCRSYN, 1.0 p.u. corresponds to 20.00 kV, assuming the default value for the Voltage base Val PP setting regardless of the voltages used in the functions. If the Voltage selection setting in PHPTOV is set to “phase-to-earth” ("1"), a value of 0.64 p.u. for Start value results in 12.8 kV (≈1.1 x 11.55 kV)

3.9.4 Technical revision history

Table 28: BASEPH technical revision history

Technical revision	Change
B	Maximum setting value is changed from 6000 to 9999 for *Current base value*

3.10 Global residual base values BASERES

3.10.1 Functionality

Almost all the current, voltage and power setting values are given in per unit (p.u.) values. The p.u. values are relational values to certain base values (given in A, kV, kVA). The base values are separate setting parameters for an IED. The base values are set independently of the used measurement device primary ratings. This allows for the settings to be given in relation to the nominal current and voltage values of the protected object, for example, if the measurement devices are oversized and their primary ratings are higher than the nominal values of the protected object.

The residual base values are defined in BASERES. The global settings related to BASERES are located in **Configuration/Analog inputs/Base values/Residual Grp 1…3** in LHMI and **Configuration/Analog inputs/Base values/ BASERES :1…3** in PST.

The BASERES (Residual Grp) is called residual base value group.

There are three groups (instances) of BASERES (Residual Grp). As a default, all the applicable functions in the IED are set to use the same group of the base values. However, in each applicable function there is a selection (Base value Sel Res advanced settings) where one of the three possible groups can be selected individually for the function in question.

For example, all EFxPTOC functions use the first group Base value Sel Res = "Residual Grp 1"e) as default and two other groups "Residual Grp 2" or "Residual Grp 3" are possible to select.

3.10.2 Settings

Table 29: BASERES Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Voltage base Val Res	0.001 - 440.000	kV	0.001	11.547	Voltage base value, residual
Current base Val Res	1 - 6000	A	1	70	Current base value, residual
S base value Res	0.05 - 18000.00	kVA	0.01	808.29	Residual power base value

3.11 Angle reference AISVBAS

3.11.1 Functionality

Analog input channels must be configured and set properly to get correct measurement results and correct protection operations. For power measuring and all directional and differential functions the directions of the input currents must be defined properly. A reference *PhaseAngleRef* can be defined to facilitate service values reading. This analog channels phase angle is always fixed to zero degree and all other angle information is shown in relation to this analog input. During testing and commissioning of the IED the reference channel can be changed to facilitate testing and service values reading.

The Reference channel is set under **Main menu/Configuration/Analog inputs/ Reference channel** in the LHMI and from **IED Configuration/Basic IED functions/Analog inputs/AISVBAS** in PCM600 parameter setting tree.

3.11.2 Settings

Table 30: AISVBAS Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
PhaseAngleRef	TRM - Channel 1 TRM - Channel 2 TRM - Channel 3 TRM - Channel 4 TRM - Channel 5 TRM - Channel 6 TRM - Channel 7 TRM - Channel 8 TRM - Channel 9 TRM - Channel 10	-	-	TRM - Channel 1	Reference channel for phase angle presentation

3.12 Parameter setting group handling

3.12.1 Functionality

The different groups of settings are used to optimize the IED operation for different system conditions. By creating and switching between fine-tuned setting sets, either from the LHMI or configurable binary inputs, results in a highly adaptable IED that can cope with a variety of system scenarios.

3.12.2 Setting group handling SETGRPS

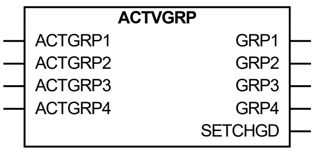
3.12.2.1 Settings

Table 31: SETGRPS Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
ActiveSetGrp	SettingGroup1 SettingGroup2 SettingGroup3 SettingGroup4	-	-	SettingGroup1	ActiveSettingGroup
MaxNoSetGrp	1 - 4	-	1	1	Max number of setting groups 1-4

3.12.3 Parameter setting groups ACTVGRP

3.12.3.1 Function block



IEC09000064_en_1.vsd

Figure 35: Function block

3.12.3.2 Signals

Table 32: ACTVGRP Input signals

Name	Type	Default	Description
ACTGRP1	BOOLEAN	0	Selects setting group 1 as active
ACTGRP2	BOOLEAN	0	Selects setting group 2 as active
ACTGRP3	BOOLEAN	0	Selects setting group 3 as active
ACTGRP4	BOOLEAN	0	Selects setting group 4 as active

Table 33: ACTVGRP Output signals

Name	Type	Description
GRP1	BOOLEAN	Setting group 1 is active
GRP2	BOOLEAN	Setting group 2 is active
GRP3	BOOLEAN	Setting group 3 is active
GRP4	BOOLEAN	Setting group 4 is active
SETCHGD	BOOLEAN	Pulse when setting changed

3.12.3.3 Settings

The function does not have any parameters available in LHMI or PCM600.

3.12.4 Operation principle

Parameter setting groups (ACTVGRP) function has four functional inputs, each corresponding to one of the setting groups stored in the IED. Activation of any of these inputs changes the active setting group. Five functional output signals are available for configuration purposes.

A setting group is selected by using the LHMI, from a front connected personal computer, remotely from the station control or station monitoring system or by activating the corresponding input to the ACTVGRP function block.

Each input of the function block can be configured with PCM600 to connect to any of the binary inputs in the IED.

The external control signals are used for activating a suitable setting group when adaptive functionality is necessary. Input signals that should activate setting groups must be either permanent or a pulse exceeding 400 ms.

More than one input may be activated at the same time. In such cases the lower order setting group has priority. This means that if, for example, both group four and group two are set to activate, group two is the one activated.

Every time the active group is changed, the output signal SETCHGD is sending a pulse.

The parameter *MaxNoSetGrp* defines the maximum number of setting groups in use to switch between.

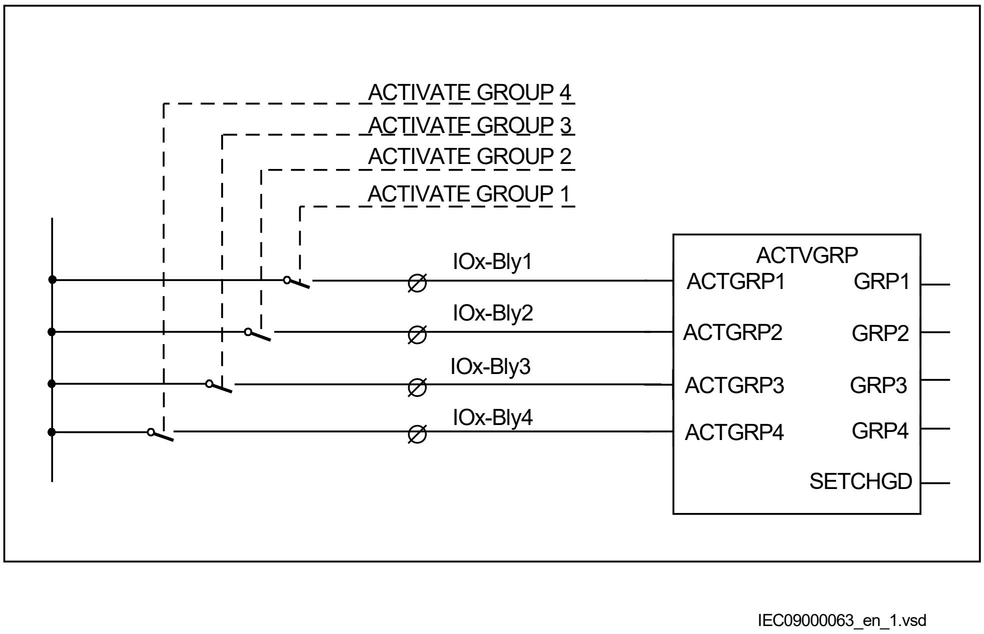


Figure 36: Connection of the function to external circuits

The above example also includes five output signals, for confirmation of which group that is active.

3.12.5 Application

Four sets of settings are available to optimize the IED operation for different system conditions. By creating and switching between fine-tuned setting sets, either from the LHMI or configurable binary inputs, results in a highly adaptable IED that can cope with a variety of system scenarios.

Different conditions in networks with different voltage levels require highly adaptable protection and control units to best provide for dependability, security and selectivity requirements. Protection units operate with a higher degree of availability, especially, if the setting values of their parameters are continuously optimized according to the conditions in the power system.

Operational departments can plan for different operating conditions in the primary equipment. The protection engineer can prepare the necessary optimized and pre-tested settings in advance for different protection functions. Four different groups of setting parameters are available in the IED. Any of them can be activated through the different programmable binary inputs by external or internal control signals.

3.13 Signal matrix for analog inputs

3.13.1 Functionality

Signal matrix for analog inputs function (SMAI), also known as the preprocessor function, processes the analog signals connected to it and gives information about all aspects of the analog signals connected, like the RMS value, phase angle, frequency, harmonic content, sequence components and so on. This information is used by the respective functions in Application Configuration, for example, protection, measurement or monitoring.

The SMAI function is used within PCM600 in direct relation with the Signal Matrix or the Application Configuration tools.

3.13.2 Signal matrix for analog inputs SMAI_20_1

3.13.2.1 Function block

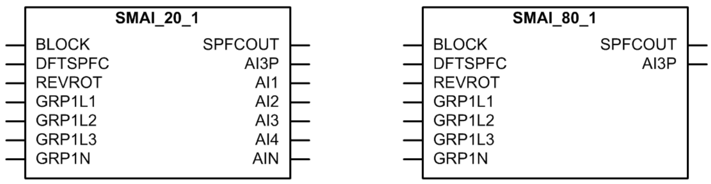


Figure 37: Function block

3.13.2.2 Signals

Table 34: SMAI_20_1 Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block group 1
DFTSPFC	REAL	20.0	Number of samples per fundamental cycle used for DFT calculation
REVROT	BOOLEAN	0	Reverse rotation group 1
GRP1L1	STRING	-	First analog input used for phase L1 or L1-L2 quantity
GRP1L2	STRING	-	Second analog input used for phase L2 or L2-L3 quantity
GRP1L3	STRING	-	Third analog input used for phase L3 or L3-L1 quantity
GRP1N	STRING	-	Fourth analog input used for residual or neutral quantity

Table 35: *SMAI_20_1 Output signals*

Name	Type	Description
SPFCOUT	REAL	Number of samples per fundamental cycle from internal DFT reference function
AI3P	GROUP SIGNAL	Grouped three phase signal containing data from inputs 1-4
AI1	GROUP SIGNAL	Quantity connected to the first analog input
AI2	GROUP SIGNAL	Quantity connected to the second analog input
AI3	GROUP SIGNAL	Quantity connected to the third analog input
AI4	GROUP SIGNAL	Quantity connected to the fourth analog input
AIN	GROUP SIGNAL	Calculated residual quantity if inputs 1-3 are connected

Table 36: *SMAI_80_1 Input signals*

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block group 1
DFTSPFC	REAL	80.0	Number of samples per fundamental cycle used for DFT calculation
REVROT	BOOLEAN	0	Reverse rotation group 1
GRP1L1	STRING	-	First analog input used for phase L1 or L1-L2 quantity
GRP1L2	STRING	-	Second analog input used for phase L2 or L2-L3 quantity
GRP1L3	STRING	-	Third analog input used for phase L3 or L3-L1 quantity
GRP1N	STRING	-	Fourth analog input used for residual or neutral quantity

Table 37: *SMAI_80_1 Output signals*

Name	Type	Description
SPFCOUT	REAL	Number of samples per fundamental cycle from internal DFT reference function
AI3P	GROUP SIGNAL	Grouped three phase signal containing data from inputs 1-4

3.13.2.3 Settings

Only values 1-3 of the parameter *GlobalBaseSel* should normally be used. The values 1-3 refer to the global base value groups Phase Grp 1, Phase Grp 2 and Phase Grp 3 correspondingly (BASEPH1, BASEPH2 and BASEPH3 in PCM600). The selection affects the actual limit for frequency calculation set by *MinValFreqMeas* which by default is 10% of the *Voltage base Val PP* in the selected group. The values 4-6 refer to Residual Grp 1, Residual Grp 2 and Residual Grp 3 (BASERES1, BASERES2 and BASERES3 in

PCM600) correspondingly and they are typically not to be used in this connection.

Table 38: SMAI_20_1 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
GlobalBaseSel[1)]	1 - 6	-	1	1	Selection of one of the Global Base Value groups
DFTRefExtOut	InternalDFTRef DFTRefGrp1 DFTRefGrp2 DFTRefGrp3 DFTRefGrp4 DFTRefGrp5 DFTRefGrp6 DFTRefGrp7 DFTRefGrp8 DFTRefGrp9 DFTRefGrp10 DFTRefGrp11 DFTRefGrp12 External DFT ref	-	-	InternalDFTRef	DFT reference for external output
DFTReference	InternalDFTRef DFTRefGrp1 DFTRefGrp2 DFTRefGrp3 DFTRefGrp4 DFTRefGrp5 DFTRefGrp6 DFTRefGrp7 DFTRefGrp8 DFTRefGrp9 DFTRefGrp10 DFTRefGrp11 DFTRefGrp12 External DFT ref	-	-	InternalDFTRef	DFT reference
ConnectionType	Ph-N Ph-Ph	-	-	Ph-N	Input connection type
AnalogInputType	Voltage Current	-	-	Voltage	Analog input signal type

1) Only values 1...3 should normally be used. The values 1...3 refer to the global base value groups Phase Grp 1, Phase Grp 2 and Phase Grp 3 correspondingly (BASEPH1, BASEPH2 and BASEPH3 in PCM600). The selection affects the actual limit for frequency calculation set by MinValFreqMeas which by default is 10 percent of the Voltage base Val PP in the selected group. Values 4...6 refer to Residual Grp 1, Residual Grp 2 and Residual Grp 3 (BASERES1, BASERES2 and BASERES3 in PCM600) correspondingly and they are typically not used here.

Table 39: SMAI_20_1 Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Negation	Off NegateN Negate3Ph Negate3Ph+N	-	-	Off	Negation
MinValFreqMeas	5 - 200	%	1	10	Limit for frequency calculation in % of UBase

Even if the *AnalogInputType* setting of a SMAI block is set to *Current*, the *MinValFreqMeas* setting is still visible. This means that the minimum level for current amplitude is based on *Voltage base Val PP*. For example, if *Voltage base Val PP* is 20000, the minimum amplitude for current is 20000 * 10% = 2000. This has practical affect only if the current measuring SMAI is used as a frequency reference for the adaptive DFT. This is not recommended, see the Setting guidelines.

Table 40: SMAI_80_1 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
GlobalBaseSel[1)]	1 - 6	-	1	1	Selection of one of the Global Base Value groups
DFTRefExtOut	InternalDFTRef DFTRefGrp1 DFTRefGrp2 DFTRefGrp3 DFTRefGrp4 DFTRefGrp5 DFTRefGrp6 DFTRefGrp7 DFTRefGrp8 DFTRefGrp9 DFTRefGrp10 DFTRefGrp11 DFTRefGrp12 External DFT ref	-	-	InternalDFTRef	DFT reference for external output
DFTReference	InternalDFTRef DFTRefGrp1 DFTRefGrp2 DFTRefGrp3 DFTRefGrp4 DFTRefGrp5 DFTRefGrp6 DFTRefGrp7 DFTRefGrp8 DFTRefGrp9 DFTRefGrp10 DFTRefGrp11 DFTRefGrp12 External DFT ref	-	-	InternalDFTRef	DFT reference
ConnectionType	Ph-N Ph-Ph	-	-	Ph-N	Input connection type
AnalogInputType	Voltage Current	-	-	Voltage	Analog input signal type

1) Only values 1...3 should normally be used. The values 1...3 refer to the global base value groups Phase Grp 1, Phase Grp 2 and Phase Grp 3 correspondingly (BASEPH1, BASEPH2 and BASEPH3 in PCM600). The selection affects the actual limit for frequency calculation set by MinValFreqMeas which by default is 10 percent of the Voltage base Val PP in the selected group. Values 4...6 refer to Residual Grp 1, Residual Grp 2 and Residual Grp 3 (BASERES1, BASERES2 and BASERES3 in PCM600) correspondingly and they are typically not used here.

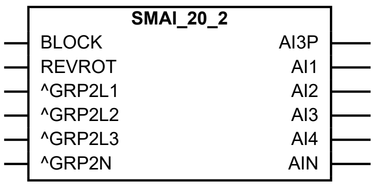
Table 41: SMAI_80_1 Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Negation	Off NegateN Negate3Ph Negate3Ph+N	-	-	Off	Negation
MinValFreqMeas	5 - 200	%	1	10	Limit for frequency calculation in % of UBase

Even if the *AnalogInputType* setting of a SMAI block is set to *Current*, the *MinValFreqMeas* setting is still visible. This means that the minimum level for current amplitude is based on *Voltage base Val PP*. For example, if *Voltage base Val PP* is 20000, the minimum amplitude for current is 20000 * 10% = 2000. This has practical affect only if the current measuring SMAI is used as a frequency reference for the adaptive DFT. This is not recommended, see the Setting guidelines.

3.13.3 Signal matrix for analog inputs SMAI_20_2

3.13.3.1 Function block



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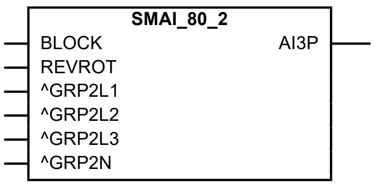


IEC09000140-2-en.vsd

Figure 38: Function block

Input and output signals on SMAI_20_2 to SMAI_20_12, and SMAI_80_2 to SMAI_80_12, are the same except for input signals GRPxL1 to GRPxN where x is equal to instance number (2 to 12).

3.13.3.2 Signals

Table 42: SMAI_20_2 Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block group 2
REVROT	BOOLEAN	0	Reverse rotation group 2
GRP2L1	STRING	-	First analog input used for phase L1 or L1-L2 quantity
GRP2L2	STRING	-	Second analog input used for phase L2 or L2-L3 quantity
GRP2L3	STRING	-	Third analog input used for phase L3 or L3-L1 quantity
GRP2N	STRING	-	Fourth analog input used for residual or neutral quantity

Table 43: SMAI_20_2 Output signals

Name	Type	Description
AI3P	GROUP SIGNAL	Grouped three phase signal containing data from inputs 1-4
AI1	GROUP SIGNAL	Quantity connected to the first analog input
AI2	GROUP SIGNAL	Quantity connected to the second analog input
AI3	GROUP SIGNAL	Quantity connected to the third analog input
AI4	GROUP SIGNAL	Quantity connected to the fourth analog input
AIN	GROUP SIGNAL	Calculated residual quantity if inputs 1-3 are connected

Table 44: SMAI_80_2 Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block group 2
REVROT	BOOLEAN	0	Reverse rotation group 2
GRP2L1	STRING	-	First analog input used for phase L1 or L1-L2 quantity
GRP2L2	STRING	-	Second analog input used for phase L2 or L2-L3 quantity
GRP2L3	STRING	-	Third analog input used for phase L3 or L3-L1 quantity
GRP2N	STRING	-	Fourth analog input used for residual or neutral quantity

Table 45: SMAI_80_2 Output signals

Name	Type	Description
AI3P	GROUP SIGNAL	Grouped three phase signal containing data from inputs 1-4

3.13.3.3 Settings

Only values 1-3 of the parameter *GlobalBaseSel* should normally be used. The values 1-3 refer to the global base value groups Phase Grp 1, Phase Grp 2 and Phase Grp 3 correspondingly (BASEPH1, BASEPH2 and BASEPH3 in PCM600). The selection affects the actual limit for frequency calculation set by *MinValFreqMeas* which by default is 10% of the *Voltage base Val PP* in the selected group. The values 4-6 refer to Residual Grp 1, Residual Grp 2 and Residual Grp 3 (BASERES1, BASERES2 and BASERES3 in PCM600) correspondingly and they are typically not to be used in this connection.

Table 46: SMAI_20_2 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
GlobalBaseSel1)	1 - 6	-	1	1	Selection of one of the Global Base Value groups
DFTReference	InternalDFTRef DFTRefGrp1 DFTRefGrp2 DFTRefGrp3 DFTRefGrp4 DFTRefGrp5 DFTRefGrp6 DFTRefGrp7 DFTRefGrp8 DFTRefGrp9 DFTRefGrp10 DFTRefGrp11 DFTRefGrp12 External DFT ref	-	-	InternalDFTRef	DFT reference
ConnectionType	Ph-N Ph-Ph	-	-	Ph-N	Input connection type
AnalogInputType	Voltage Current	-	-	Voltage	Analog input signal type

1) Only values 1...3 should normally be used. The values 1...3 refer to the global base value groups Phase Grp 1, Phase Grp 2 and Phase Grp 3 correspondingly (BASEPH1, BASEPH2 and BASEPH3 in PCM600). The selection affects the actual limit for frequency calculation set by MinValFreqMeas which by default is 10 percent of the Voltage base Val PP in the selected group. Values 4...6 refer to Residual Grp 1, Residual Grp 2 and Residual Grp 3 (BASERES1, BASERES2 and BASERES3 in PCM600) correspondingly and they are typically not used here.

Table 47: SMAI_20_2 Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Negation	Off NegateN Negate3Ph Negate3Ph+N	-	-	Off	Negation
MinValFreqMeas	5 - 200	%	1	10	Limit for frequency calculation in % of UBase

Even if the *AnalogInputType* setting of a SMAI block is set to *Current*, the *MinValFreqMeas* setting is still visible. This means that the minimum level for current amplitude is based on *Voltage base Val PP*. For example, if *Voltage base Val PP* is 20000, the minimum amplitude for current is 20000 * 10% = 2000. This has practical affect only if the current measuring SMAI is used as a frequency reference for the adaptive DFT. This is not recommended, see the Setting guidelines.

Table 48: SMAI_80_2 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
GlobalBaseSel[1)]	1 - 6	-	1	1	Selection of one of the Global Base Value groups
DFTReference	InternalDFTRef DFTRefGrp1 DFTRefGrp2 DFTRefGrp3 DFTRefGrp4 DFTRefGrp5 DFTRefGrp6 DFTRefGrp7 DFTRefGrp8 DFTRefGrp9 DFTRefGrp10 DFTRefGrp11 DFTRefGrp12 External DFT ref	-	-	InternalDFTRef	DFT reference
ConnectionType	Ph-N Ph-Ph	-	-	Ph-N	Input connection type
AnalogInputType	Voltage Current	-	-	Voltage	Analog input signal type

1) Only values 1...3 should normally be used. The values 1...3 refer to the global base value groups Phase Grp 1, Phase Grp 2 and Phase Grp 3 correspondingly (BASEPH1, BASEPH2 and BASEPH3 in PCM600). The selection affects the actual limit for frequency calculation set by MinValFreqMeas which by default is 10 percent of the Voltage base Val PP in the selected group. Values 4...6 refer to Residual Grp 1, Residual Grp 2 and Residual Grp 3 (BASERES1, BASERES2 and BASERES3 in PCM600) correspondingly and they are typically not used here.

Table 49: SMAI_80_2 Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Negation	Off NegateN Negate3Ph Negate3Ph+N	-	-	Off	Negation
MinValFreqMeas	5 - 200	%	1	10	Limit for frequency calculation in % of UBase

Even if the *AnalogInputType* setting of a SMAI block is set to *Current*, the *MinValFreqMeas* setting is still visible. This means that the minimum level for current amplitude is based on *Voltage base Val PP*. For example, if *Voltage base Val PP* is 20000, the minimum amplitude for current is 20000 * 10% = 2000. This has practical affect only if the current measuring SMAI is used as a frequency reference for the adaptive DFT. This is not recommended, see the Setting guidelines.

3.13.4 Operation principle

Every SMAI can receive four analog signals (three phases and one neutral value), either voltage or current. The *AnalogInputType* setting should be set according to the input connected. The signal received by SMAI is processed internally and in total 244 different electrical parameters are obtained for example RMS value, peak-to-peak, frequency and so on. The activation of BLOCK input resets all outputs to “0”.

Two types of SMAI functions are available: SMAI_20 and SMAI_80.

SMAI_20 does all the calculation based on nominal 20 samples per line frequency period, this gives a sample frequency of 1 kHz at 50 Hz nominal line frequency and 1.2 kHz at 60 Hz nominal line frequency. However, there are a few applications which require a nominal 80 samples per line frequency period, giving the sample frequency of 4 kHz at 50 Hz nominal line frequency and 4.8 kHz at 60 Hz nominal line frequency. This is handled by the SMAI_80 function.

SMAI_20 function is available with three different task times, whereas SMAI_80 function is available with one task time.

Table 50: SMAI functions available in the 630 series

Product	Available SMAI
REF630	12 instances of SMAI_20 function with task time of 10 ms and SMAI_80 function with task time of 5 ms.
REG630	12 instances of SMAI_20 with task time of 10 ms and 3 ms.
REM630	12 instances of SMAI_20 with task time of 10 ms and 5 ms.
RET630	12 instances of SMAI_20 with task time of 10 ms and 3 ms.

The output signals AI1...AI4 in SMAI_20_x function block are direct outputs of the connected input signals GRPxL1, GRPxL2, GRPxL3 and GRPxN. GRPxN is always the neutral current. If GRPxN is not connected, the output AI4 is zero. The AIN output is the calculated residual parameter, obtained as a sum of inputs GRPxL1, GRPxL2 and GRPxL3 but is equal to output AI4 if GRPxN is connected. The outputs signal AI1, AI2, AI3 and AIN are normally connected to the analog disturbance recorder. When the setting *AnalogInputType* is set to "Current", the polarity of calculated residual current at output AIN is inversed.

The SMAI function block always calculates the residual quantities in case only the three phases (Ph-N) are connected (GRPxN input not used).

Similarly, the output signal AI3P in the SMAI function block is a group output signal containing all processed electrical information from inputs GRPxL1, GRPxL2, GRPxL3 and GRPxN. Applications with a few exceptions are always connected to AI3P.

The input signal REVROT is used to reverse the phase order.

A few points need to be ensured for SMAI to process the analog signal correctly.

- It is not mandatory to connect all the inputs of SMAI function. However, it is very important that same set of three phase analog signals should be connected to one SMAI function.
- The sequence of input connected to SMAI function inputs GRPxL1, GRPxL2, GRPxL3 and GRPxN should normally represent phase A, phase B, phase C and neutral currents respectively.
- It is possible to connect analog signals available as “Ph-N” or “Ph-Ph” to SMAI. *ConnectionType* should be set according to the input connected.
- If the GRPxN input is not connected and all three phase-to-earth inputs are connected, SMAI calculates the neutral input on its own and it is available at the AI3P and AIN outputs. It is necessary that the *ConnectionType* should be set to “Ph-N”.
- If any two phase-to-earth inputs and neutral currents are connected, SMAI calculates the remaining third phase-to-neutral input on its own and it is available at the AI3P output. It is necessary that the *ConnectionType* should be set to “Ph-N”.
- If any two phase-to-phase inputs are connected, SMAI calculates the remaining third phase-to-phase input on its own. It is necessary that the *ConnectionType* should be set to “Ph-Ph”.
- All three inputs GRPxLx should be connected to SMAI for calculating sequence components for *ConnectionType* set to “Ph-N”.
- At least two inputs GRPxLx should be connected to SMAI for calculating the positive and negative sequence component for *ConnectionType* set to “Ph-Ph”. Calculation of zero sequence requires GRPxN input to be connected.
- Negation setting inverts (reverse) the polarity of the analog input signal. It is recommended that use of this setting is done with care, a mistake in setting may lead to maloperation of directional functions.
- If *AnalogInputType* is set to "Current" and input GROUPxN is not connected, the AIN output is internally negated. This way the calculated Io gives the same output as would a measured Io from the core-balanced current transformer.
- If *AnalogInputType* is set to "Voltage" and input GROUPxN is not connected, the AIN output is divided by 3. This way the calculated Uo gives the same output as would a measured Uo from the VT open delta winding.

Frequency adaptivity

SMAI function performs DFT calculations for obtaining various electrical parameters. DFT uses some reference frequency for performing calculations. For most of the cases, these calculations are done using a fixed DFT reference based on system frequency. However, if the frequency of the network is expected to vary more than 2 Hz from the nominal frequency, more accurate DFT results can be obtained if the adaptive DFT is used. This means that the frequency of the network is tracked and the DFT calculation is adapted according to that.

DFTRefExtOut and *DFTReference* need to be set appropriately for adaptive DFT calculations.

DFTRefExtOut is valid only for the instance of function block SMAI_20_1 and SMAI_80_1. It decides the reference block for external output `SPFCOUT`.

DFTReference decides the DFT reference for DFT calculations. *DFTReference* set to "InternalDFTRef" uses fixed DFT reference based on the set system frequency. *DFTReference* set to “DFTRefGrpX” uses DFT reference from the selected group block, when own group selected adaptive DFT reference is used based on the calculated signal frequency from own group. *DFTReference* set to “External DFT Ref” uses reference based on input signal `DFTSPFC`.

Set *DFTRefExtOut* and *DFTReference* to default value “InternalDFTRef” if no VT inputs are available. However, if it is necessary to use frequency adaptive DFT (*DFTReference* set to other than default, referring current measuring SMAI) when no voltages are available, the *MinValFreqMeas* setting is still set in reference to *Voltage base Val PP* (of the selected BASEPH group). This means that the minimum level for the current amplitude is based on *Voltage base Val PP*. For example, if *Voltage base Val PP* is 20000, the resulting minimum amplitude for current is 20000 × 10% = 2000.

MinValFreqMeas is the minimum value of the voltage for which the frequency is calculated, expressed as percent of *Voltage base Val PP* (of the selected BASEPH group).

The example shows a situation with adaptive frequency tracking with one reference selected for all instances. In practice each instance can be adapted to the needs of the actual application.

Consider an example of IED having ten analog channels 7I and 3U. Channels 1…3 dedicated for measuring phase side currents, channels 5…7 dedicated for measuring neutral side currents and channels 8…10 dedicated for measuring phase side voltages. Channel 4 is dedicated for measuring neutral current on phase side of the generator.

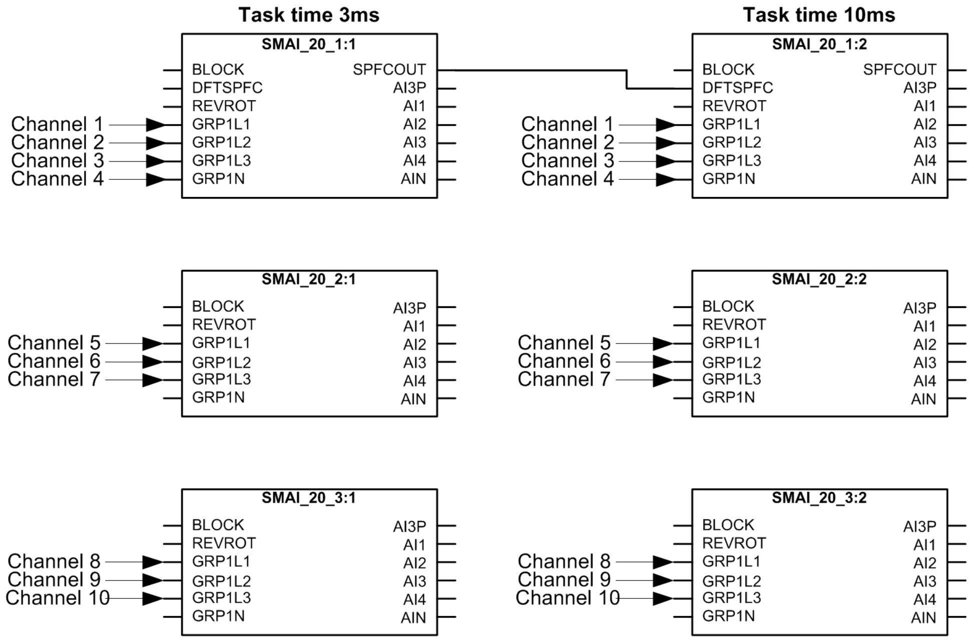


Figure 39: Configuration of SMAI block

The generator IED should perform satisfactorily over a wide range of frequency. SMAI blocks are configured such that the parameters are calculated using frequency adaptive approach. If frequency is expected to vary beyond ±2 Hz from nominal fn, it is advisable to use adaptive approach to avoid high measurement errors especially with DFT measurement mode. It is also advisable to have common DFT reference for both voltage and current SMAI blocks, whether it is “InternalDFTRef”, or “ExternalDFTRef” or “DFTRefGrpx”.

The three phase group signals are connected to SMAI block as indicated in Figure 39. Phase side currents are connected to SMAI_20_1, neutral side currents are connected to SMAI_20_2 and voltages are connected to SMAI_20_3.

If the funtions in the IED operates at 3 ms , it is required that the analog channels are also connected to SMAI block operating on 3 ms task time, and the AI3P output of SMAI is connected to group input of such functions.

Reference signal is required for frequency adaptivity and it is recommended that voltage signal is taken as reference. As the voltage channels are connected to SMAI_20_3, SMAI_20_3 needs to be selected in the configuration to control the frequency tracking. In SMAI_20_3, either 3 ms task time or 10 ms task time is considered for reference. For example, if SMAI_20_3 is working at 3 ms task time, the setting *DFTReference* is set to “DFTRefGrp3” for SMAI_20_1/2/3 (3 ms). This setting instructs SMAI block to consider the frequency available from SMAI_20_3 working on 3 ms task time for different parameter calculation.

The DFT calculation depends on how stable is the available reference signal. Changing the reference signal might affect the measurement.

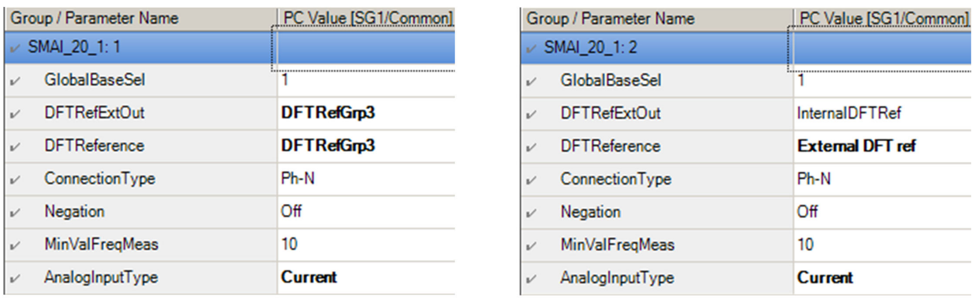
The same frequency information needs to be provided to SMAI working on 10 ms task time. This is done by connecting output `SPFCOUT` of SMAI_20_1 (3 ms) to input `DFTSPFC` of SMAI_20_1 (10 ms) and setting *DFTRefExtOut* of SMAI_20_1 (3 ms) to “DFTRefGrp3”. This routes the frequency available at SMAI_20_3 (3 ms) at `SPFCOUT` of SMAI_20_1 (10 ms) function.

In order to make all SMAI block working at 10 ms to adapt this reference frequency, the setting *DFTReference* is set to “External DFT ref” for SMAI_20_1/2/3 (10 ms).

When *DFTReference* is set as “InternalDFTRef”, SMAI block will consider frequency to be fixed as 50 Hz or 60 Hz.

All SMAI blocks up to the one which is measuring the voltage must be made available in the configuration. For each SMAI both instances 1 and 2 must be included. Therefore voltage is measured by SMAI_20_3 (which is used for DFT reference) and the configuration includes SMAI_20_1/2/3 (3 ms) and SMAI_20_1/2/3 (10 ms). If SMAI_20_2(3 ms) is not needed in the configuration it must still be included for satisfactory operation.

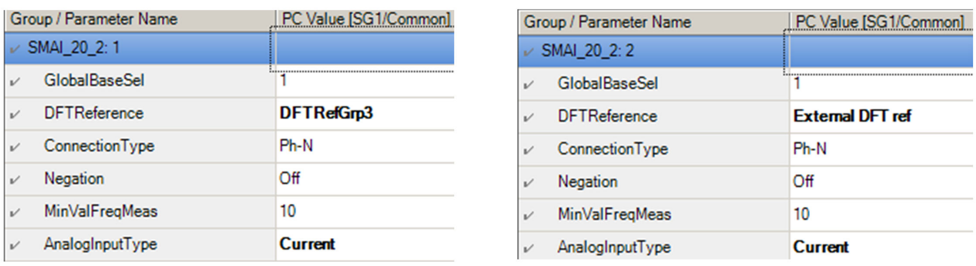
The setting table as viewed in PCM600 is shown for the example.



Group / Parameter Name	PC Value [SG1/Common]
SMAI_20_1: 1	
GlobalBaseSel	1
DFTRefExtOut	**DFTRefGrp3**
DFTReference	**DFTRefGrp3**
ConnectionType	Ph-N
Negation	Off
MinValFreqMeas	10
AnalogInputType	**Current**

Group / Parameter Name	PC Value [SG1/Common]
SMAI_20_1: 2	
GlobalBaseSel	1
DFTRefExtOut	InternalDFTRef
DFTReference	**External DFT ref**
ConnectionType	Ph-N
Negation	Off
MinValFreqMeas	10
AnalogInputType	**Current**

Figure 40: SMAI_20_1 settings



Group / Parameter Name	PC Value [SG1/Common]
SMAI_20_2: 1	
GlobalBaseSel	1
DFTReference	**DFTRefGrp3**
ConnectionType	Ph-N
Negation	Off
MinValFreqMeas	10
AnalogInputType	**Current**

Group / Parameter Name	PC Value [SG1/Common]
SMAI_20_2: 2	
GlobalBaseSel	1
DFTReference	**External DFT ref**
ConnectionType	Ph-N
Negation	Off
MinValFreqMeas	10
AnalogInputType	**Current**

Figure 41: SMAI_20_2 settings

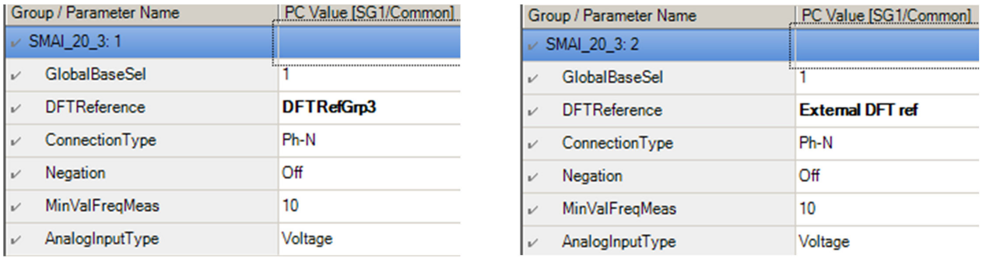


Figure 42: SMAI_20_3 settings

3.13.5 Application

Signal matrix for analog inputs function (SMAI), also known as the preprocessor function, processes the analog signals connected to it and gives information about all aspects of the analog signals connected, like the RMS value, phase angle, frequency, harmonic content, sequence components and so on. This information is used by the respective functions in Application Configuration, for example, protection, measurement or monitoring.

The SMAI function is used within PCM600 in direct relation with the Signal Matrix or the Application Configuration tools.

3.14 Measured value expander block MVEXP

3.14.1 Function block

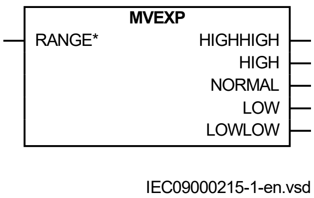


Figure 43: Function block

3.14.2 Functionality

The current and voltage measurements functions (CMMXU, RESCMMXU, RESVMMXU, VPHMMXU, VPPMMXU and PWRMMXU), current and voltage sequence measurement functions (CSMSQI and VSMSQI) and IEC 61850 generic communication I/O functions (MVGGIO) are provided with measurement supervision functionality. All measured values can be supervised with four settable limits: low-low limit, low limit, high limit and high-high limit. The measure value expander block has been introduced to enable translating the integer output signal from the measuring functions to five binary signals: below low-low limit, below low limit, normal, above high-high limit or above high limit. The output signals can be used as conditions in the configurable logic or for alarming purpose.

3.14.3 Operation principle

The input signal must be connected to a range output of a measuring function block (CMMXU, RESCMMXU, RESVMMXU, VPHMMXU, VPPMMXU, PWRMMXU, CSMSQI, VSMSQI or MVGGIO). The function block converts the input integer value to five binary output signals.

Table 51: Input integer value converted to binary output signals

Output	Measured supervised value				
	below low-low limit	between low-low and low limit	between low and high limit	between high-high and high limit	above high-high limit
LOWLOW	High				
LOW		High			
NORMAL			High		
HIGH				High	
HIGHHIGH					High

3.14.4 Application

The current and voltage measurement functions (CMMXU, RESCMMXU, RESVMMXU, VPHMMXU, VPPMMXU and PWRMMXU), current and voltage sequence measurement functions (CSMSQI and VSMSQI) and IEC 61850 generic communication I/O functions (MVGGIO) are provided with measurement supervision functionality. All measured values can be supervised with four settable limits: low-low limit, low limit, high limit and high-high limit. The measure value expander block (MVEXP) has been introduced to enable translating the integer output signal from the measuring functions to five binary signals: below low-low limit, below low limit, normal, above high-high limit or above high limit. The output signals can be used as conditions in the configurable logic or for alarming purpose.

3.14.5 Signals

Table 52: MVEXP Input signals

Name	Type	Default	Description
RANGE	INTEGER	0	Measured value range

Table 53: MVEXP Output signals

Name	Type	Description
HIGHHIGH	BOOLEAN	Measured value is above high-high limit
HIGH	BOOLEAN	Measured value is between high and high-high limit
NORMAL	BOOLEAN	Measured value is between high and low limit
LOW	BOOLEAN	Measured value is between low and low-low limit
LOWLOW	BOOLEAN	Measured value is below low-low limit

3.14.6 Settings

The function does not have any parameters available in LHMI or PCM600.

3.15 Fixed signals FXDSIGN

3.15.1 Function block

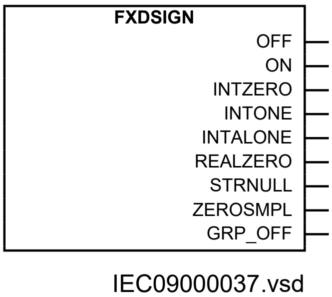


Figure 44: Function block

3.15.2 Functionality

The Fixed signals function (FXDSIGN) generates a number of pre-set (fixed) signals that can be used in the configuration of an IED, either for forcing the unused inputs in other function blocks to a certain level/value, or for creating certain logic.

3.15.3 Operation principle

The FXDSIGN function block has nine outputs.

- OFF is a boolean signal, fixed to OFF (boolean 0) value
- ON is a boolean signal, fixed to ON (boolean 1) value
- INTZERO is an integer number, fixed to integer value 0

- INTONE is an integer number, fixed to integer value 1
- INTALONE is an integer value FFFF (hex)
- REALZERO is a floating point real number, fixed to 0.0 value
- STRNULL is a string, fixed to an empty string (null) value
- ZEROSMPL is a channel index, fixed to 0 value
- GRP_OFF is a group signal, fixed to 0 value

3.15.4 Application

The Fixed signals function (FXDSIGN) generates a number of pre-set (fixed) signals that can be used in the configuration of an IED, either for forcing the unused inputs in other function blocks to a certain level/value, or for creating certain logic.

3.15.5 Signals

Table 54: FXDSIGN Output signals

Name	Type	Description
OFF	BOOLEAN	Boolean signal fixed off
ON	BOOLEAN	Boolean signal fixed on
INTZERO	INTEGER	Integer signal fixed zero
INTONE	INTEGER	Integer signal fixed one
INTALONE	INTEGER	Integer signal fixed all ones
REALZERO	REAL	Real signal fixed zero
STRNULL	STRING	String signal with no characters
ZEROSMPL	GROUP SIGNAL	Channel id for zero sample
GRP_OFF	GROUP SIGNAL	Group signal fixed off

3.15.6 Settings

The function does not have any parameters available in LHMI or PCM600.

3.16 Pulse counter PCGGIO

3.16.1 Function block

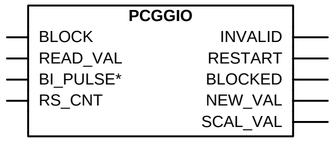


Figure 45: Function block

3.16.2 Functionality

Pulse counter (PCGGIO) function counts externally generated binary pulses, for instance pulses coming from an external energy meter, for calculation of energy consumption values. The pulses are captured by the BIO (binary input/output) module and read by the PCGGIO function. A scaled service value is available over the station bus.

3.16.3 Operation principle

The registration of pulses is done according to setting of *CountCriteria* parameter on one of the 9 binary input channels located on the BIO module. Pulse counter values are sent to the station HMI with predefined cyclicity without reset.

The reporting time period can be set in the range from 1 second to 60 minutes and is synchronized with absolute system time. Interrogation of additional pulse counter values can be done with a command (intermediate reading) for a single counter. All active counters can also be read by IEC 61850.

Pulse counter (PCGGIO) function in the IED supports unidirectional incremental counters. That means only positive values are possible. The counter uses a 32 bit format, that is, the reported value is a 32-bit, signed integer with a range 0...+2147483647. The counter value is stored in semiretain memory.

The reported value to station HMI over the station bus contains Identity, Scaled Value (pulse count x scale), Time, and Pulse Counter Quality. The Pulse Counter Quality has four options.

- Invalid (board hardware error or configuration error)
- Wrapped around
- Blocked
- Adjusted

The transmission of the counter value can be done as a service value, that is, the value frozen in the last integration cycle is read by the station HMI from the database. PCGGIO updates the value in the database when an integration cycle is finished and activates the NEW_VAL signal in the function block. This signal can be time tagged, and transmitted to the station HMI. This time corresponds to the time when the value was frozen by the function.

The BLOCK and READ_VAL inputs can be connected to blocks, which are intended to be controlled either from the station HMI or/and the LHMI. As long as the BLOCK signal is set, the pulse counter is blocked. The signal connected to READ_VAL performs readings according to the setting of parameter *CountCriteria*. The signal must be a pulse with a length >1 second.

The BI_PULSE input is connected to the used input of the function block for the binary input output module (BIO).

The RS_CNT input is used for resetting the counter.

Each PCGGIO function block has four binary output signals that can be used for event recording: INVALID, RESTART, BLOCKED and NEW_VAL. These signals and the SCAL_VAL signal are accessable over IEC 61850.

The INVALID signal is a steady signal and is set if the binary input module, where the pulse counter input is located, fails or has wrong configuration.

The RESTART signal is a steady signal and is set when the reported value does not comprise a complete integration cycle. That is, in the first message after IED start-up, in the first message after deblocking, and after the counter has wrapped around during last integration cycle.

The BLOCKED signal is a steady signal and is set when the counter is blocked. There are two reasons why the counter is blocked.

- The BLOCK input is set
- The binary input module, where the counter input is situated, is inoperative

The NEW_VAL signal is a pulse signal. The signal is set if the counter value was updated since last report.

The SCAL_VAL signal consists of scaled value (according to parameter *Scale*), time and status information.

3.16.4 Application

Pulse counter (PCGGIO) function counts externally generated binary pulses, for instance pulses coming from an external energy meter, for calculation of energy consumption values. The pulses are captured by the binary input module (BIO), and read by the PCGGIO function. The number of pulses in the counter is reported via the station bus to the substation automation system or read via the station monitoring system as a service value. When using IEC 61850-8-1, a scaled service value is available over the station bus.

The normal use for this function is the counting of energy pulses from external energy meters.

3.16.5 Signals

Table 55: PCGGIO Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
READ_VAL	BOOLEAN	0	Initiates an additional pulse counter reading
BI_PULSE	BOOLEAN	0	Connect binary input channel for metering
RS_CNT	BOOLEAN	0	Resets pulse counter value

Table 56: PCGGIO Output signals

Name	Type	Description
INVALID	BOOLEAN	The pulse counter value is invalid
RESTART	BOOLEAN	The reported value does not comprise a complete integration cycle
BLOCKED	BOOLEAN	The pulse counter function is blocked
NEW_VAL	BOOLEAN	A new pulse counter value is generated
SCAL_VAL	REAL	Scaled value with time and status information

3.16.6 Settings

Table 57: PCGGIO Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On
EventMask	NoEvents ReportEvents	-	-	NoEvents	Report mask for analog events from pulse counter
CountCriteria	Off RisingEdge Falling edge OnChange	-	-	RisingEdge	Pulse counter criteria
Scale	1.000 - 90000.000	-	0.001	1.000	Scaling value for SCAL_VAL output to unit per counted value
Quantity	Count ActivePower ApparentPower ReactivePower ActiveEnergy ApparentEnergy ReactiveEnergy	-	-	Count	Measured quantity for SCAL_VAL output
tReporting	1 - 3600	s	1	60	Cycle time for reporting of counter value

3.16.7 Measured values

Table 58: PCGGIO Measured values

Name	Type	Default	Description
ResetCounter	BOOLEAN	0	Resets pulse counter value from LHMI

3.16.8 Monitored data

Table 59: PCGGIO Monitored data

Name	Type	Values (Range)	Unit	Description
CNT_VAL	INTEGER	-	-	Actual pulse counter value
SCAL_VAL	REAL	-	-	Scaled value with time and status information

3.16.9 Technical data

Table 60: Pulse counter PCGGIO technical data

Function	Setting range	Accuracy
Cycle time for report of counter value	(1–3600) s	-

3.17 Event counter CNTGGIO

3.17.1 Function block

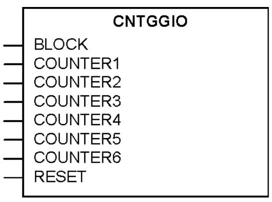


Figure 46: Function block

3.17.2 Functionality

The event counter function CNTGGIO consists of six counters which are used for storing the number of times each counter has been activated. It is also provided with a common blocking function for all six counters to be used, for example, at testing. Each counter can be set to "On" or "Off" separately with a parameter setting.

3.17.3 Operation principle

The event counter function has six inputs for increasing the counter values for each of the six counters respectively. The content of the counters is increased by one step for each positive edge of the input respectively. The maximum count-up speed is 10 pulses per second. The maximum counter value is 10000. The counter stops at 10000 and no restart takes places, even if the count exceeds 10000.

A mechanism for limiting the number of writings per time period is included in the product to avoid the risk of the flash memory becoming worn out due to too many writings. As a result, it can take a long time, up to one hour, before a new value is stored in the flash memory. If a new CNTGGIO value is not stored before auxiliary power interruption, it is lost. The CNTGGIO-stored values in the flash memory are, however, not lost at an auxiliary power interruption.

The function block also has an input `BLOCK`. The activation of the `BLOCK` input blocks all six counters. The inputs can be used for blocking the counters at testing, for example.

All inputs are configured via PCM600.

3.17.3.1 Reporting

The content of the counters can be read in the LHMI.

Reset of counters can be performed in the LHMI and with a binary input.

Reading of the content and resetting of the counters can also be performed remotely with PCM600 or, for example, MicroSCADA.

3.17.4 Technical data

Table 61: CNTGGIO Technical data

Function	Range or value	Accuracy
Counter value	0-10000	-
Maximum count up speed	10 pulses/second	-

3.18 Logic rotating switch for function selection and LHMI presentation SLGGIO

3.18.1 Function block

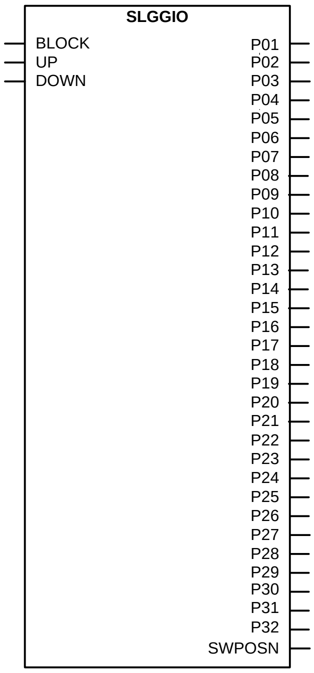


Figure 47: Function block

3.18.2 Functionality

The logic rotating switch for function selection and LHMI presentation (SLGGIO) (or the selector switch function block) is used to get a selector switch functionality similar to the one provided by a hardware selector switch. Hardware selector switches are used extensively by utilities, in order to have different functions operating on pre-set values. Hardware switches are however sources for maintenance issues, lower system reliability and an extended purchase portfolio. The logic selector switches eliminate all these problems.

3.18.3 Operation principle

The logic rotating switch for function selection and LHMI presentation (SLGGIO) function has two operating inputs, UP and DOWN. When a signal is received on the UP input, the block activates the output next to the present activated output in ascending order. If the present activated output is, for example, 3 and one operates the UP input, the output 4 is activated. When a signal is received on the DOWN input, the block activates the output next to the present activated output in descending order. If the present activated output is, for example, 3 and one operates the DOWN input, the output 2 is activated. Depending on the output settings, the output signals can be steady or pulsed. In case of steady signals, and in case of UP or DOWN operation, the previously active output is deactivated. Also, depending on the settings, one can have a time delay between the UP or DOWN activation signal positive front and the output activation.

Besides the inputs visible in the application configuration in the Application Configuration tool, there are other possibilities to set the wanted position directly without activating the intermediate positions, either locally or remotely, using **Select before execute** dialog box. The function operation can be blocked by activating the BLOCK input. In this case, the present position is kept and further operation is blocked. SLGGIO function block has also an integer value output that generates the actual position number. The positions and the block names are fully settable. These names appear in the menu, so the user can see the position names instead numbers.

SLGGIO function can be connected to Dynamic Text (32 Inputs), Select Button (32 Inputs) and Indication Button (32 Inputs) display symbols.

When the relay is set to the "Remote" mode through the QCCBAY function, the `UP` and `DOWN` inputs of SLGGIO are to be given over communication and the ACT inputs are disregarded.

3.18.4 Signals

Table 62: SLGGIO Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
UP	BOOLEAN	0	Binary "UP" command
DOWN	BOOLEAN	0	Binary "DOWN" command

Table 63: SLGGIO Output signals

Name	Type	Description
P01	BOOLEAN	Selector switch position 1
P02	BOOLEAN	Selector switch position 2
P03	BOOLEAN	Selector switch position 3
P04	BOOLEAN	Selector switch position 4
P05	BOOLEAN	Selector switch position 5
P06	BOOLEAN	Selector switch position 6

Table continues on next page

Name	Type	Description
P07	BOOLEAN	Selector switch position 7
P08	BOOLEAN	Selector switch position 8
P09	BOOLEAN	Selector switch position 9
P10	BOOLEAN	Selector switch position 10
P11	BOOLEAN	Selector switch position 11
P12	BOOLEAN	Selector switch position 12
P13	BOOLEAN	Selector switch position 13
P14	BOOLEAN	Selector switch position 14
P15	BOOLEAN	Selector switch position 15
P16	BOOLEAN	Selector switch position 16
P17	BOOLEAN	Selector switch position 17
P18	BOOLEAN	Selector switch position 18
P19	BOOLEAN	Selector switch position 19
P20	BOOLEAN	Selector switch position 20
P21	BOOLEAN	Selector switch position 21
P22	BOOLEAN	Selector switch position 22
P23	BOOLEAN	Selector switch position 23
P24	BOOLEAN	Selector switch position 24
P25	BOOLEAN	Selector switch position 25
P26	BOOLEAN	Selector switch position 26
P27	BOOLEAN	Selector switch position 27
P28	BOOLEAN	Selector switch position 28
P29	BOOLEAN	Selector switch position 29
P30	BOOLEAN	Selector switch position 30
P31	BOOLEAN	Selector switch position 31
P32	BOOLEAN	Selector switch position 32
SWPOSN	INTEGER	Switch position as integer value

3.18.5 Settings

Table 64: SLGGIO Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
Number of positions	2 - 32	-	1	32	Number of positions in the switch
Output type	Pulsed Steady	-	-	Steady	Output type, steady or pulse
Pulse time	0.000 - 60.000	s	0.001	0.200	Operate pulse duration
Output time delay	0.000 - 60000.000	s	0.010	0.000	Output time delay
Stop at extremes	Disabled Enabled	-	-	Disabled	Stop when min or max position is reached

3.18.6 Monitored data

Table 65: SLGGIO Monitored data

Name	Type	Values (Range)	Unit	Description
SWPOSN	INTEGER	-	-	Switch position as integer value

3.19 Selector mini switch VSGGIO

3.19.1 Function block

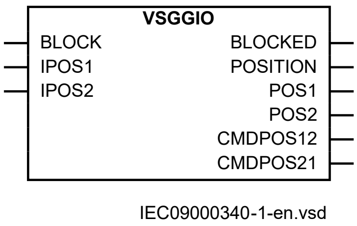


Figure 48: Function block

3.19.2 Functionality

The Selector mini switch VSGGIO is a multipurpose function used for a variety of applications, as a general purpose switch.

VSGGIO can be controlled from the menu or from a symbol on the single-line diagram on the LHMI.

3.19.3 Operation principle

Selector mini switch (VSGGIO) function can be used for double purpose, in the same way as switch controller (GNRLCSWI) functions are used.

- For indication on the single-line diagram. Position is received through the `IPOS1` and `IPOS2` inputs and distributed in the configuration through the `POS1` and `POS2` outputs, or to IEC 61850 through reporting, or GOOSE.
- For commands that are received via the LHMI and distributed in the configuration through outputs `CMDPOS12` and `CMDPOS21`.
  The output `CMDPOS12` is set when the function receives a CLOSE command from the LHMI when the single-line diagram is displayed and the object is chosen.
  The output `CMDPOS21` is set when the function receives an OPEN command from the LHMI when the single-line diagram is displayed and the object is chosen.

It is important for indication in the single-line diagram that a symbol is associated with a controllable object, otherwise the symbol is not displayed on the screen. A symbol is created and configured in Graphical Display Editor in PCM600.

Both indications and commands are done in double-bit representation, where a combination of signals on both inputs/outputs generate the wanted result.

The following table shows the relationship between IPOS1/IPOS2 inputs and the name of the string that is shown on the single-line diagram. The value of the strings are set in Parameter Setting.

Table 66: Relationship between IPOS1/IPOS2 inputs and the name of the string that is shown on the single-line diagram

IPOS1	IPOS2	Name of displayed string	Default string value
0	0	PosUndefined	P00
1	0	Position1	P01
0	1	Position2	P10
1	1	PosBadState	P11

3.19.4 Application

Selector mini switch (VSGGIO) function is a multipurpose function used in PCM600 for a variety of applications as a general purpose switch. VSGGIO can be used for both to acquire an external switch position, through the IPOS1 and the IPOS2 inputs, and to represent it through the single-line diagram symbols. It can also be used in the configuration through the outputs POS1 and POS2 or it can be used to give switching commands through the CMDPOS12 and CMDPOS21 outputs.

The POSITION output is an integer output, showing the actual position as an integer number 0–3.

An example where VSGGIO is configured to switch Autorecloser on–off from a button symbol on the LHMI is shown in Figure 49. The I and O buttons on the LHMI are normally used for on–off operations of the circuit breaker.

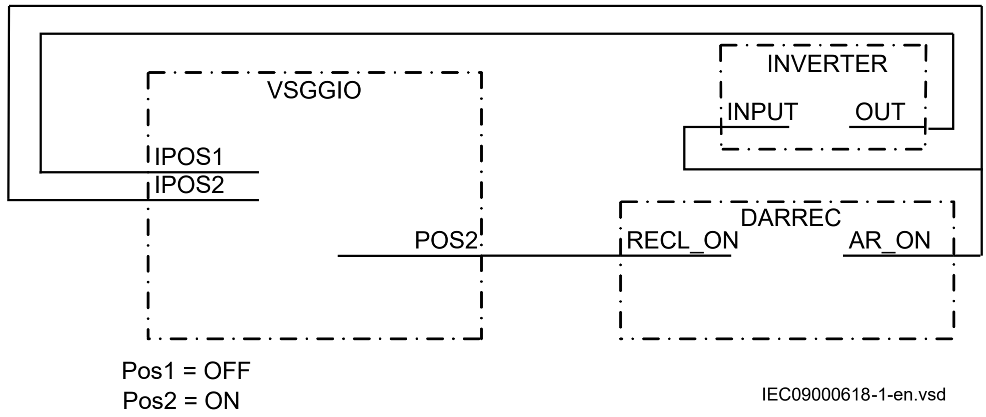


Figure 49: Controlling Autorecloser from LHMI through Selector mini switch

3.19.5 Signals

Table 67: VSGGIO Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
IPOS1	BOOLEAN	0	Position 1 indicating input
IPOS2	BOOLEAN	0	Position 2 indicating input

Table 68: VSGGIO Output signals

Name	Type	Description
BLOCKED	BOOLEAN	The function is active but the functionality is blocked
POSITION	INTEGER	Position indication, integer
POS1	BOOLEAN	Position 1 indication, logical signal
POS2	BOOLEAN	Position 2 indication, logical signal
CMDPOS12	BOOLEAN	Execute command from position 1 to position 2
CMDPOS21	BOOLEAN	Execute command from position 2 to position 1

3.19.6 Settings

Table 69: VSGGIO Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off / On
CtlModel	Dir Norm SBO Enh	-	-	Dir Norm	Specifies the type for control model according to IEC 61850
Mode	Steady Pulsed	-	-	Pulsed	Operation mode
tSelect	0.000 - 60.000	s	0.001	30.000	Max time between select and execute signals
tPulse	0.000 - 60.000	s	0.001	0.200	Command pulse lenght

3.20 IEC 61850 generic communication I/O functions DPGGIO

3.20.1 Function block

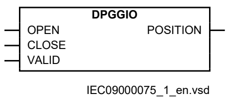


Figure 50: Function block

3.20.2 Functionality

The IEC 61850 generic communication I/O functions (DPGGIO) function block is used to send double indications to other systems or equipment in the substation. It is especially used in the interlocking and reservation station-wide logics.

3.20.3 Operation principle

Upon receiving the input signals, the IEC 61850 generic communication I/O functions (DPGGIO) function block sends the signals over IEC 61850-8-1 to the equipment or system that requests these signals. To be able to get the signals, PCM600 must be used to define which function block in which equipment or system should receive this information.

3.20.4 Signals

Table 70: DPGGIO Input signals

Name	Type	Default	Description
OPEN	BOOLEAN	0	Open indication
CLOSE	BOOLEAN	0	Close indication
VALID	BOOLEAN	0	Valid indication

Table 71: DPGGIO Output signals

Name	Type	Description
POSITION	INTEGER	Double point indication

3.20.5 Settings

The function does not have any parameters available in LHMI or PCM600.

3.21 Single point generic control 8 signals SPC8GGIO

3.21.1 Function block

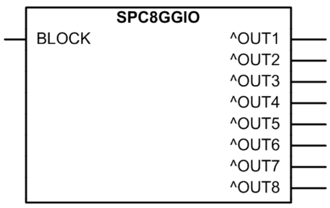


Figure 51: Function block

3.21.2 Functionality

The Single point generic control 8 signals (SPC8GGIO) function block is a collection of 8 single point commands, designed to bring in commands from REMOTE (SCADA) to those parts of the logic configuration that do not need extensive command receiving functionality (for example, GNRLCSWI). In this way, simple commands can be sent directly to the IED outputs, without confirmation. Confirmation (status) of the result of the commands is supposed to be achieved by other means, such as binary inputs and SPGGIO function blocks. The commands can be pulsed or steady.

3.21.3 Operation principle

Upon sending a command from an allowed operator position (see LOCREM), one of the 8 outputs is activated. The settings *Latchedx* and *tPulsex*, where x is the respective output, determines if the signal is pulsed (and how long the pulse is) or latched (steady). BLOCK blocks the operation of the function; if a command is sent, no output activates.

For operation of SPC8GGIO the only usable operator position is REMOTE.

3.21.4 Signals

Table 72: SPC8GGIO Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function

Table 73: SPC8GGIO Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1
OUT2	BOOLEAN	Output2
OUT3	BOOLEAN	Output3
OUT4	BOOLEAN	Output4
OUT5	BOOLEAN	Output5
OUT6	BOOLEAN	Output6
OUT7	BOOLEAN	Output7
OUT8	BOOLEAN	Output8

3.21.5 Settings

Table 74: SPC8GGIO Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On
Latched1	Pulsed Latched	-	-	Pulsed	Setting for pulsed/latched mode for output 1
tPulse1	0.01 - 6000.00	s	0.01	0.10	Output1 Pulse Time
Latched2	Pulsed Latched	-	-	Pulsed	Setting for pulsed/latched mode for output 2
tPulse2	0.01 - 6000.00	s	0.01	0.10	Output2 Pulse Time

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Latched3	Pulsed Latched	-	-	Pulsed	Setting for pulsed/latched mode for output 3
tPulse3	0.01 - 6000.00	s	0.01	0.10	Output3 Pulse Time
Latched4	Pulsed Latched	-	-	Pulsed	Setting for pulsed/latched mode for output 4
tPulse4	0.01 - 6000.00	s	0.01	0.10	Output4 Pulse Time
Latched5	Pulsed Latched	-	-	Pulsed	Setting for pulsed/latched mode for output 5
tPulse5	0.01 - 6000.00	s	0.01	0.10	Output5 Pulse Time
Latched6	Pulsed Latched	-	-	Pulsed	Setting for pulsed/latched mode for output 6
tPulse6	0.01 - 6000.00	s	0.01	0.10	Output6 Pulse Time
Latched7	Pulsed Latched	-	-	Pulsed	Setting for pulsed/latched mode for output 7
tPulse7	0.01 - 6000.00	s	0.01	0.10	Output7 Pulse Time
Latched8	Pulsed Latched	-	-	Pulsed	Setting for pulsed/latched mode for output 8
tPulse8	0.01 - 6000.00	s	0.01	0.10	Output8 pulse time

3.22 Test mode functionality TESTMODE

3.22.1 Function block

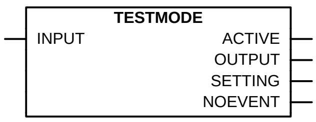


Figure 52: Function block

3.22.2 Functionality

When the Test mode functionality TESTMODE is activated, all the protection functions in the IED are automatically blocked. It is then possible to unblock every function(s) individually from the LHMI to perform the required tests.

When leaving TESTMODE, all blockings are removed and the IED resumes normal operation. However, if during TESTMODE operation, power is removed and later restored, the IED remains in TESTMODE with the same protection functions blocked or unblocked as before the power was removed. All testing is done with the actually set and configured values within the IED. No settings are changed to avoid mistakes.

3.22.3 Operation principle

IED functions can be tested in test mode. The IED can be set to test mode either by activating the input `SIGNAL` on the function block TESTMODE, or setting *TestMode* to "On" in the LHMI.

When the IED is in test mode, the `ACTIVE` of the function block TESTMODE is activated. The outputs of the function block TESTMODE show the cause of the *Test mode* is set to "On" state, that is, input from configuration (`OUTPUT` output is activated) or setting from LHMI (`SETTING` output is activated).

When the IED is in test mode, the yellow STARTLED flashes and all functions are blocked. Any function can be unblocked individually regarding functionality and event signalling.

Forcing of binary output signals is only possible when the IED is in test mode.

Most of the IED functions can be individually blocked by local HMI settings. To enable blockings, the IED must be in test mode (output `ACTIVE` is activated). When leaving the test mode and entering the normal mode, the blockings are disabled and everything is set to normal operation. In the test mode, all testing can be done with the actually set and configured values within the IED. If any setting values are changed during the testing, they should be changed back to original values before entering the normal mode.

The blocked functions are still blocked next time entering the test mode, if the blockings are not reset.

The blocking of a function concerns all the output signals from the actual function, so no outputs are activated.

When a binary input is used to set the IED in test mode and a parameter that requires restart of the application, is changed, the IED re-enters test mode and all functions are blocked, also the functions that were unblocked before the change. During the re-entering to test mode, all functions are temporarily unblocked for a short time, which may lead to unwanted operations. This is only valid if the IED is put in TEST mode by a binary input, not by LHMI.

The TESTMODE function block can be used to automatically block functions when a test handle is inserted in a test switch. A contact in the test switch (RTXP24 contact 29-30) can supply a binary input which in turn is configured to the TESTMODE function block.

Each of the functions includes the blocking from the TESTMODE function block.

The functions can also be blocked from sending events over IEC 61850 station bus to prevent filling station and SCADA databases with test events, for example during a maintenance test.

3.22.4 Application

The protection and control IEDs may have a complex configuration with many included functions. To make the testing procedure easier, the IEDs include the feature that allows individual blocking of a single-, several-, or all functions.

This means that it is possible to see when a function is activated or trips. It also enables the user to follow the operation of several related functions to check correct functionality and to check parts of the configuration, and so on.

3.22.5 Signals

Table 75: TESTMODE Input signals

Name	Type	Default	Description
INPUT	BOOLEAN	0	Sets terminal in test mode when active

Table 76: TESTMODE Output signals

Name	Type	Description
ACTIVE	BOOLEAN	Terminal in test mode when active
OUTPUT	BOOLEAN	Test input is active
SETTING	BOOLEAN	Test mode setting is (On) or not (Off)
NOEVENT	BOOLEAN	Event disabled during testmode

3.22.6 Settings

Table 77: TESTMODE Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
TestMode	Off On	-	-	Off	Test mode in operation (On) or not (Off)
EventDisable	Off On	-	-	Off	Event disable during testmode
CmdTestBit	Off On	-	-	Off	Command bit for test required or not during testmode

3.23 Disturbance report DRRDRE

3.23.1 Function block

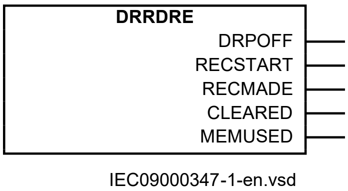


Figure 53: Function block

3.23.2 Functionality

Complete and reliable information about disturbances in the primary and/or in the secondary system together with continuous event-logging is accomplished by the disturbance report functionality.

Disturbance report DRRDRE, always included in the IED, acquires sampled data of all selected analog input and binary signals connected to the function block with a maximum of 40 analog and 64 binary signals.

The Disturbance report functionality is a common name for several functions.

- Event list
- Indications
- Event recorder
- Trip value recorder
- Disturbance recorder

The Disturbance report function is characterized by great flexibility regarding configuration, starting conditions, recording times, and large storage capacity.

A disturbance is defined as an activation of an input to the AxRADR or BxRBDR function blocks, which are set to trigger the disturbance recorder. All signals from start of pre-fault time to the end of post-fault time are included in the recording.

Every disturbance report recording is saved in the IED in the standard Comtrade format. The same applies to all events, which are continuously saved in a ring-buffer. The LHMI is used to get information about the recordings. The disturbance report files may be uploaded to PCM600 for further analysis using the disturbance handling tool.

3.23.3 Operation principle

Disturbance report DRRDRE is a common name for several functions to supply the operator, analysis engineer, and so on, with sufficient information about events in the system.

- Event list
- Indications
- Event recorder
- Trip value recorder
- Disturbance recorder

Figure 54 shows the relations between Disturbance Report, included functions and function blocks. Event list, Event recorder and Indications uses information from the binary input function blocks (BxRBDR). Trip value recorder uses analog information from the analog input function blocks (AxRADR). Disturbance recorder DRRDRE acquires information from both AxRADR and BxRBDR.

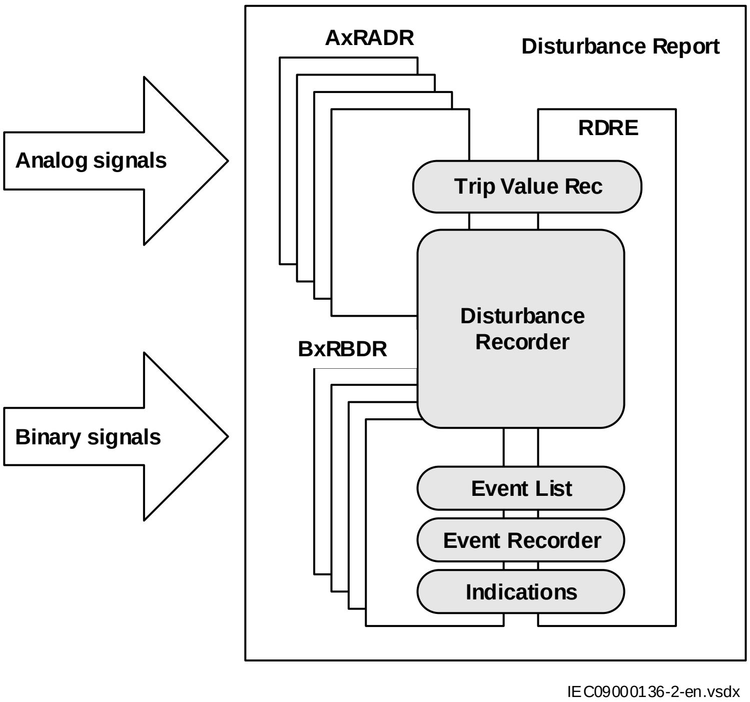


Figure 54: Disturbance report functions and related function blocks

The whole disturbance report can contain information for a number of recordings, each with the data coming from all the parts mentioned above. The event list function is working continuously, independent of disturbance triggering, recording time, and so on. All information in the disturbance report is stored in non-volatile flash memories. This implies that no information is lost in case of loss of auxiliary power. Each report gets an identification number in the interval from 0-999.

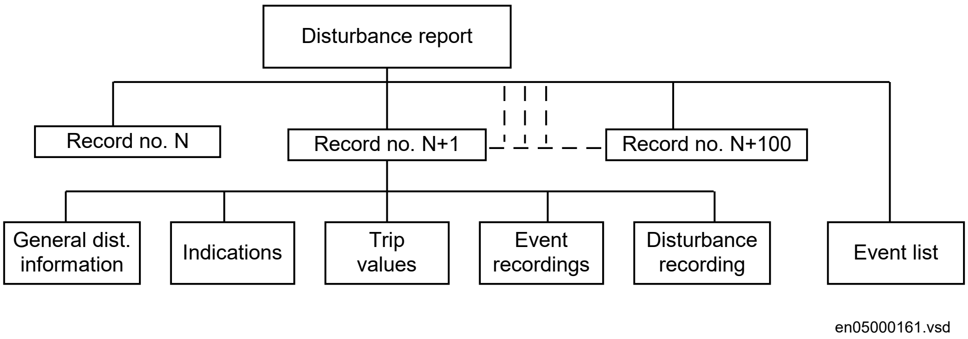


Figure 55: Disturbance report structure

Up to 100 disturbance reports can be stored. If a new disturbance is to be recorded when the memory is full, the oldest disturbance report is overwritten by the new one. The total recording capacity for the disturbance recorder is depending of sampling frequency, number of analog and binary channels and recording time. In a 50 Hz system it is possible to record 100 where the maximum recording time is 3.4 seconds. The memory limit does not affect the rest of the disturbance report (Event list, Event recorder, Indications and Trip value recorder).

The maximum number of recordings depend on each recordings total recording time. Long recording time reduces the number of recordings to less than 100.

3.23.3.1 Disturbance information

Date and time of the disturbance, the indications, events, fault location and the trip values are available on the LHMI.

To acquire a complete disturbance report, use a PC and either the PCM600 Disturbance Handling tool or MMS (over 61850) client. The PC can be connected to IED front port, or remotely via a station bus.

3.23.3.2 Indications

Indications is a list of signals that are activated during the total recording time of the disturbance (not time-tagged). See the section about indications for detailed information.

3.23.3.3 Event recorder

The event recorder can contain a list of up to 150 time-tagged events which have occurred during a disturbance. The information is available via the LHMI or PCM600. See the event recorder section for detailed information.

3.23.3.4 Event list

The event list may contain a list of totally 1000 time-tagged events. The list information is continuously updated when the selected binary signals change state. The oldest data is overwritten. The logged signals can be presented via LHMI, WHMI or PCM600. See the event list section for detailed information.

3.23.3.5 Trip value recorder

The recorded trip values include the phasors of the selected analog signals before the fault and during the fault. See the trip value recorder section for detailed information.

3.23.3.6 Disturbance recorder

The disturbance recorder records analog and binary signal data before, during and after the fault. See the disturbance recorder section for detailed information.

3.23.3.7 Time tagging

The IED has a built-in real-time calendar and clock. This function is used for all time tagging within the disturbance report

3.23.3.8 Recording times

Disturbance report DRRDRE records information about a disturbance during a settable time frame. The recording times are valid for the whole disturbance report. Disturbance recorder, event recorder and indication function register disturbance data and events during tRecording, the total recording time.

The total recording time, tRecording, of a recorded disturbance is:

tRecording = *Pre-trigger time* + tFault + *Post-trigger time* or *Pre-trigger time* + *Recording time limit*, depending on which criterion stops the current disturbance recording

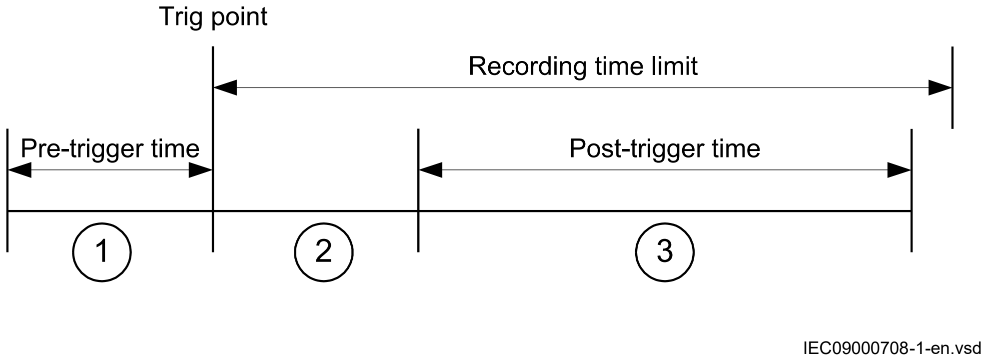


Figure 56: Recording times definition

Pre-trigger time, 1	Pre-trigger recording time. The time before the fault including the operate time of the trigger. Use the setting *Pre-trigger time* to set this time.
tFault, 2	Fault time of the recording. The fault time cannot be set. It continues as long as any valid trigger condition, binary or analog, persists (unless limited by *Recording time limit* the limit time).
Post-trigger time, 3	Post fault recording time. The time the disturbance recording continues after all activated triggers are reset. Use the setting *Post-trigger time* to set this time.
Recording time limit	Limit time. The maximum allowed recording time after the disturbance recording was triggered. The limit time is used to eliminate the consequences of a trigger that does not reset within a reasonable time interval. It limits the maximum recording time of a recording and prevents subsequent overwriting of already stored disturbances. Use the setting *Recording time limit* to set this time.

3.23.3.9 Analog signals

Up to 40 analog signals can be selected for recording by the disturbance recorder and triggering of the disturbance report function. Of those signals, 20 are reserved for external analog signals from analog input modules via preprocessing function blocks (SMAI). The last 20 channels can be connected to internally calculated analog signals available as function block output signals (phase differential currents, bias currents and so on).

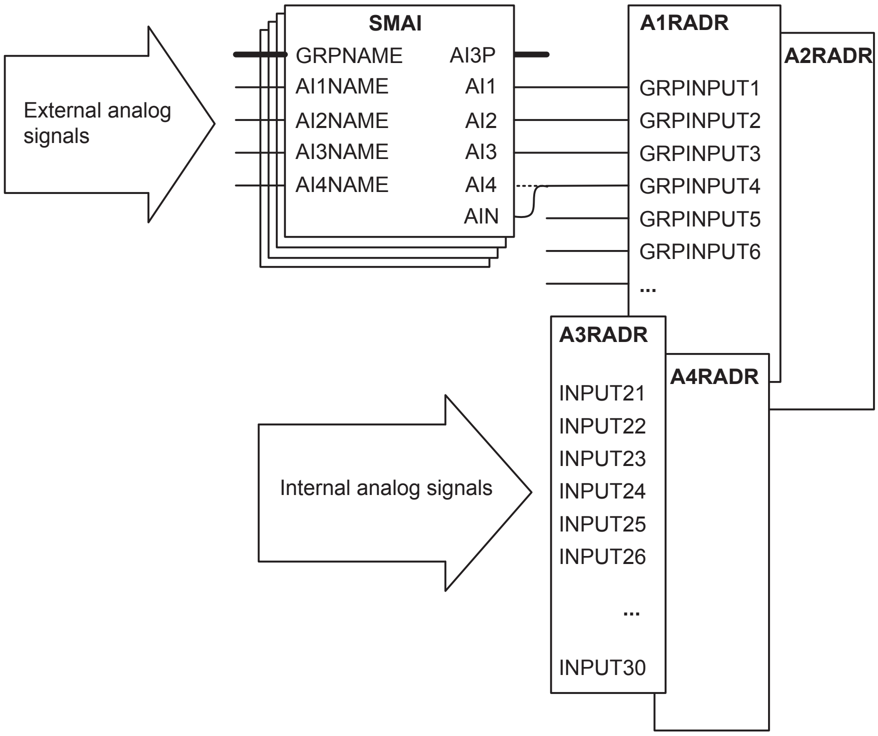


Figure 57: Analog input function blocks

The external input signals are acquired, filtered and skewed, and after configuration available as an input signal on the AxRADR function block via the SMAI function block. The information is saved at the disturbance report base sampling rate (1000 or 1200 Hz). Internally calculated signals are updated according to the cycle time of the specific function. If a function is running at lower speed than the base sampling rate, th disturbance recorder uses the latest updated sample until a new updated sample is available.

Application Configuration tool is used for analog configuration of the disturbance report.

The SMAI function block calculates the residual quantities in cases where only the three phases are connected (AI4-input not used). SMAI makes the information available as a group signal output, phase outputs and calculated residual output (AIN-output). In situations where AI4-input is used as an input signal the corresponding information is available on the non-calculated output (AI4) on the SMAI function block. Connect the signals to the AxRADR accordingly.

For each of the analog signals, *Operation Ch* = "On" means that it is recorded by the disturbance recorder. The trigger is independent of the setting of *Operation Ch*, and triggers even if operation is set to "Off". Both undervoltage and overvoltage can be used as trigger conditions. The same applies for the current signals.

If *Operation Ch* = "Off", no waveform (samples) are recorded and reported in graph. However, the trip value, pre-fault and fault value are recorded and reported. The input channel can still be used to trig the disturbance recorder.

If *Operation Ch* = "On", waveform (samples) is recorded and reported in graph.

The analog signals are presented only in the disturbance recording, but they affect the entire disturbance report when being used as triggers.

3.23.3.10 Binary signals

Up to 64 binary signals can be selected to be handled by disturbance report. The signals can be selected from internal logical and binary input signals. A binary signal is selected to be recorded in two occasions.

- Corresponding function block is included in the configuration
- Signal is connected to the input of the function block

Each of the 64 signals can be selected as a trigger of the disturbance report (*Operation Ch* = "Off"). A binary signal can be selected to activate the yellow (START) and red (TRIP) LED on the LHMI: *Set LED* = "Off/Start/Trip/Start and Trip".

The selected signals are presented in the event recorder, event list and the disturbance recording. But they affect the whole disturbance report when they are used as triggers. The indications are also selected from these 64 signals with LHMI: *Show indication*="Show/Hide".

3.23.3.11 Trigger signals

The trigger conditions affect the entire disturbance report, except the event list, which runs continuously. As soon as at least one trigger condition is fulfilled, a complete disturbance report is recorded. On the other hand, if no trigger condition is fulfilled, there is no disturbance report, no indications, and so on. It is important to choose the right signals as trigger conditions.

There are three different trigger types.

- Manual trigger
- Binary-signal trigger
- Analog-signal trigger (over/under function)

Manual trigger

A disturbance report can be manually triggered from the LHMI, WHMI, PCM600 or via station bus (IEC 61850). When the trigger is activated, the manual trigger signal is generated. This feature is especially useful for testing.

Binary signal trigger

Any binary signal state, that is, logic one or a logic zero, can be selected to generate a trigger (*Trigger level* = "Trig on 0/Trig on 1"). When a binary signal is selected to generate a trigger from a logic zero, the selected signal is not listed in the indications list of the disturbance report.

Analog signal trigger

All analog signals are available for trigger purposes, whether they are recorded in the disturbance recorder or not. The settings are *Over trigger Ch*, *Under trigger Ch*, *Over Trg Lev Ch* and *Under Trg Lev Ch*.

The check of the trigger condition is based on peak-to-peak values. When this is found, the absolute average value of these two peak values is calculated. If the average value is above the threshold level for an overvoltage or overcurrent trigger, this trigger is indicated with a greater than (>) sign with the user-defined name.

If the average value is below the set threshold level for an undervoltage or undercurrent trigger, this trigger is indicated with a less than (<) sign with its name. The procedure is separately performed for each channel.

This method of checking the analog start conditions gives a function which is insensitive to DC offset in the signal. The operate time for this start is typically in the range of one cycle, 20 ms for a 50 Hz network.

All under/over trig signal information is available on the LHMI and PCM600.

3.23.3.12 Post retrigger

Disturbance report function does not automatically respond to any new trig condition during a recording, after all the signals set as trigger signals have been reset. However, under certain circumstances the fault condition may reoccur during the post-fault recording, for instance by automatic reclosing to a still faulty power line.

In order to capture the new disturbance it is possible to allow retriggering (*Post-retrig* = "On") during the post-fault time. In this case a new, complete recording starts and, during a period, run in parallel with the initial recording.

When the retrig parameter is disabled (*Post-retrig* = "Off"), a new recording does not start until the post-fault (*Post-trigger time* or *Recording time limit*) period is terminated. If a new trig occurs during the post-fault period and lasts longer than the proceeding recording, a new complete recording is started.

Disturbance report function can handle at maximum 3 simultaneous disturbance recordings.

3.23.4 Application

To get fast, complete and reliable information about disturbances in the primary and/or in the secondary system, it is important to gather information on fault currents, voltages and events. It is also important to have a continuous event-logging to enable monitoring in an overview perspective. These tasks are accomplished by the disturbance report function DRRDRE. The function provides a better understanding of the power system behavior and related primary and secondary equipment during and after a disturbance.

The analysis of the recorded data provides valuable information that can be used to explain a disturbance, in changing IED setting plan, to improve existing equipment, and so on. This information can also be used when planning for and designing new installations, that is, a disturbance recording can be a part of functional analysis.

Disturbance report DRRDRE is always included in the IED. It acquires sampled data of all the selected analog and binary signals connected to the function blocks.

- Maximum 20 external analog signals
- 20 internal derived analog signals
- 64 binary signals

Disturbance report function is a common name for several functions, such as indications, event recorder, event list, trip value recorder and disturbance recorder.

Disturbance report function is characterized by great flexibility as far as configuration, starting conditions, recording times, and large storage capacity are concerned. Thus, disturbance report is not dependent on the operation of protective functions, and it can record disturbances that are not discovered by protective functions. Disturbance report can be used as an advanced stand-alone disturbance recorder.

Every disturbance report recording is saved in the IED. The same applies to all events which are continuously saved in a ring-buffer. LHMI can be used to get information about the recordings, and the disturbance report files can be uploaded in the PCM600 using the disturbance handling tool, for report reading or further analysis (using WaveWin, that can be found on the PCM600 installation CD). The user can also upload disturbance report files using MMS (over IEC 61850-8-1) clients.

If the IED is connected to a station bus (IEC 61850-8-1), the disturbance recorder (record made and fault number) and the fault locator information are available as GOOSE or report control data.

The analog output data from the load shedding function block for example, sheddable load, load mismatch and so on, is connected to the A4ARDR function block for recording the changes in the output data during a specified time period. This recording is initaiated by a binary trigger connected to one of the BxRBDR components. A pre-trigger time (max value = 3 s) and a post-trigger time (max value = 10 s) can be configured and the changes during the configured period of time is recorded. These changes can be viewed using the Disturbance Recording Viewing tool. Apart from generating the disturbance records , BxRBDR can be used for creating process events and for configuring the start and trip LED on the LHMI overlay. Binary output from the load shedding function block can be connected to the BxRBDR block to generate the process events.

Presently the disturbance recorder does not support calculated analog values or sample values from an application thread that has a SMAI function configured for 80 samples/cycle.

3.23.5 Signals

Table 78: DRRDRE Output signals

Name	Type	Description
DRPOFF	BOOLEAN	Disturbance report function turned off
RECSTART	BOOLEAN	Disturbance recording started
RECMADE	BOOLEAN	Disturbance recording made
CLEARED	BOOLEAN	All disturbances in the disturbance report cleared
MEMUSED	BOOLEAN	More than 80% of memory used

3.23.6 Settings

Table 79: DRRDRE Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On
Pre-trigger time	0.05 - 3.00	s	0.01	0.10	Pre-fault recording time
Post-trigger time	0.1 - 10.0	s	0.1	0.5	Post-fault recording time
Recording time limit	0.5 - 8.0	s	0.1	1.0	Fault recording time limit
Post-retrig	Off On	-	-	Off	Post-fault retrig enabled (On) or not (Off)
Max Num records	10 - 100	-	1	100	Maximum number of stored disturbances
Reference channel	1 - 30	Ch	1	1	Trip value recorder, phasor reference channel
Operation mode test	Off On	-	-	Off	Operation mode during test mode

3.23.7 Monitored data

Table 80: DRRDRE Monitored data

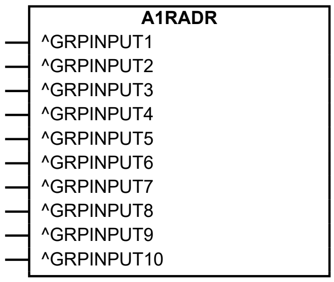
Name	Type	Values (Range)	Unit	Description
DRPOFF	BOOLEAN	0=FALSE 1=TRUE	-	Disturbance report function turned off
RECSTART	BOOLEAN	0=FALSE 1=TRUE	-	Disturbance recording started
RECMADE	BOOLEAN	0=FALSE 1=TRUE	-	Disturbance recording made
CLEARED	BOOLEAN	0=FALSE 1=TRUE	-	All disturbances in the disturbance report cleared
MEMUSED	BOOLEAN	0=FALSE 1=TRUE	-	More than 80% of memory used
Memory used	INTEGER	-	%	Memory usage (0-100%)
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
Under Lev Trg Ch 1	BOOLEAN	0=FALSE 1=TRUE	-	Under level trig for analog channel 1 activated
Over Lev Trg Ch 1	BOOLEAN	0=FALSE 1=TRUE	-	Over level trig for analog channel 1 activated
Fault number	INTEGER	-	-	Disturbance fault number

Monitored data values are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

3.23.8 Analog input signals A1RADR and A2RADR

3.23.8.1 Function block



IEC09000349-1-en.vsd

Figure 58: Function block, analog inputs

3.23.8.2 Signals

The input signal tables for A1RADR and A2RADR are similar except for the GRPINPUT number.

- A1RADR, GRPINPUT1 - GRPINPUT10
- A2RADR, GRPINPUT11 - GRPINPUT20

Table 81: A1RADR Input signals

Name	Type	Default	Description
GRPINPUT1	GROUP SIGNAL	-	Group signal for input 1

Values are the same for each input signal. The channel numbers are shown after the parameter name in LHMI and PCM600.

3.23.8.3 Settings

Setting tables for A1RADR and A2RADR are similar except for channel numbers.

- A1RADR, channel01 - channel10
- A2RADR, channel11 - channel20

Table 82: A1RADR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation Ch 1	Off On	-	-	Off	Operation On/Off
Function type Ch 1	0 - 255	-	1	0	Function type for analog channel 1 (IEC-60870-5-103)
Information Num Ch 1	0 - 255	-	1	0	Information number for analog channel 1 (IEC-60870-5-103)

Table 83: A1RADR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Nominal value Ch 1	0.0 - 999999.9	-	0.1	0.0	Nominal value for analog channel 1
Under trigger Ch 1	Off On	-	-	Off	Use under level trigger for analog channel 1 (on) or not (off)
Under Trg Lev Ch 1	0 - 200	%	1	50	Under trigger level for analog channel 1 in % of signal
Over trigger Ch 1	Off On	-	-	Off	Use over level trigger for analog channel 1 (on) or not (off)
Over Trg Lev Ch 1	0 - 5000	%	1	200	Over trigger level for analog channel 1 in % of signal

Settings are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

3.23.8.4 Technical revision history

Table 84: A1RADR technical revision history

Technical revision	Change
B	Added IEC 60870-5-103 support

Table 85: A2RADR technical revision history

Technical revision	Change
B	Added IEC 60870-5-103 support

3.23.9 Analog input signals A3RADR and A4RADR

3.23.9.1 Function block

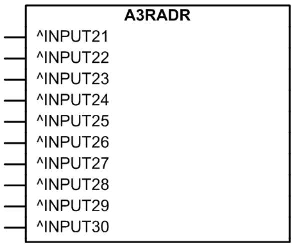


Figure 59: A3RADR function block, derived analog inputs

3.23.9.2 Signals

Input signal tables for A3RADR and A4RADR are similar except for the GRPINPUT number.

- A3RADR, INPUT21 - INPUT30
- A4RADR, INPUT31 - INPUT40

Table 86: A3RADR Input signals

Name	Type	Default	Description
INPUT21	REAL	0.0	Analog channel 21

3.23.9.3 Settings

Setting tables for A3RADR and A4RADR are similar except for the channel numbers.

- A3RADR, channel 21 - channel 30
- A4RADR, channel 31 - channel 40

Table 87: A3RADR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation Ch 21	Off On	-	-	Off	Operation On/Off
Function type Ch 21	0 - 255	-	1	0	Function type for analog channel 21 (IEC-60870-5-103)
Information Num Ch21	0 - 255	-	1	0	Information number for analog channel 21 (IEC-60870-5-103)

Table 88: A3RADR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Nominal value Ch 21	0.0 - 999999.9	-	0.1	0.0	Nominal value for analog channel 21
Under trigger Ch 21	Off On	-	-	Off	Use under level trigger for analog channel 21 (on) or not (off)
Under Trg Lev Ch 21	0 - 200	%	1	50	Under trigger level for analog channel 21 in % of signal
Over trigger Ch 21	Off On	-	-	Off	Use over level trigger for analog channel 21 (on) or not (off)
Over Trg Lev Ch 21	0 - 5000	%	1	200	Over trigger level for analog channel 21 in % of signal

3.23.9.4 Technical revision history

Table 89: A3RADR technical revision history

Technical revision	Change
B	Added IEC 60870-5-103 support Changed the recorder so that calculated values from configuration can be recorded instead of sample values from physical channels (similar to A4RADR)

Table 90: A4RADR technical revision history

Technical revision	Change
B	Added IEC 60870-5-103 support

3.23.10 Binary input signals BxRBDR

3.23.10.1 Function block

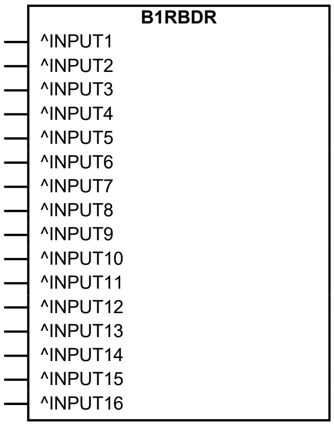


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Figure 60: Function block, binary inputs

3.23.10.2 Signals

Input signal tables for B1RBDR - B4RBDR are all similar except for the INPUT number.

- B1RBDR, INPUT1 - INPUT16
- B2RBDR, INPUT17 - INPUT32
- B3RBDR, INPUT33 - INPUT48
- B4RBDR, INPUT49 - INPUT64

Table 91: B1RBDR Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	0	Binary channel 1

Values are the same for each input signal. The channel numbers are shown after the parameter name in LHMI and PCM600.

3.23.10.3 Settings

Table 92: B1RBDR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Trigger operation 1	Off On	-	-	Off	Trigger operation On/Off
Set LED 1	Off Start Trip Start and Trip	-	-	Off	Set LED on HMI for binary channel 1
Function type Ch 1	0 - 255	-	1	0	Function type for binary channel 1 (IEC -60870-5-103)
Information Num Ch 1	0 - 255	-	1	0	Information number for binary channel 1 (IEC -60870-5-103)

Table 93: B1RBDR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Trigger level 1	Trig on 0 Trig on 1	-	-	Trig on 1	Trigger on positive (1) or negative (0) slope for binary input 1
Show indication 1	Hide Show	-	-	Hide	Indication mask for binary channel 1

Settings are the same for each channel. The channel numbers are shown after the parameter name in LHMI and PCM600.

Setting tables for B1RBDR - B4RBDR are all similar except for the binary channel numbers.

- B1RBDR, channel1 - channel16
- B2RBDR, channel17 - channel32
- B3RBDR, channel33 - channel48
- B4RBDR, channel49 - channel64

3.23.10.4 Technical revision history

Table 94: B1RBDR technical revision history

Technical revision	Change
B	Added IEC 60870-5-103 support

Table 95: B2RBDR technical revision history

Technical revision	Change
B	Added IEC 60870-5-103 support

Table 96: B3RBDR technical revision history

Technical revision	Change
B	Added IEC 60870-5-103 support

Table 97: B4RBDR technical revision history

Technical revision	Change
B	Added IEC 60870-5-103 support

3.23.11 Technical data

Table 98: DRRDRE technical data

Function	Range or value	Accuracy
Pre-fault time	(0.05–3.00) s	-
Post-fault time	(0.1–10.0) s	-
Limit time	(0.5–8.0) s	-
Maximum number of recordings	100, first in - first out	-
Time tagging resolution	1 ms	See time synchronization technical data
Maximum number of analog inputs	20 + 20 (external + internally derived)	-
Maximum number of binary inputs	64	-
Maximum number of phasors in the Trip Value recorder per recording	30	-
Maximum number of indications in a disturbance report	64	-
Maximum number of events in the Event recording per recording	150	-
Maximum number of events in the Event list	1000, first in - first out	-
Maximum total recording time (3.4 s recording time and maximum number of channels, typical value)	340 seconds (100 recordings) at 50 Hz, 280 seconds (80 recordings) at 60 Hz	-
Sampling rate	1 kHz at 50 Hz 1.2 kHz at 60 Hz	-
Recording bandwidth	(5-300) Hz	-

3.23.12 Technical revision history

Table 99: DRRDRE technical revision history

Technical revision	Change
B	Internal improvements

3.24 Indications

3.24.1 Functionality

To get fast, condensed and reliable information about disturbances in the primary and/or in the secondary system it is important to know, for example binary signals that have changed status during a disturbance. This information is used in the short perspective to get information via the LHMI in a straightforward way.

There are three LEDs on the LHMI (Ready, Start and Trip), which display status information about the IED.

The Indication list function shows all selected binary input signals connected to the Disturbance report function that have changed status during a disturbance.

The indication information is available for each of the recorded disturbances in the IED and the user may use the LHMI to get the information.

3.24.2 Operation principle

The LED indications display various information.

- Ready LED
  - Steady light: In service
  - Flashing light: Internal fail
  - Dark: No power supply
- Start LED
  - Function controlled by *Set LED n* setting in disturbance report function.
- Trip LED
  - Function controlled by *Set LED n* setting in disturbance report function.

Indication list

The possible indication signals are the same as the ones chosen for the disturbance report function and disturbance recorder.

The indication function tracks 0 to 1 changes of binary signals during the recording period of the collection window. This means that constant logic zero, constant logic one or state changes from logic one to logic zero are not visible in the indications list. Signals are not time tagged. There are some requirements that must be fulfilled so that the signals are recorded in the indications list.

- Signal must be connected to binary input BxRBDR function block
- DRRDRE parameter *Operation* must be set "On"
- DRRDRE must be trigged (binary or analog)
- Input signal must change state from logical 0 to 1 during the recording time.

Indications are selected with the indication mask (*Set LED n*) when setting the binary inputs.

The name of the binary signal that appears in the Indication function is the user-defined name assigned at theIED configuration. The same name is used in disturbance recorder function, indications and event recorder function.

3.24.3 Signals

The indications function logs the same binary input signals as the disturbance report function.

3.24.4 Technical data

Table 100: Indications DRRDRE technical data

Function		Value
Buffer capacity	Maximum number of indications presented for single disturbance	64
	Maximum number of recorded disturbances	100

3.25 Event recorder

3.25.1 Functionality

Quick, complete and reliable information about disturbances in the primary and/or in the secondary system is vital, for example, time-tagged events logged during disturbances. This information is used for different purposes in the short term (for example corrective actions) and in the long term (for example functional analysis).

The event recorder logs all selected binary input signals connected to the disturbance report function. Each recording can contain up to 150 time-tagged events.

The event recorder information is available for the disturbances locally in the IED. The information can be uploaded to the PCM600 and further analyzed using the Disturbance Handling tool.

The event recording information is an integrated part of the disturbance record (Comtrade file).

3.25.2 Operation principle

When one of the trig conditions for the disturbance report is activated, the event recorder logs every status change in the 64 selected binary signals. The events can be generated by both internal logical signals and binary input channels. The internal signals are time-tagged in the main processor module, while the binary input channels are time-tagged directly in each I/O module. The events are collected during the total recording time (pre-, post-fault and limit time), and stored in the disturbance report flash memory at the end of each recording.

In case of overlapping recordings, when *PostRetrig* = *On* and a new trig signal appears during the post-fault time, events are saved in both recording files.

The binary input signal name appearing in the event recording is the user-defined name assigned during the IED configuration. The same name is used in the disturbance recorder function, indications and event recorder function.

The event record is stored as a part of the disturbance report information and managed via the LHMI or PCM600.

Events can not be read from the IED if more than one user accesses the IED simultaneously.

3.25.3 Signals

The event recorder function logs the same binary input signals as the disturbance report function.

3.25.4 Technical data

Table 101: Event recorder DRRDRE technical data

Function		Value
Buffer capacity	Maximum number of events in disturbance report	150
	Maximum number of disturbance reports	100
Resolution		1 ms
Accuracy		Depending on time synchronizing

3.26 Event list

3.26.1 Functionality

Continuous event-logging is useful for monitoring the system from an overview perspective, and is a complement to specific disturbance recorder functions.

The event list logs all binary input signals connected to the disturbance report function. The list can contain up to 1000 time-tagged events stored in a ring-buffer.

The event list information is available in the IED, and is reported to higher control systems via the station bus together with other logged events in the IED. The LHMI can be used to view the event list.

To view the events occurring while the event list is displayed in the LHMI, the list has to be closed and reopened.

3.26.2 Operation principle

When a binary signal connected to the disturbance report function changes status, the event list function stores input name, status and time in the event list in chronological order. The list can contain up to 1000 events from both internal logic signals and binary input channels. If the list is full, the oldest event is overwritten when a new event arrives.

The list can be configured to show the oldest or the newest events first with a setting on the LHMI.

The event list function runs continuously, whereas the event recorder function is active only during a disturbance.

The binary signal name that appears in the event recording is the user-defined name assigned during the IED configuration. The same name is used in the disturbance recorder function , indications and the event recorder function.

The event list is stored and managed separate from the disturbance report information.

3.26.3 Signals

The event list logs the same binary input signals as configured for the disturbance report function.

3.26.4 Technical data

Table 102: Event list DRRDRE technical data

Function		Value
Buffer capacity	Maximum number of events in the list	1000
Resolution		1 ms
Accuracy		Depending on time synchronizing

3.27 Trip value recorder

3.27.1 Functionality

Information about the pre-fault and fault values for currents and voltages are vital for the disturbance evaluation.

The trip value recorder calculates the values of all selected analog input signals connected to the disturbance report function. The result is magnitude and phase angle before and during the fault for each analog input signal.

The trip value recorder information is available for the disturbances locally in the IED.

The information may be uploaded to the PCM600 and further analyzed using the Disturbance Handling tool.

The trip value recorder information is an integrated part of the disturbance record (Comtrade file).

3.27.2 Operation principle

Trip value recorder calculates and presents both fault and pre-fault amplitudes as well as the phase angles of all the selected analog input signals. The DRRDRE parameter *Reference channel* points out which input signal is used as the angle reference.

When the disturbance report function is triggered, the sample for the fault interception is searched for by checking the non-periodic changes in the analog input signals. The channel search order is consecutive, starting with the analog input with the lowest number.

When a starting point is found, the Fourier estimation of the pre-fault values of the complex values of the analog signals starts 1.5 cycle before the fault sample. The estimation uses samples during one period. The post-fault values are calculated using the RLS method. The calculation starts a few samples after the fault sample and uses samples during 1/2 - 2 cycles, depending on the shape of the signals.

If no starting point is found in the recording, the disturbance report trig sample is used as the start sample for the Fourier estimation. The estimation uses samples during one cycle before the trig sample. In this case the calculated values are used both as pre-fault and fault values.

The name of the analog signal that appears in the Trip value recorder function is the user-defined name assigned when the IED is configured. The same name is used in the disturbance recorder function.

The trip value record is stored as a part of the disturbance report information (LMBRFLO) and managed in PCM600 or via the LHMI.

3.27.3 Signals

The trip value recorder function uses analog input signals connected to A1RADR or A2RADR (not A3RADR and A4RADR).

3.27.4 Technical data

Table 103: Trip value recorder DRRDRE technical data

Function		Value
Buffer capacity	Maximum number of analog inputs	20
	Maximum number of disturbance reports	100

3.28 Disturbance recorder

3.28.1 Functionality

The disturbance recorder function supplies fast, complete and reliable information about disturbances in the power system. It facilitates understanding the system behavior and the related primary and secondary equipment during and after a disturbance. Recorded information is used for different purposes in the short perspective (for example corrective actions) and long perspective (for example functional analysis).

The disturbance recorder acquires sampled data from the selected analog- and binary signals connected to the disturbance report function (maximum 40 analog and 64 binary signals). The binary signals available are the same as for the event recorder function.

The function is characterized by great flexibility and is not dependent on the operation of protection functions. It can record disturbances not detected by protection functions.

The disturbance recorder information for the last 100 disturbances are saved in the IED.The list of recordings can be viewed via LHMI.

For report reading or further analysis, the disturbance recording information can be uploaded in PCM600 using the Disturbance Handling tool (using WaveWin, that can be found on the PCM600 installation CD).

3.28.2 Operation principle

Disturbance recording is based on the acquisition of binary and analog signals. The binary signals can be either true binary input signals or internal logical signals generated by the functions in the IED. The analog signals to be recorded are input channels from the TRMthrough SMAI and some internally derived analog signals.

Disturbance recorder collects analog values and binary signals continuously, in a cyclic buffer. The pre-fault buffer operates according to the FIFO principle; old data is being overwritten as new data arrives when the buffer is full. The size of this buffer is determined by the set pre-fault recording time.

Upon detection of a fault condition (triggering), the disturbance is time tagged and the data storage continues in a post-fault buffer. The storage process continues as long as the fault condition prevails - plus a certain additional time. This is called the post-fault time and it can be set in the disturbance report.

The above mentioned two parts form a disturbance recording. The whole memory, intended for disturbance recordings, acts as a cyclic buffer and when it is full, the oldest recording is overwritten. Up to the last 100 recordings are stored in the IED.

The time tagging refers to the activation of the trigger that starts the disturbance recording. A recording can be trigged by manual start, binary input and/or from analog inputs (over-/underlevel trig).

A user-defined name for each of the signals can be set. These names are common for all functions within the disturbance report functionality.

3.28.2.1 Disturbance recorder memory and storage

The maximum number of recordings depend on each recording's total recording time. Long recording time reduces the number of recordings to less than 100.

When a recording is completed, a post-recording process starts.

- Saving the data for analog channels with corresponding data for binary signals
- Add relevant data to be used by PCM600
- Compression of the data, which is performed without losing any data accuracy
- Storing the compressed data in a non-volatile memory (flash memory)

The recorded disturbance is now ready for retrieval and evaluation.

The recording files comply with the Comtrade standard IEC 60255-24 and are divided into three files; a header file (HDR), a configuration file (CFG) and a data file (DAT).

The header file (optional in the standard) contains basic information about the disturbance, that is, information from the disturbance report sub-functions. PCM600 use this information and present the recording in a user-friendly way.

General

- Station name, object name and unit name
- Date and time for the trig of the disturbance
- Record number
- Sampling rate
- Time synchronization source
- Recording times
- Activated trig signal
- Active setting group

Analog

- Signal names for selected analog channels
- Information, for example trig on analog inputs
- Primary and secondary instrument transformer rating
- Over- or Undertrig: level and operation
- Over- or Undertrig status at time of trig
- CT direction

Binary

- Signal names
- Status of binary input signals

The mandatory configuration file contains information needed to interpret the data file. For example sampling rate, number of channels, system frequency, and channel info.

The mandatory data file contains values for each input channel for each sample in the record (scaled value). The data file also contains a sequence number and time stamp for each set of samples.

3.28.3 Signals

See the disturbance report for input and output signals.

3.28.4 Settings

See the disturbance report for settings.

3.28.5 Technical data

Table 104: DRRDRE technical data

Function		Value
Buffer capacity	Maximum number of analog inputs	40
	Maximum number of binary inputs	64
	Maximum number of disturbance reports	100
Maximum total recording time (3.4 s recording time and maximum number of channels, typical value)		340 seconds (100 recordings) at 50 Hz 280 seconds (80 recordings) at 60 Hz

3.29 Non-volatile memory

In addition to the setting values, the IED can store some data in the non-volatile memory.

- Configuration
- Trip lock-out
- Events
- Disturbance records
- CB conditioning monitoring values
- Thermal loading
- Number of auto-reclosure shots and starts/trips of the protection stages (only REF630)
- Function key & alarm LED states
- Protection function recorded data

3.30 Self supervision with internal event list

3.30.1 Functionality

The Self supervision with internal event list (INTERRSIG and SELFSUPEVLST) function reacts to internal system events generated by the different built-in self-supervision elements. The internal events are saved in an internal event list.

3.30.2 Internal error signals INTERRSIG

3.30.2.1 Function block

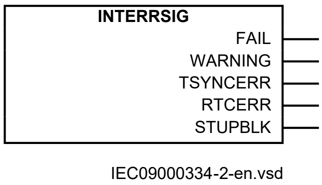


Figure 61: Function block

3.30.2.2 Signals

Table 105: INTERRSIG Output signals

Name	Type	Description
FAIL	BOOLEAN	Internal fail
WARNING	BOOLEAN	Internal warning
TSYNCERR	BOOLEAN	Time synchronization error
RTCERR	BOOLEAN	Real time clock error
STUPBLK	BOOLEAN	Application startup block

3.30.2.3 Settings

The function does not have any parameters available in LHMI or PCM600.

3.30.3 Internal event list SELFSUPEVLST

3.30.3.1 Settings

The function does not have any parameters available in LHMI or PCM600.

3.30.4 Operation principle

The self-supervision operates continuously.

- Normal micro-processor watchdog function.
- Checking of digitized measuring signals.
- Other alarms, for example hardware and time synchronization.

The SELFSUPEVLST function status can be monitored from the LHMI, from the Event Viewer in PCM600 or from a SMS/SCS system.

Under the Diagnostics menu in the LHMI the present information from the self-supervision function can be reviewed. The information can be found under **Monitoring/Internal Events** or **Monitoring/IED Status**. The information from the self-supervision function is also available in the Event Viewer in PCM600.

A self-supervision summary can be obtained by means of the potential free alarm contact (INTERNAL FAIL) located on the power supply module. This output relay is activated (no fault) and deactivated (fault) by the Internal Fail signal, see Figure 62. Also the software watchdog timeout and the undervoltage detection of the PSM deactivates the relay.

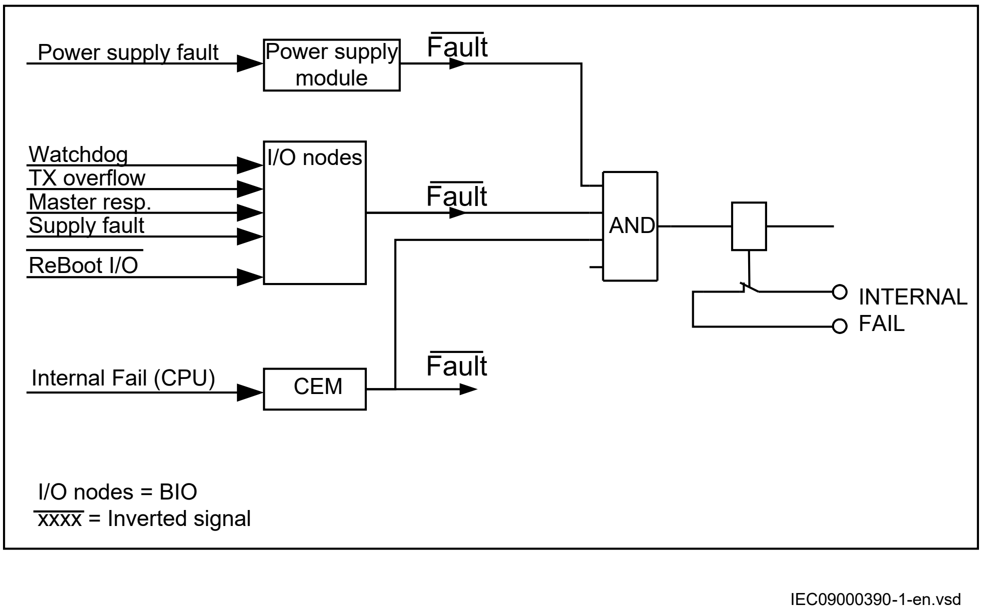


Figure 62: Hardware self-supervision, potential-free contact

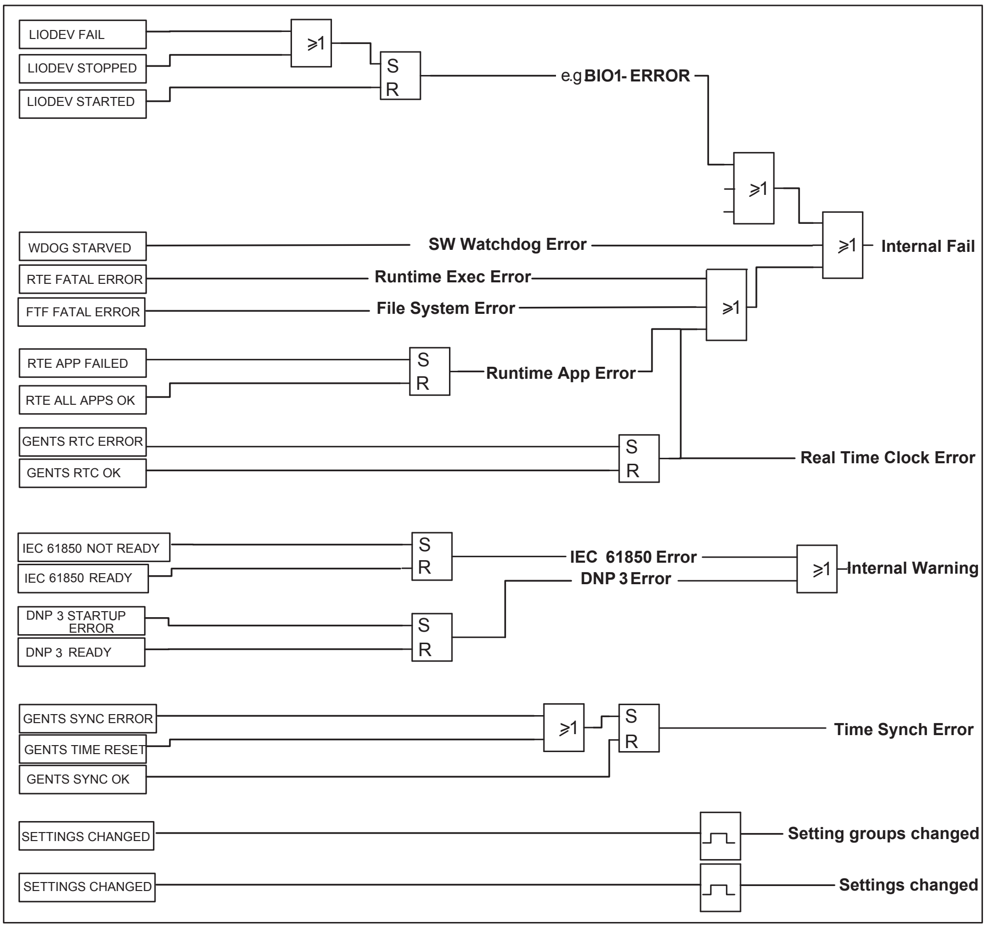


Figure 63: Self supervision, function block internal signals

Some signals are available from the INTERRSIG function block. The signals from INTERRSIG function block are sent as events to the station level of the control system. The signals from the INTERRSIG function block can also be connected to binary outputs for signalization via output relays or they can be used as conditions for other functions if required/desired.

Individual error signals from I/O modules can be obtained from respective module in Signal Matrix. Error signals from time synchronization can be obtained from the time synchronization block INTERSIG.

3.30.4.1 Internal signals

SELFSUPEVLST function provides several status signals, that describe the IED condition. As they provide information about the internal status of the IED, they are also called internal signals. The internal signals can be divided into two groups.

- Standard signals are always presented in the IED, see Table 106.
- Hardware dependent internal signals are collected depending on the hardware configuration, see Table 107.

Explanations of internal signals are listed in Table 108.

Table 106: SELFSUPEVLST standard internal signals

Name of signal	Description
Internal Fail	Internal fail status
Internal Warning	Internal warning status
Real Time Clock Error	Real time clock status
Time Synch Error	Time synchronization status
Runtime App Error	Runtime application error status
Runtime Exec Error	Runtime execution error status
IEC61850 Error	IEC 61850 error status
SW Watchdog Error	SW watchdog error status
Setting(s) Changed	Setting(s) changed
Setting Group(s) Changed	Setting group(s) changed
File System Error	Fault tolerant file system status
DNP3 Error	DNP3 error status

Table 107: Self-supervision's hardware dependent internal signals

Card	Name of signal	Description
PSM	PSM-Error	Power supply module error status
TRM	TRM-Error	Transformator module error status
COM	COM-Error	Communication module error status
BIO	BIO-Error	Binary input/output module error status
AIM	AIM-Error	Analog input module error status
RTD	RTD-Error	Resistance temperature detector / mA-output module error status

Table 108: Explanations of internal signals

Name of signal	Reasons for activation
Internal Fail	This signal is active if one or more of the following internal signals are active; Real Time Clock Error, Runtime App Error, Runtime Exec Error, SW Watchdog Error, File System Error
Internal Warning	This signal is active if one or more of the following internal signals are active; IEC 61850 Error, DNP3 Error
Real Time Clock Error	This signal is active if there is a hardware error with the real time clock.
Time Synch Error	This signal is active when the source of the time synchronization is lost, or when the time system has to make a time reset.

Table continues on next page

Name of signal	Reasons for activation
Runtime Exec Error	This signal is active if the Runtime Engine failed to do some actions with the application threads. The actions can be loading of settings or parameters for components, changing of setting groups, loading or unloading of application threads.
IEC61850 Error	This signal is active if the IEC 61850 stack did not succeed in some actions like reading IEC 61850 configuration, startup, for example.
SW Watchdog Error	This signal is activated when the IED has been under too heavy load for at least 5 minutes. The operating systems background task is used for the measurements.
Runtime App Error	This signal is active if one or more of the application threads are not in the state that Runtime Engine expects. The states can be CREATED, INITIALIZED, RUNNING, for example.
Setting(s) Changed	This signal generates an internal event to the internal event list if any setting(s) is changed.
Setting Group(s) Changed	This signal generates an internal event to the Internal Event List if any setting group(s) is changed.
File System Error	This signal is active if both the working file and the backup file are corrupted and cannot be recovered.
DNP3 Error	This signal is active when DNP3 detects any configuration error during startup.

3.30.4.2 Run-time model

The analog signals to the A/D converter is internally distributed into two different converters, one with low amplification and one with high amplification, see Figure 64.

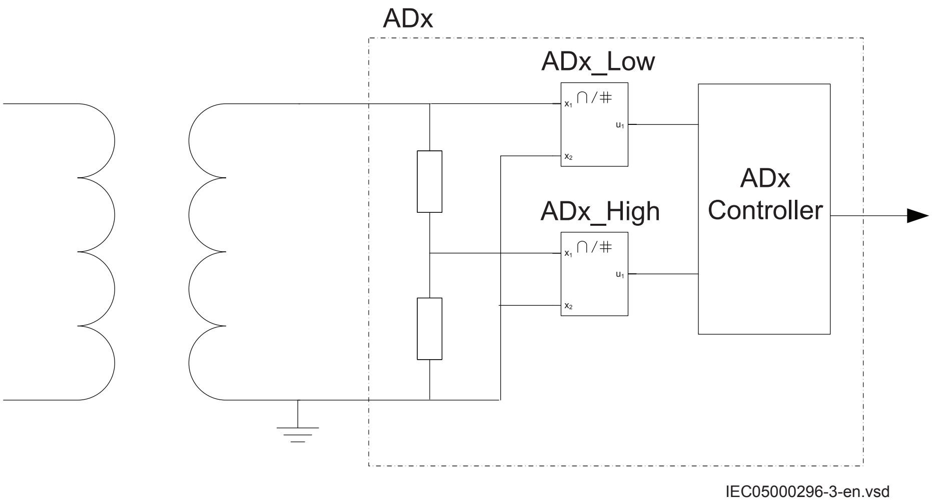


Figure 64: Simplified drawing of A/D converter for the IED.

The technique to split the analog input signal into two A/D converter(s) with different amplification makes it possible to supervise the A/D converters under normal conditions where the signals from the two A/D converters should be identical. An alarm is given if the signals are out of the boundaries. Another benefit is that it improves the dynamic performance of the A/D conversion.

The self-supervision of the A/D conversion is controlled by the ADx_Controller function. One of the tasks for the controller is to perform a validation of the input signals. This is done in a validation filter which has mainly two objects. First is the validation part that checks that the A/D conversion seems to work as expected. Secondly, the filter chooses which of the two signals is sent to the CPU, that is the signal that has the most suitable signal level, the *ADx_LO* or the 16 times higher *ADx_HI*.

When the signal is within measurable limits on both channels, a direct comparison of the two A/D converter channels can be performed. If the validation fails, the CPU is informed and an alarm is given for A/D converter failure.

The ADx_Controller also supervise other parts of the A/D converter.

3.30.5 Application

The protection and control IEDs have many functions included. Self supervision with internal event list (SELFSUPEVLST) and internal error signals (INTERRSIG) function provides supervision of the IED. The fault signals make it easier to analyze and locate a fault.

Both hardware and software supervision is included and possible faults can be indicated through a hardware contact on the power supply module and/or through the software communication.

Internal events are generated by the built-in supervisory functions. The supervisory functions supervise the status of the various modules in the IED and, in case of failure, a corresponding event is generated. Similarly, when the failure is corrected, a corresponding event is generated.

Apart from the built-in supervision of the various modules, events are also generated when the status changes for the built-in real time clock (in operation/out of order) or external time synchronization (in operation/out of order). Events are also generated whenever any setting in the IED is changed.

The internal events are time tagged with a resolution of 1 ms and stored in a list. The list can store up to 40 events. The list is based on the FIFO principle, that is, when it is full, the oldest event is overwritten. The list can be cleared via the LHMI.

The list of internal events provides valuable information, which can be used during commissioning and fault tracing.

The list of internal events can be found in the LHMI, WHMI or PCM600.

The list can be cleared via the LHMI or WHMI menu **Clear/Clear internal event list**.

3.30.6 Technical data

Table 109: Self supervision with internal event list

Data	Value
Recording manner	Continuous, event controlled
List size	

3.31 Time synchronization

3.31.1 Functionality

The time synchronization source selector is used to select a common source of absolute time for the IED when it is a part of a protection system. This makes it possible to compare event and disturbance data between all IEDs in a station automation system.

Do not use the MicroSCADA OPC server as a time synchronization source.

3.31.2 Time synchronization TIMESYNCHGEN

3.31.2.1 Settings

Table 110: TIMESYNCHGEN Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
CoarseSyncSrc	Off SNTP DNP IEC60870-5-103	-	-	Off	Coarse time synchronization source
FineSyncSource	Off SNTP IRIG-B	-	-	Off	Fine time synchronization source
SyncMaster	Off SNTP-Server	-	-	Off	Activate IED as synchronization master

Coarse time synchronization is used to set the time on the very first message and if any message has an offset of more than ten seconds. If no FineSyncSource is given, the CoarseSyncSrc is used to synchronize the time.

Fine time synchronization is used to set the time on the first message after a time reset or if the source may always set the fine time, and the source gives a large offset towards the IED time. After this, the time is used to synchronize the time after a spike filter, that is, if the source glitches momentarily or there is a momentary error, this is neglected. The only fine synchronization source that may always set the time is IRIG-B.

It is not recommended to use SNTP as both fine and coarse synchronization source, as some clocks sometimes send out a bad message. For example, Arbiter clocks sometimes send out a "zero-time message", which if SNTP is set as coarse synchronization source (with or without SNTP as fine synchronization source) leads to a jump to "2036-02-07 06:28" and back.

3.31.3 Time synchronization via SNTP

3.31.3.1 Settings

Table 111: SNTP Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
ServerIP-Add	0 - 255	IP Address	1	0.0.0.0	Server IP-address
RedServIP-Add	0 - 255	IP Address	1	0.0.0.0	Redundant server IP-address

3.31.4 Time system, summer time begin DSTBEGIN

3.31.4.1 Settings

Table 112: DSTBEGIN Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
MonthInYear	January February March April May June July August September October November December	-	-	March	Month in year when daylight time starts
DayInWeek	Sunday Monday Tuesday Wednesday Thursday Friday Saturday	-	-	Sunday	Day in week when daylight time starts
WeekInMonth	Last First Second Third Fourth	-	-	Last	Week in month when daylight time starts
UTCTimeOfDay	00:00 00:30 1:00 1:30 ... 48:00	-	-	1:00	UTC Time of day in hours when daylight time starts

3.31.5 Time system, summer time ends DSTEND

3.31.5.1 Settings

Table 113: DSTEND Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
MonthInYear	January February March April May June July August September October November December	-	-	October	Month in year when daylight time ends
DayInWeek	Sunday Monday Tuesday Wednesday Thursday Friday Saturday	-	-	Sunday	Day in week when daylight time ends
WeekInMonth	Last First Second Third Fourth	-	-	Last	Week in month when daylight time ends
UTCTimeOfDay	00:00 00:30 1:00 1:30 ... 48:00	-	-	1:00	UTC Time of day in hours when daylight time ends

3.31.6 Time zone from UTC TIMEZONE

3.31.6.1 Settings

Table 114: TIMEZONE Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
NoHalfHourUTC	-24 - 24	-	1	0	Number of half-hours from UTC

3.31.7 Time synchronization via IRIG-B

3.31.7.1 Settings

Table 115: IRIG-B Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
TimeDomain	LocalTime UTC	-	-	LocalTime	Time domain
Encoding	IRIG-B 1344 1344TZ	-	-	IRIG-B	Type of encoding
TimeZoneAs1344	MinusTZ PlusTZ	-	-	PlusTZ	Time zone as in 1344 standard

3.31.8 Operation principle

The error of a clock is the difference between the actual time of the clock and the time the clock is intended to have. Clock accuracy indicates the increase in error, that is, the time gained or lost by the clock. A disciplined clock knows its own faults and tries to compensate for them.

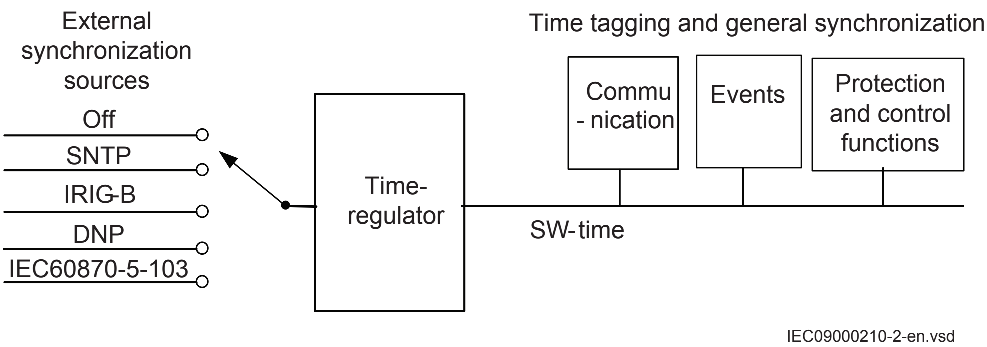


Figure 65: Design of time system (clock synchronization)

From a general point of view synchronization can be seen as a hierarchical structure. A function is synchronized from a higher level and provides synchronization to lower levels.

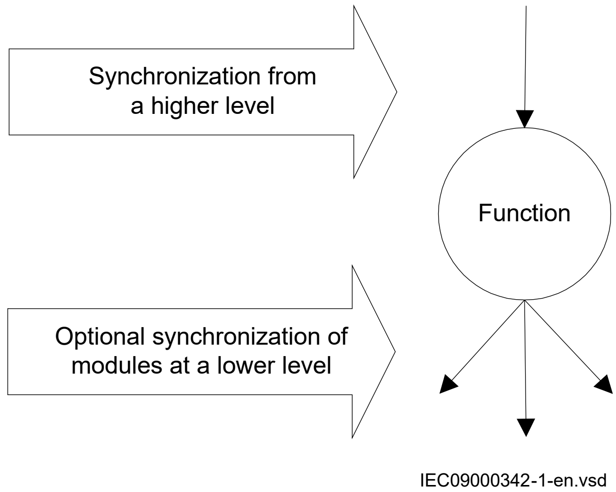


Figure 66: Synchronization principle

A function is said to be synchronized when it periodically receives synchronization messages from a higher level. As the level decreases, the accuracy of the synchronization decreases as well. A function can have several potential sources of synchronization with different maximum errors. This gives the function the possibility to choose the source with the best quality and to adjust its internal clock after this source. The maximum error of a clock can be defined in three ways.

- The maximum error of the last used synchronization message
- The time since the last used synchronization message
- The rate accuracy of the internal clock in the function

3.31.8.1 Real-time clock operation

The IED has a built-in real-time clock (RTC) with a resolution of one second. The clock has a built-in calendar that handles leap years through 2038.

Real-time clock at power off

During power off, the system time in the IED is kept by a capacitor-backed real-time clock that provides 35 ppm accuracy for 5 days. This means that if the power is off, the time in the IED may drift with 3 seconds per day, during 5 days, and after this time the time is lost completely.

Time synchronization startup procedure

The first message that contains the full time (as for instance SNTP and IRIG-B) gives an accurate time to the IED. The IED is brought into a safe state and the time is set to the correct value. After the initial setting of the clock, one of three things happens with each of the coming synchronization messages, configured as “fine”.

- If the synchronization message, which is similar to the other messages, from its origin has an offset compared to the internal time in the IED, the message is used directly for synchronization, that is, for adjusting the internal clock to obtain zero offset at the next coming time message.

- If the synchronization message has an offset that is large compared to the other messages, a spike-filter in the IED removes this time-message.
- If the synchronization message has an offset that is large, and the following message also has a large offset, the spike filter does not act and the offset in the synchronization message is compared to a threshold that defaults to 500 milliseconds. If the offset is more than the threshold, the IED is brought into a safe state and the clock is set to the correct time. If the offset is lower than the threshold, the clock is adjusted with 10 000 ppm until the offset is removed. With an adjustment of 10 000 ppm, it takes 50 seconds to remove an offset of 500 milliseconds.

Synchronization messages configured as coarse are only used for initial setting of the time. After this has been done, the messages are checked against the internal time and only an offset of more than 10 seconds resets the time.

Rate accuracy

In the IED, the rate accuracy at cold start is 100 ppm but if the IED is synchronized for a while, the rate accuracy is approximately 1 ppm if the surrounding temperature is constant. Normally, it takes 20 minutes to reach full accuracy.

Time-out on synchronization sources

All synchronization interfaces has a time-out and a configured interface must receive time-messages regularly in order not to give an error signal (TSYNCERR). Normally, the time-out is set so that one message can be lost without getting a TSYNCERR, but if more than one message is lost, a TSYNCERR is given.

3.31.8.2 Synchronization alternatives

Two main alternatives of external time synchronization are available. The synchronization message is applied either via any of the communication ports of the IED as a telegram message including date and time or via IRIG-B.

Synchronization via SNTP

SNTP provides a ping-pong method of synchronization. A message is sent from an IED to an SNTP server, and the SNTP server returns the message after filling in a reception time and a transmission time. SNTP operates via the normal Ethernet network that connects IEDs together in an IEC 61850 network. For SNTP to operate properly, there must be an SNTP server present, preferably in the same station. The SNTP synchronization provides an accuracy that gives +/- 1 ms accuracy for binary inputs. The IED itself can be set as an SNTP time server.

The SNTP server to be used is connected to the local network, that is not more than 4-5 switches or routers away from the IED. The SNTP server is dedicated for its task, or at least equipped with a real-time operating system, that is not a PC with SNTP server software. The SNTP server should be stable, that is, either synchronized from a stable source like GPS, or local without synchronization. Using a local SNTP server without synchronization as primary or secondary server in a redundant configuration is not recommended.

Synchronization via IRIG-B

IRIG-B is a protocol used only for time synchronization. A clock can provide local time of the year in this format. The “B” in IRIG-B states that 100 bits per second are transmitted, and the message is sent every second. After IRIG-B there numbers stating if and how the signal is modulated and the information transmitted.

To receive IRIG-B there are one dedicated connector for the IRIG-B port. IRIG-B 00x messages can be supplied via the galvanic interface, where x (in 00x) means a number in the range of 1-7.

If the x in 00x is 4, 5, 6 or 7, the time message from IRIG-B contains information of the year. If x is 0, 1, 2 or 3, the information contains only the time within the year, and year information has to come from the tool or LHMI.

The IRIG-B input also takes care of IEEE1344 messages that are sent by IRIG-B clocks, as IRIG-B previously did not have any year information. IEEE1344 is compatible with IRIG-B and contains year information and information of the time-zone.

It is recommended to use IEEE 1344 for supplying time information to the IRIG-B module. In this case, send also the local time in the messages.

Synchronization via DNP

The DNP3 communication can be the source for the coarse time synchronization, while the fine time synchronization needs a source with higher accuracy.

See the communication protocol manual for a detailed description of the DNP3 protocol.

Synchronization via IEC60870-5-103

The IEC60870-5-103 communication can be the source for the coarse time synchronization, while the fine tuning of the time synchronization needs a source with higher accuracy.

See the communication protocol manual for a detailed description of the IEC60870-5-103 protocol.

3.31.9 Application

Time synchronization is used to achieve a common time base for the IEDs in a protection and control system. This makes comparison of events and disturbance data between all IEDs in the system possible.

Time-tagging of internal events and disturbances are an excellent help when evaluating faults. Without time synchronization, only the events within the IED can be compared to one another. With time synchronization, events and disturbances within the entire station, and even between line ends, can be compared at evaluation.

In the IED, the internal time can be synchronized from a number of sources.

- SNTP
- IRIG-B
- DNP
- IEC60870-5-103

Do not use the MicroSCADA OPC server as a time synchronization source.

3.31.10 Technical data

Table 116: Time synchronization, time tagging

Function	Value
Time tagging resolution, events and sampled measurement values	1 ms
Time tagging error with synchronization once/min (minute pulse synchronization), events and sampled measurement values	± 1.0 ms typically
Time tagging error with SNTP synchronization, sampled measurement values	± 1.0 ms typically

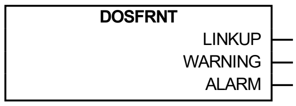
3.32 Denial of service

3.32.1 Functionality

The Denial of service functions (DOSLAN1 and DOSFRNT) are designed to limit overload on the IED produced by heavy Ethernet network traffic. The communication facilities must not be allowed to compromise the primary functionality of the device. All inbound network traffic is quota controlled so that too heavy network loads can be controlled. Heavy network load might for instance be the result of malfunctioning equipment connected to the network.

3.32.2 Denial of service, frame rate control for front port DOSFRNT

3.32.2.1 Function block



IEC09000133-1-en.vsd

Figure 67: Function block

3.32.2.2 Signals

Table 117: DOSFRNT Output signals

Name	Type	Description
LINKUP	BOOLEAN	Ethernet link status
WARNING	BOOLEAN	Frame rate is higher than normal state
ALARM	BOOLEAN	Frame rate is higher than throttle state

3.32.2.3 Settings

The function does not have any parameters available in LHMI or PCM600.

3.32.2.4 Monitored data

Table 118: DOSFRNT Monitored data

Name	Type	Values (Range)	Unit	Description
State	INTEGER	0=Off 2=Throttle 3=DiscardLow 4=DiscardAll 5=StopPoll 1=Normal	-	Frame rate control state
Quota	INTEGER	-	%	Quota level in percent 0-100
IPPackRecNorm	INTEGER	-	-	Number of IP packets received in normal mode
IPPackRecPoll	INTEGER	-	-	Number of IP packets received in polled mode
IPPackDisc	INTEGER	-	-	Number of IP packets discarded
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
NonIPPackRecNorm	INTEGER	-	-	Number of non IP packets received in normal mode
NonIPPackRecPoll	INTEGER	-	-	Number of non IP packets received in polled mode
NonIPPackDisc	INTEGER	-	-	Number of non IP packets discarded

3.32.3 Denial of service, frame rate control for LAN1 port DOSLAN1

3.32.3.1 Function block

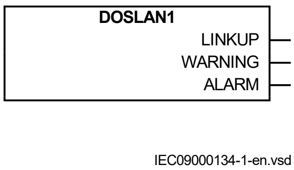


Figure 68: Function block

3.32.3.2 Signals

Table 119: DOSLAN1 Output signals

Name	Type	Description
LINKUP	BOOLEAN	Ethernet link status
WARNING	BOOLEAN	Frame rate is higher than normal state
ALARM	BOOLEAN	Frame rate is higher than throttle state

3.32.3.3 Settings

The function does not have any parameters available in LHMI or PCM600.

3.32.3.4 Monitored data

Table 120: DOSLAN1 Monitored data

Name	Type	Values (Range)	Unit	Description
State	INTEGER	0=Off 2=Throttle 3=DiscardLow 4=DiscardAll 5=StopPoll 1=Normal	-	Frame rate control state
Quota	INTEGER	-	%	Quota level in percent 0-100
IPPackRecNorm	INTEGER	-	-	Number of IP packets received in normal mode
IPPackRecPoll	INTEGER	-	-	Number of IP packets received in polled mode
IPPackDisc	INTEGER	-	-	Number of IP packets discarded
NonIPPackRecNorm	INTEGER	-	-	Number of non IP packets received in normal mode
NonIPPackRecPoll	INTEGER	-	-	Number of non IP packets received in polled mode
NonIPPackDisc	INTEGER	-	-	Number of non IP packets discarded

3.32.4 Operation principle

The denial of service functions (DOSLAN1 and DOSFRNT) measures the IED communication load and, if necessary, limit it to avoid compromising the IEDs control and protection functionality due to high CPU load. The function has three outputs.

- LINKUP indicates the Ethernet link status
- WARNING indicates that communication (frame rate) is higher than normal
- ALARM indicates that the IED limits communication

3.33 IEC 61850-8-1 communication protocol

3.33.1 Functionality

IEC 61850-8-1 protocol allows IEDs from different vendors to exchange information and simplifies system engineering. Peer-to-peer communication according to GOOSE is part of the standard. Disturbance files uploading is provided.

The event system has a rate limiter to reduce CPU load. Each channel has a quota of 10 events/second. If the quota is exceeded the event channel is blocked until the event changes is below the quota.

3.33.2 Communication interfaces and protocols

Table 121: Supported station communication interfaces and protocols

Protocol	Ethernet		Serial	
	100BASE-TX RJ-45	100BASE-FX LC	Glass fibre (ST connector)	Plastic fibre (snap-in connector)
IEC 61850–8–1	●	●	-	-
DNP3	●	●	-	-
IEC 60870-5-103	-	-	●	●
● = Supported				

3.33.3 Application

The IEC 61850-8-1 communication protocol allows vertical communication to HSI clients. It allows horizontal communication between two or more IEDs from one or several vendors to exchange information, and to use it in the performance of their functions and for correct co-operation.

GOOSE, which is part of the IEC 61850–8–1 standard, allows the IEDs to communicate state and control information amongst themselves, using a publish-subscribe mechanism. When detecting an event, the IED(s) use a multi-cast transmission to notify the devices that have registered to receive the data. An IED can report its status by publishing a GOOSE message. It can also request a control action to be directed at any device in the network.

IEC 61850–8–1 specifies only the interface to the substation LAN. The LAN itself is left to the system integrator.

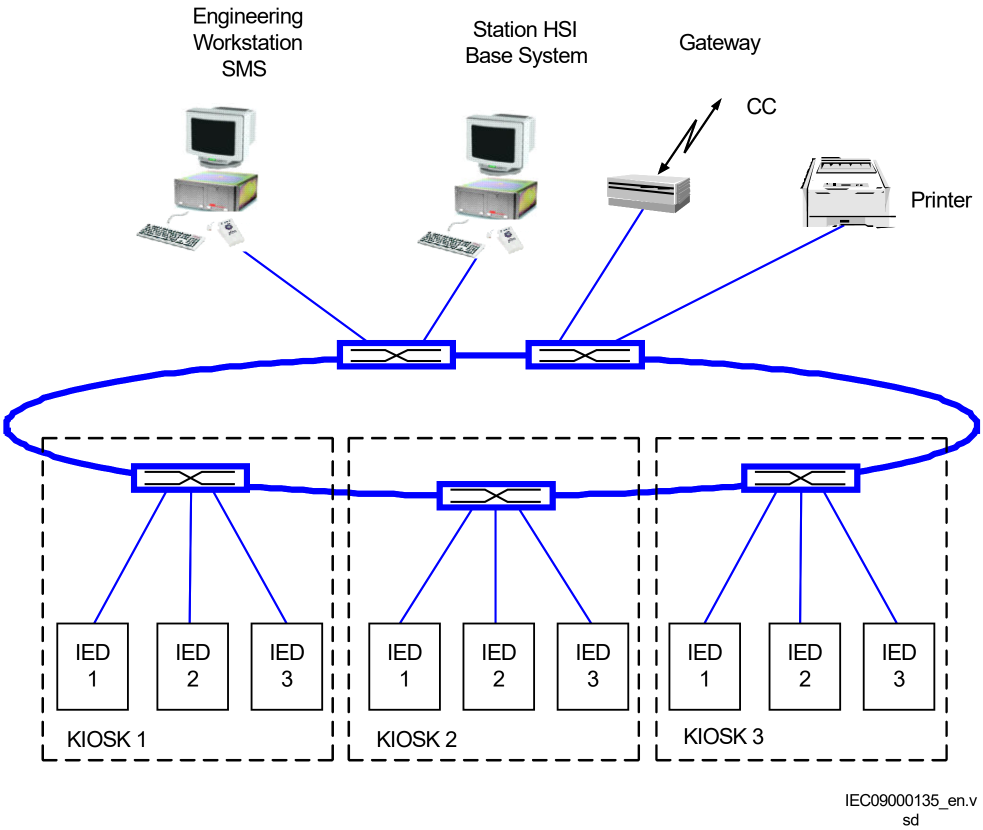


Figure 69: Example of a communication system with IEC 61850–8–1

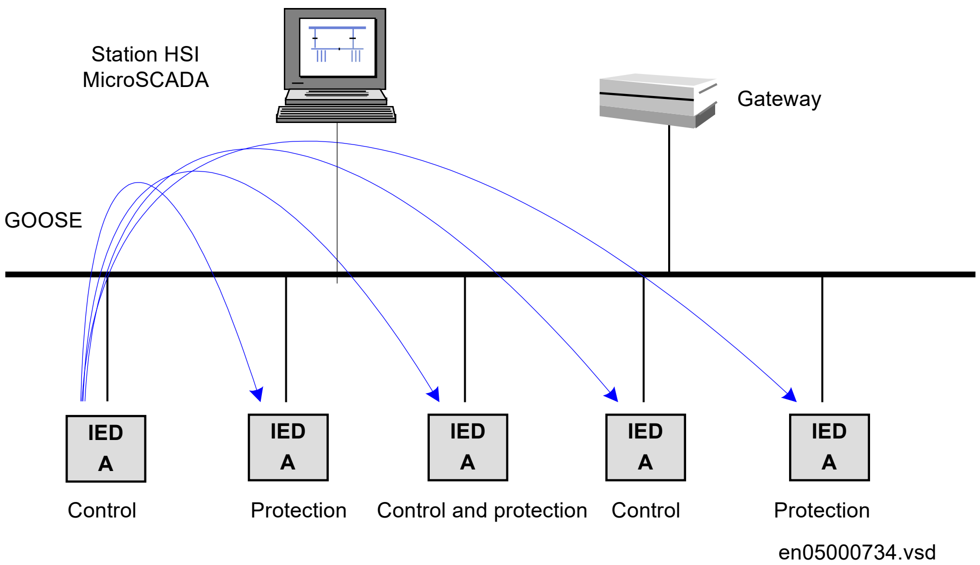


Figure 70: Example of a broadcasted GOOSE message, peer-to-peer communication

3.33.3.1 Horizontal communication via GOOSE

GOOSE messages are sent in horizontal communication between the IEDs. The information, which is exchanged, is used for station wide interlocking, breaker failure protection, busbar voltage selection and so on.

The simplified principle is shown in Figure 71. When IED1 has decided to transmit the data set it forces a transmission via the station bus. All other IEDs receive the data set, but only those who have this data set in their address list takes it and keeps it in an input container. It is defined, that the receiving IED takes the content of the received data set and makes it available for the application configuration.

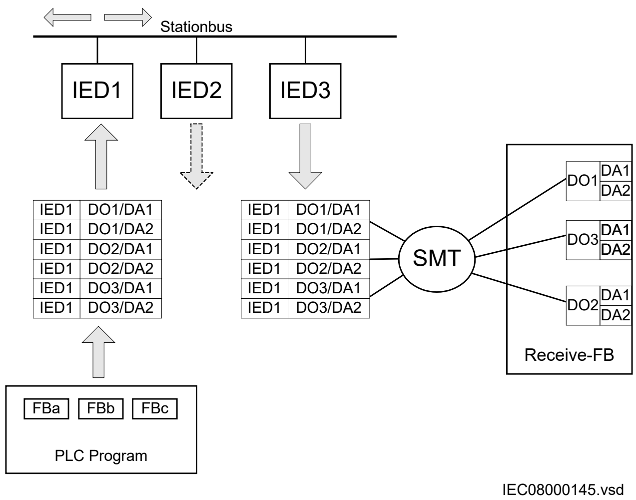
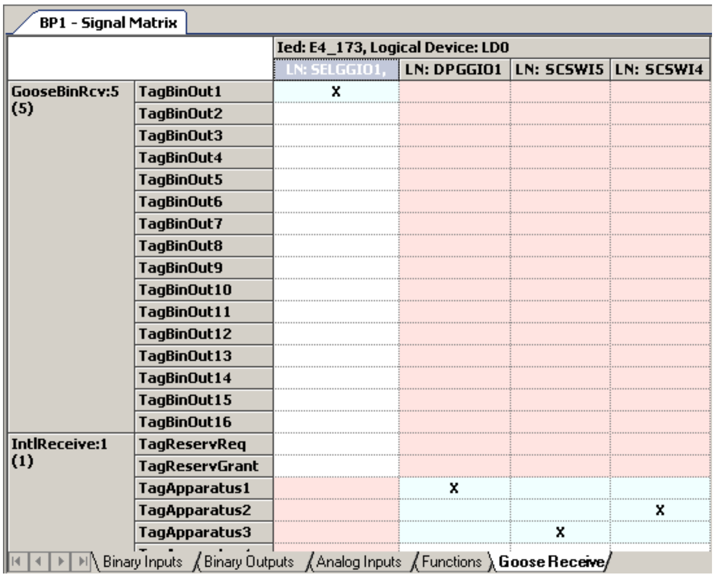


Figure 71: SMT: GOOSE principle and signal routing with Signal Matrix

Special function blocks take the data set and present it via the function block as output signals for application functions in the application configuration. Different GOOSE receive function blocks are available for the specific tasks.

Signal Matrix links the different data object attributes (for example stVal or magnitude) to the output signal to make it available for functions in the application configuration. When a matrix cell array is marked red the IEC 61850-8-1 data attribute type does not fit together, even if the GOOSE receive function block is the partner. Signal Matrix checks this on the content of the received data set.

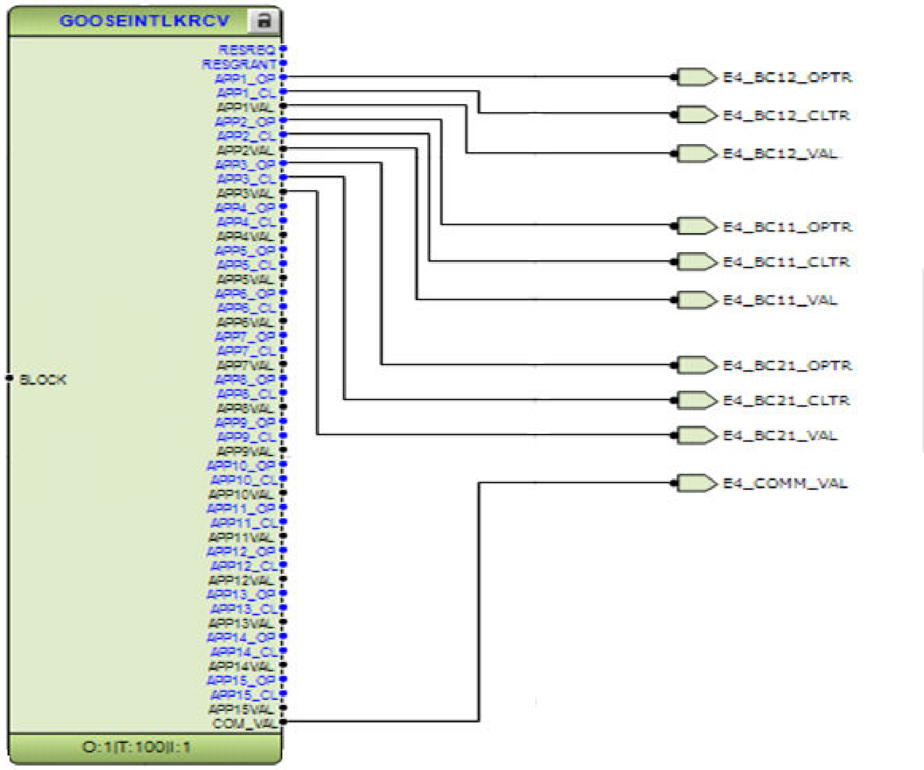


IEC08000174.vsd

Figure 72: SMT: GOOSE marshalling with Signal Matrix

GOOSE receive function blocks extract process information, received by the data set, into single attribute information that can be used within the application configuration. Crosses in the SMT matrix connect received values to the respective function block signal in Signal Matrix.

The corresponding quality attribute is automatically connected by Signal Matrix. This quality attribute is available in Application Configuration, through the outputs of the available GOOSE function blocks.



IEC08000171_1_en.vsd

Figure 73: SMT: GOOSE receive function block with converted signals

3.33.4 Settings

Table 122: IEC61850-8-1 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

3.33.5 Technical data

Table 123: IEC 61850-8-1 communication protocol

Function	Value
Protocol	IEC 61850-8-1
Communication speed for the IEDs	100BASE-FX
Protocol	IEC 608–5–103
Communication speed for the IEDs	9600 or 19200 Bd
Protocol	DNP3.0

Table continues on next page

Function	Value
Communication speed for the IEDs	300–19200 Bd
Protocol Communication speed for the IEDs	TCP/IP, Ethernet 100 Mbit/s

3.34 Horizontal communication via GOOSE for interlocking GOOSEINTLKRCV

3.34.1 Function block

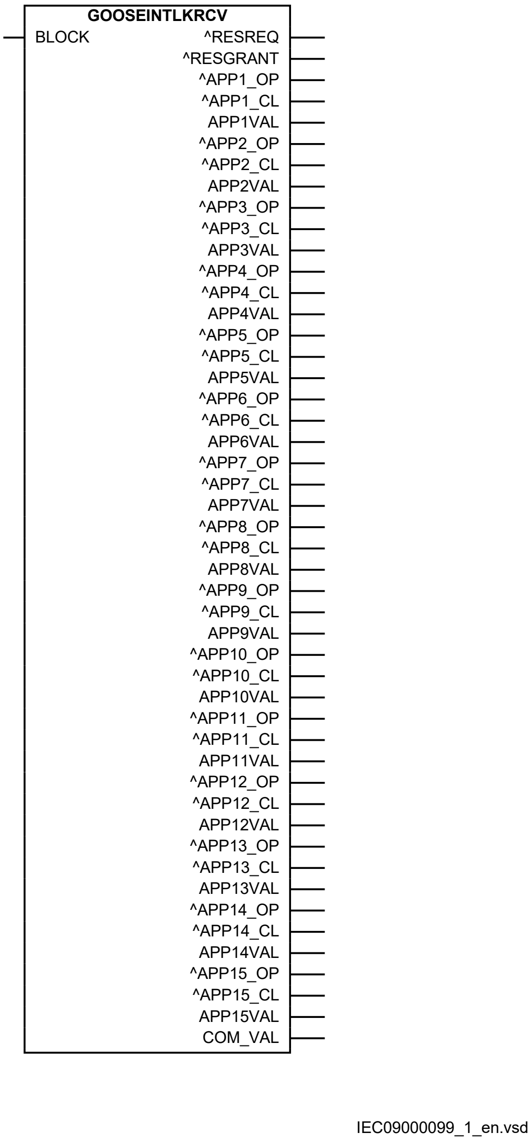


Figure 74: Function block

3.34.2 Signals

Table 124: GOOSEINTLKRCV Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of output signals

Table 125: GOOSEINTLKRCV Output signals

Name	Type	Description
RESREQ	BOOLEAN	Reservation request
RESGRANT	BOOLEAN	Reservation granted
APP1_OP	BOOLEAN	Apparatus 1 position is open
APP1_CL	BOOLEAN	Apparatus 1 position is closed
APP1VAL	BOOLEAN	Apparatus 1 position is valid
APP2_OP	BOOLEAN	Apparatus 2 position is open
APP2_CL	BOOLEAN	Apparatus 2 position is closed
APP2VAL	BOOLEAN	Apparatus 2 position is valid
APP3_OP	BOOLEAN	Apparatus 3 position is open
APP3_CL	BOOLEAN	Apparatus 3 position is closed
APP3VAL	BOOLEAN	Apparatus 3 position is valid
APP4_OP	BOOLEAN	Apparatus 4 position is open
APP4_CL	BOOLEAN	Apparatus 4 position is closed
APP4VAL	BOOLEAN	Apparatus 4 position is valid
APP5_OP	BOOLEAN	Apparatus 5 position is open
APP5_CL	BOOLEAN	Apparatus 5 position is closed
APP5VAL	BOOLEAN	Apparatus 5 position is valid
APP6_OP	BOOLEAN	Apparatus 6 position is open
APP6_CL	BOOLEAN	Apparatus 6 position is closed
APP6VAL	BOOLEAN	Apparatus 6 position is valid
APP7_OP	BOOLEAN	Apparatus 7 position is open
APP7_CL	BOOLEAN	Apparatus 7 position is closed
APP7VAL	BOOLEAN	Apparatus 7 position is valid
APP8_OP	BOOLEAN	Apparatus 8 position is open
APP8_CL	BOOLEAN	Apparatus 8 position is closed
APP8VAL	BOOLEAN	Apparatus 8 position is valid
APP9_OP	BOOLEAN	Apparatus 9 position is open
APP9_CL	BOOLEAN	Apparatus 9 position is closed
APP9VAL	BOOLEAN	Apparatus 9 position is valid
APP10_OP	BOOLEAN	Apparatus 10 position is open
APP10_CL	BOOLEAN	Apparatus 10 position is closed
APP10VAL	BOOLEAN	Apparatus 10 position is valid

Table continues on next page

Name	Type	Description
APP11_OP	BOOLEAN	Apparatus 11 position is open
APP11_CL	BOOLEAN	Apparatus 11 position is closed
APP11VAL	BOOLEAN	Apparatus 11 position is valid
APP12_OP	BOOLEAN	Apparatus 12 position is open
APP12_CL	BOOLEAN	Apparatus 12 position is closed
APP12VAL	BOOLEAN	Apparatus 12 position is valid
APP13_OP	BOOLEAN	Apparatus 13 position is open
APP13_CL	BOOLEAN	Apparatus 13 position is closed
APP13VAL	BOOLEAN	Apparatus 13 position is valid
APP14_OP	BOOLEAN	Apparatus 14 position is open
APP14_CL	BOOLEAN	Apparatus 14 position is closed
APP14VAL	BOOLEAN	Apparatus 14 position is valid
APP15_OP	BOOLEAN	Apparatus 15 position is open
APP15_CL	BOOLEAN	Apparatus 15 position is closed
APP15VAL	BOOLEAN	Apparatus 15 position is valid
COM_VAL	BOOLEAN	Receive communication status is valid

3.34.3 Settings

Table 126: GOOSEINTLKRCV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On

3.35 Goose binary receive GOOSEBINRCV

3.35.1 Function block

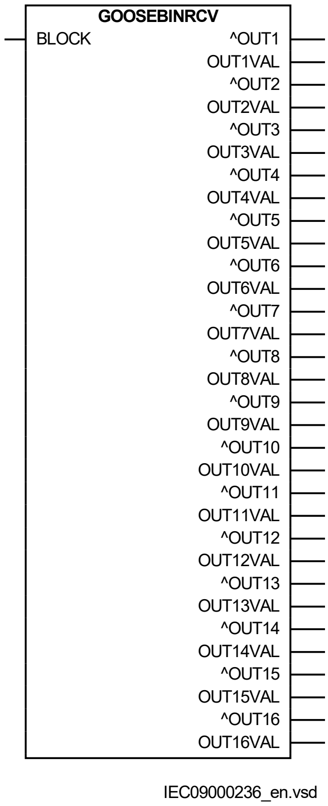


Figure 75: Function block

3.35.2 Signals

Table 127: GOOSEBINRCV Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of output signals

Table 128: GOOSEBINRCV Output signals

Name	Type	Description
OUT1	BOOLEAN	Binary output 1
OUT1VAL	BOOLEAN	Valid data on binary output 1
OUT2	BOOLEAN	Binary output 2
OUT2VAL	BOOLEAN	Valid data on binary output 2
OUT3	BOOLEAN	Binary output 3
Table continues on next page		

Name	Type	Description
OUT3VAL	BOOLEAN	Valid data on binary output 3
OUT4	BOOLEAN	Binary output 4
OUT4VAL	BOOLEAN	Valid data on binary output 4
OUT5	BOOLEAN	Binary output 5
OUT5VAL	BOOLEAN	Valid data on binary output 5
OUT6	BOOLEAN	Binary output 6
OUT6VAL	BOOLEAN	Valid data on binary output 6
OUT7	BOOLEAN	Binary output 7
OUT7VAL	BOOLEAN	Valid data on binary output 7
OUT8	BOOLEAN	Binary output 8
OUT8VAL	BOOLEAN	Valid data on binary output 8
OUT9	BOOLEAN	Binary output 9
OUT9VAL	BOOLEAN	Valid data on binary output 9
OUT10	BOOLEAN	Binary output 10
OUT10VAL	BOOLEAN	Valid data on binary output 10
OUT11	BOOLEAN	Binary output 11
OUT11VAL	BOOLEAN	Valid data on binary output 11
OUT12	BOOLEAN	Binary output 12
OUT12VAL	BOOLEAN	Valid data on binary output 12
OUT13	BOOLEAN	Binary output 13
OUT13VAL	BOOLEAN	Valid data on binary output 13
OUT14	BOOLEAN	Binary output 14
OUT14VAL	BOOLEAN	Valid data on binary output 14
OUT15	BOOLEAN	Binary output 15
OUT15VAL	BOOLEAN	Valid data on binary output 15
OUT16	BOOLEAN	Binary output 16
OUT16VAL	BOOLEAN	Valid data on binary output 16

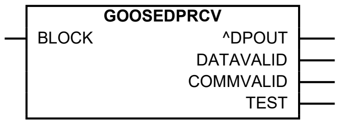
3.35.3 Settings

Table 129: GOOSEBINRCV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On

3.36 GOOSE function block to receive a double point GOOSEDPRCV

3.36.1 Function block



IEC10000249-1-en.vsd

Figure 76: Function block

3.36.2 Functionality

GOOSEDPRCV is used to receive a double point value using IEC61850 protocol via GOOSE.

3.36.3 Operation principle

The DATAVALID output is HIGH if the incoming message is with valid data.

The COMMVALID output becomes LOW when the sending IED is under total failure condition and the GOOSE transmission from the sending IED does not happen.

The TEST output will go HIGH if the sending IED is in test mode.

The input of this GOOSE block must be linked in Signal Matrix by means of a cross to receive the double point values.

The implementation for IEC 61850 quality data handling is restricted to a simple level. If quality data validity is GOOD, the DATAVALID output is HIGH. If quality data validity is INVALID, QUESTIONABLE, OVERFLOW, FAILURE or OLD DATA, the DATAVALID output is LOW.

3.36.4 Signals

Table 130: GOOSEDPRCV Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function

Table 131: GOOSEDPRCV Output signals

Name	Type	Description
DPOUT	INTEGER	Double point output
DATAVALID	BOOLEAN	Data valid for double point output
COMMVALID	BOOLEAN	Communication valid for double point output
TEST	BOOLEAN	Test output

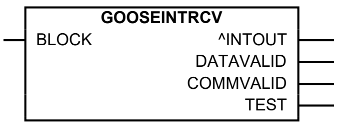
3.36.5 Settings

Table 132: GOOSEDPRCV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On

3.37 GOOSE function block to receive an integer value GOOSEINTRCV

3.37.1 Function block



IEC10000250-1-en.vsd

Figure 77: Function block

3.37.2 Functionality

GOOSEINTRCV is used to receive an integer value using IEC61850 protocol via GOOSE.

3.37.3 Operation principle

The DATAVALID output is HIGH if the incoming message is with valid data.

The COMMVALID output becomes LOW when the sending IED is under total failure condition and the GOOSE transmission from the sending IED does not happen.

The TEST output will go HIGH if the sending IED is in test mode.

The input of this GOOSE block must be linked in Signal Matrix by means of a cross to receive the integer values.

The implementation for IEC 61850 quality data handling is restricted to a simple level. If quality data validity is GOOD, the DATAVALID output is HIGH. If quality data validity is INVALID, QUESTIONABLE, OVERFLOW, FAILURE or OLD DATA, the DATAVALID output is LOW.

3.37.4 Signals

Table 133: GOOSEINTRCV Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function

Table 134: GOOSEINTRCV Output signals

Name	Type	Description
INTOUT	INTEGER	Integer output
DATAVALID	BOOLEAN	Data valid for integer output
COMMVALID	BOOLEAN	Communication valid for integer output
TEST	BOOLEAN	Test output

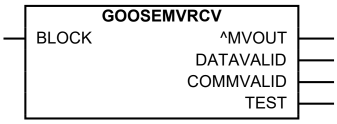
3.37.5 Settings

Table 135: GOOSEINTRCV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On

3.38 GOOSE function block to receive a measurand value GOOSEMVRCV

3.38.1 Function block



IEC10000251-1-en.vsd

Figure 78: Function block

3.38.2 Functionality

GOOSEMVRCV is used to receive measured value using IEC61850 protocol via GOOSE.

3.38.3 Operation principle

The DATAVALID output is HIGH if the incoming message is with valid data.

The COMMVALID output becomes LOW when the sending IED is under total failure condition and the GOOSE transmission from the sending IED does not happen.

The TEST output will go HIGH if the sending IED is in test mode.

The input of this GOOSE block must be linked in Signal Matrix by means of a cross to receive the float values.

The implementation for IEC 61850 quality data handling is restricted to a simple level. If quality data validity is GOOD, the DATAVALID output is HIGH. If quality data validity is INVALID, QUESTIONABLE, OVERFLOW, FAILURE or OLD DATA, the DATAVALID output is LOW.

3.38.4 Signals

Table 136: GOOSEMVRCV Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function

Table 137: GOOSEMVRCV Output signals

Name	Type	Description
MVOUT	REAL	Measurand value output
DATAVALID	BOOLEAN	Data valid for measurand value output
COMMVALID	BOOLEAN	Communication valid for measurand value output
TEST	BOOLEAN	Test output

3.38.5 Settings

Table 138: GOOSEMVRCV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On

3.39 GOOSE function block to receive a single point value GOOSESPRCV

3.39.1 Function block

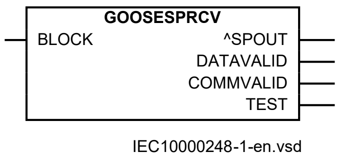


Figure 79: Function block

3.39.2 Functionality

GOOSESPRCV is used to receive a single point value using IEC61850 protocol via GOOSE.

3.39.3 Operation principle

The DATAVALID output is HIGH if the incoming message is with valid data.

The COMMVALID output becomes LOW when the sending IED is under total failure condition and the GOOSE transmission from the sending IED does not happen.

The TEST output will go HIGH if the sending IED is in test mode.

The input of this GOOSE block must be linked in Signal Matrix by means of a cross to receive the binary single point values.

The implementation for IEC 61850 quality data handling is restricted to a simple level. If quality data validity is GOOD, the DATAVALID output is HIGH. If quality data validity is INVALID, QUESTIONABLE, OVERFLOW, FAILURE or OLD DATA, the DATAVALID output is LOW.

3.39.4 Signals

Table 139: GOOSESPRCV Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function

Table 140: GOOSESPRCV Output signals

Name	Type	Description
SPOUT	BOOLEAN	Single point output
DATAVALID	BOOLEAN	Data valid for single point output
COMMVALID	BOOLEAN	Communication valid for single point output
TEST	BOOLEAN	Test output

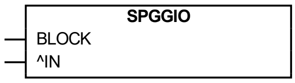
3.39.5 Settings

Table 141: GOOSESPRCV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On

3.40 IEC 61850 generic communication I/O function SPGGIO

3.40.1 Function block



IEC09000237_en_1.vsd

Figure 80: Function block

3.40.2 Functionality

IEC61850 generic communication I/O functions (SPGGIO) is used to send one single logical signal to other systems or equipment in the substation.

3.40.3 Operation principle

Upon receiving a signal at its input, IEC61850 generic communication I/O functions (SPGGIO) function sends the signal over IEC 61850-8-1 to the equipment or system that requests this signal. To get the signal, PCM600 must be used to define which function block in which equipment or system should receive this information.

3.40.4 Application

IEC 61850-8-1 generic communication I/O functions (SPGGIO) function is used to send one single logical output to other systems or equipment in the substation. It has one visible input, that should be connected in ACT.

3.40.5 Signals

Table 142: SPGGIO Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
IN	BOOLEAN	0	Input status

3.40.6 Settings

The function does not have any parameters available in LHMI or PCM600.

3.41 IEC 61850 generic communication I/O function MVGGIO

3.41.1 Function block

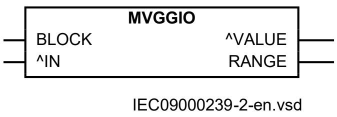


Figure 81: Function block

3.41.2 Functionality

IEC 61850 generic communication I/O functions (MVGGIO) function is used to send the instantaneous value of an analog signal to other systems or equipment in the substation. It can also be used inside the same IED, to attach a RANGE aspect to an analog value and to permit measurement supervision on that value.

3.41.3 Operation principle

Upon receiving an analog signal at its input, the IEC61850 generic communication I/O functions (MVGGIO) give the instantaneous value of the signal and the range, as output values. In the same time, it sends over IEC 61850-8-1 the value, to other IEC 61850 clients in the substation.

3.41.4 Application

IEC 61850 generic communication I/O functions (MVGGIO) function is used to send the instantaneous value of an analog signal to other systems or equipment in the substation. It can also be used inside the same IED, to attach a RANGE aspect to an analog value and to permit measurement supervision on that value.

3.41.5 Signals

Table 143: MVGGIO Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
IN	REAL	0	Analog input value

Table 144: MVGGIO Output signals

Name	Type	Description
VALUE	REAL	Magnitude of deadband value
RANGE	INTEGER	Range

3.41.6 Settings

Table 145: MVGGIO Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
BasePrefix	micro milli unit kilo Mega Giga Tera	-	-	unit	Base prefix (multiplication factor)
MV db	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
MV zeroDb	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
MV hhLim	-5000.00 - 5000.00	xBase	0.01	900.00	High High limit multiplied with the base prefix (multiplication factor)
MV hLim	-5000.00 - 5000.00	xBase	0.01	800.00	High limit multiplied with the base prefix (multiplication factor)
MV lLim	-5000.00 - 5000.00	xBase	0.01	-800.00	Low limit multiplied with the base prefix (multiplication factor)
MV llLim	-5000.00 - 5000.00	xBase	0.01	-900.00	Low Low limit multiplied with the base prefix (multiplication factor)
MV min	-5000.00 - 5000.00	xBase	0.01	-1000.00	Minimum value multiplied with the base prefix (multiplication factor)
MV max	-5000.00 - 5000.00	xBase	0.01	1000.00	Maximum value multiplied with the base prefix (multiplication factor)
MV dbType	Cyclic Dead band Int deadband	-	-	Dead band	Reporting type
MV limHys	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range (common for all limits)

3.41.7 Monitored data

Table 146: MVGGIO Monitored data

Name	Type	Values (Range)	Unit	Description
VALUE	REAL	-	-	Magnitude of deadband value
RANGE	INTEGER	1=High 2=Low 3=High-High 4=Low-Low 0=Normal	-	Range

3.42 IEC 60870-5-103 communication protocol

3.42.1 Functionality

IEC 60870-5-103 is an unbalanced (master-slave) protocol for coded-bit serial communication exchanging information with a control system, and with a data transfer rate up to 19200 bit/s. In IEC terminology, a primary station is a master and a secondary station is a slave. The communication is based on a point-to-point principle. The master must have software that can interpret IEC 60870-5-103 communication messages.

For the 630 series vendor-specific IEC 60870-5-103 implementation, see the communication protocol manual.

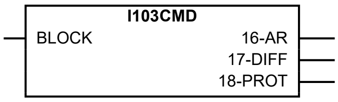
3.42.2 Settings

Table 147: IEC60870-5-103 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation
SlaveAddress	1 - 31	-	1	1	Slave address
BaudRate	9600 Bd 19200 Bd	-	-	9600 Bd	Baudrate on serial line
RevPolarity	Off On	-	-	On	Invert polarity
CycMeasRepTime	1.0 - 1800.0	s	0.1	5.0	Cyclic reporting time of measurments
MasterTimeDomain	UTC Local Local with DST	-	-	UTC	Master time domain
TimeSyncMode	IEDTime LinMastTime IEDTimeSkew	-	-	IEDTime	Time synchronization mode
EvalTimeAccuracy	5ms 10ms 20ms 40ms Off	-	-	5ms	Evaluate time accuracy for invalid time
EventRepMode	SeqOfEvent HiPriSpont	-	-	SeqOfEvent	Event reporting mode

3.43 Function commands for IEC 60870-5-103 I103CMD

3.43.1 Function block



IEC10000282-1-en.vsd

Figure 82: Function block

3.43.2 Functionality

I103CMD is a command function block in control direction with pre-defined output signals.

3.43.3 Signals

Table 148: I103CMD Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of commands

Table 149: I103CMD Output signals

Name	Type	Description
16-AR	BOOLEAN	Information number 16, block of autorecloser
17-DIFF	BOOLEAN	Information number 17, block of differential protection
18-PROT	BOOLEAN	Information number 18, block of protection

3.43.4 Settings

Table 150: I103CMD Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	1	Function type (1-255)

3.44 IED commands for IEC 60870-5-103 I103IEDCMD

3.44.1 Function block

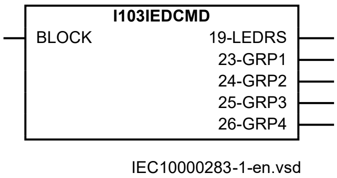


Figure 83: Function block

3.44.2 Functionality

I103IEDCMD is a command block in control direction with defined IED functions.

3.44.3 Signals

Table 151: I103IEDCMD Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of commands

Table 152: I103IEDCMD Output signals

Name	Type	Description
19-LEDRS	BOOLEAN	Information number 19, reset LEDs
23-GRP1	BOOLEAN	Information number 23, activate setting group 1
24-GRP2	BOOLEAN	Information number 24, activate setting group 2
25-GRP3	BOOLEAN	Information number 25, activate setting group 3
26-GRP4	BOOLEAN	Information number 26, activate setting group 4

3.44.4 Settings

Table 153: I103IEDCMD Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	255	Function type (1-255)

3.45 Function commands user defined for IEC 60870-5-103 I103USRCMD

3.45.1 Function block

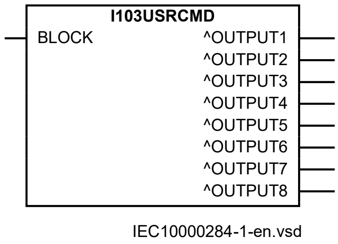


Figure 84: Function block

3.45.2 Functionality

I103USRCMD is a command block in control direction with user defined output signals. These function blocks include the *FunctionType* parameter for each block in the private range, and the Information number parameter for each output signal.

3.45.3 Signals

Table 154: I103USRCMD Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of commands

Table 155: I103USRCMD Output signals

Name	Type	Description
OUTPUT1	BOOLEAN	Command output 1
OUTPUT2	BOOLEAN	Command output 2
OUTPUT3	BOOLEAN	Command output 3
OUTPUT4	BOOLEAN	Command output 4
OUTPUT5	BOOLEAN	Command output 5
OUTPUT6	BOOLEAN	Command output 6
OUTPUT7	BOOLEAN	Command output 7
OUTPUT8	BOOLEAN	Command output 8

3.45.4 Settings

Table 156: I103USRCMD Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	1	Function type (1-255)
PulseMode	Steady Pulsed	-	-	Pulsed	Pulse mode
PulseLength	0.200 - 60.000	s	0.001	0.400	Pulse length
InfNo_1	1 - 255	-	1	1	Information number for output 1 (1-255)
InfNo_2	1 - 255	-	1	2	Information number for output 2 (1-255)
InfNo_3	1 - 255	-	1	3	Information number for output 3 (1-255)
InfNo_4	1 - 255	-	1	4	Information number for output 4 (1-255)
InfNo_5	1 - 255	-	1	5	Information number for output 5 (1-255)
InfNo_6	1 - 255	-	1	6	Information number for output 6 (1-255)
InfNo_7	1 - 255	-	1	7	Information number for output 7 (1-255)
InfNo_8	1 - 255	-	1	8	Information number for output 8 (1-255)

3.46 Function commands generic for IEC 60870-5-103 I103GENCMD

3.46.1 Function block

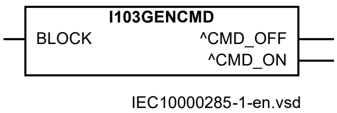


Figure 85: Function block

3.46.2 Functionality

I103GENCMD is used for transmitting generic commands over IEC 60870-5-103. The function has two outputs signals CMD_OFF and CMD_ON that can be used to implement double-point command schemes.

3.46.3 Signals

Table 157: I103GENCMD Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of command

Table 158: I103GENCMD Output signals

Name	Type	Description
CMD_OFF	BOOLEAN	Command output OFF
CMD_ON	BOOLEAN	Command output ON

3.46.4 Settings

Table 159: I103GENCMD Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 127	-	1	1	Function type (1-127)
PulseLength	0.000 - 60.000	s	0.001	0.400	Pulse length
InfNo	32 - 239	-	1	32	Information number for command output (32-239)

3.47 IED commands with position and select for IEC 60870-5-103 I103POSCMD

3.47.1 Function block

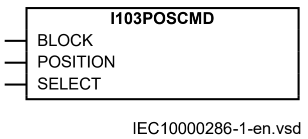


Figure 86: Function block

3.47.2 Functionality

I103POSCMD is used for controllable switching devices. It has double-point position indicators that are getting the position value as an integer (POSITION output of the GNRLCSWI function block) and sending it over IEC 60870-5-103 (1=OPEN; 2=CLOSE).The standard does not define the use of values 0 and 3 . However, when connected to a switching device, these values are transmitted.

The BLOCK input blocks only the signals in monitoring direction (the position information), not the commands via IEC 60870-5-103. The SELECT input is used to indicate that the monitored apparatus has been selected (in a select-before-operate type of control)

3.47.3 Signals

Table 160: I103POSCMD Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of command
POSITION	INTEGER	0	Position of controllable object
SELECT	BOOLEAN	0	Select of controllable object

3.47.4 Settings

Table 161: I103POSCMD Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	1	Fucntion type (1-255)
InfNo	160 - 196	-	4	160	Information number for command output (1-255)

3.48 Measurands for IEC 60870-5-103 I103MEAS

3.48.1 Function block

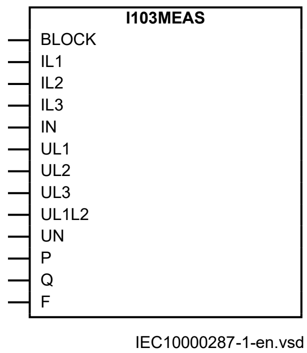


Figure 87: Function block

3.48.2 Functionality

103MEAS is a function block that reports all valid measuring types depending on connected signals.

The measured values come from the corresponding MMXU function block and are depending on the function block settings. The event reporting interval is set by the *CycMeasRepTime* parameter of the IEC 60870-5-103 communication settings.

Input signals of the IEC 60870-5-103 I103MEAS block should be connected to the corresponding outputs of the MMXU application functions. Depending on the connected input signals, the IEC 60870-5-103 protocol automatically selects the proper ASDU Meas 3 or Meas 9 to be used as Class 2 data.

3.48.3 Signals

Table 162: I103MEAS Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of service value reporting
IL1	REAL	0.0	Service value for current phase L1
IL2	REAL	0.0	Service value for current phase L2
IL3	REAL	0.0	Service value for current phase L3
IN	REAL	0.0	Service value for residual current IN
UL1	REAL	0.0	Service value for voltage phase L1
UL2	REAL	0.0	Service value for voltage phase L2
UL3	REAL	0.0	Service value for voltage phase L3
UL1L2	REAL	0.0	Service value for voltage phase-phase L1-L2
UN	REAL	0.0	Service value for residual voltage UN
P	REAL	0.0	Service value for active power
Q	REAL	0.0	Service value for reactive power
F	REAL	0.0	Service value for system frequency

3.48.4 Settings

Table 163: I103MEAS Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	1	Function type (1-255)
MaxIL1	1 - 99999	A	1	3000	Maximum current phase L1
MaxIL2	1 - 99999	A	1	3000	Maximum current phase L2
MaxIL3	1 - 99999	A	1	3000	Maximum current phase L3
MaxIN	1 - 99999	A	1	3000	Maximum residual current IN
MaxUL1	0.05 - 2000.00	kV	0.05	230.00	Maximum voltage for phase L1
MaxUL2	0.05 - 2000.00	kV	0.05	230.00	Maximum voltage for phase L2
MaxUL3	0.05 - 2000.00	kV	0.05	230.00	Maximum voltage for phase L3
MaxUL1-UL2	0.05 - 2000.00	kV	0.05	400.00	Maximum voltage for phase-phase L1-L2
MaxUN	0.05 - 2000.00	kV	0.05	230.00	Maximum residual voltage UN
MaxP	0.00 - 2000.00	MW	0.05	1200.00	Maximum value for active power
MaxQ	0.00 - 2000.00	MVA	0.05	1200.00	Maximum value for reactive power
MaxF	50.0 - 60.0	Hz	10.0	50.0	Maximum system frequency

Maximum value corresponds to the value 4096 on the master side.

3.49 Measurands user defined signals for IEC 60870-5-103 I103MEASUSR

3.49.1 Function block

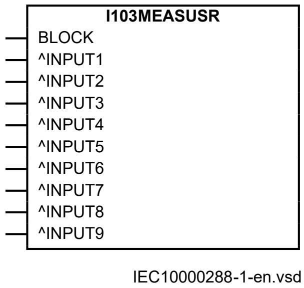


Figure 88: Function block

3.49.2 Functionality

I103MEASUSR is a function block with user defined input measurands in monitor direction. These function blocks include the *FunctionType* parameter for each block in the private range, and the Information number parameter for each block.

If I103MEASUSR is used to report angles, they are in radians.

3.49.3 Signals

Table 164: I103MEASUSR Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of service value reporting
INPUT1	REAL	0.0	Service value for measurement on input 1
INPUT2	REAL	0.0	Service value for measurement on input 2
INPUT3	REAL	0.0	Service value for measurement on input 3
INPUT4	REAL	0.0	Service value for measurement on input 4
INPUT5	REAL	0.0	Service value for measurement on input 5
INPUT6	REAL	0.0	Service value for measurement on input 6
INPUT7	REAL	0.0	Service value for measurement on input 7
INPUT8	REAL	0.0	Service value for measurement on input 8
INPUT9	REAL	0.0	Service value for measurement on input 9

3.49.4 Settings

Table 165: I103MEASUSR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	25	Function type (1-255)
InfNo	1 - 255	-	1	1	Information number for measurands (1-255)
MaxMeasur1	0.05 - 10000000000.00	-	0.05	1000.00	Maximum value for measurement on input 1
MaxMeasur2	0.05 - 10000000000.00	-	0.05	1000.00	Maximum value for measurement on input 2
MaxMeasur3	0.05 - 10000000000.00	-	0.05	1000.00	Maximum value for measurement on input 3
MaxMeasur4	0.05 - 10000000000.00	-	0.05	1000.00	Maximum value for measurement on input 4
MaxMeasur5	0.05 - 10000000000.00	-	0.05	1000.00	Maximum value for measurement on input 5
MaxMeasur6	0.05 - 10000000000.00	-	0.05	1000.00	Maximum value for measurement on input 6
MaxMeasur7	0.05 - 10000000000.00	-	0.05	1000.00	Maximum value for measurement on input 7
MaxMeasur8	0.05 - 10000000000.00	-	0.05	1000.00	Maximum value for measurement on input 8
MaxMeasur9	0.05 - 10000000000.00	-	0.05	1000.00	Maximum value for measurement on input 9

3.50 Function status auto-recloser for IEC 60870-5-103 I103AR

3.50.1 Function block

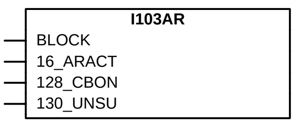


Figure 89: Function block

3.50.2 Functionality

I103AR is a function block with defined functions for autorecloser indications in monitor direction. This block includes the *FunctionType* parameter, and the information number parameter is defined for each output signal.

3.50.3 Signals

Table 166: I103AR Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of status reporting
16_ARACT	BOOLEAN	0	Information number 16, auto-recloser active
128_CBON	BOOLEAN	0	Information number 128, circuit breaker on by auto-recloser
130_UNSU	BOOLEAN	0	Information number 130, unsuccessful reclosing

3.50.4 Settings

Table 167: I103AR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	1	Function type (1-255)

3.51 Function status earth-fault for IEC 60870-5-103 I103EF

3.51.1 Function block

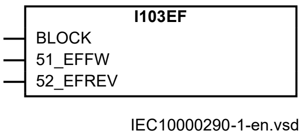


Figure 90: Function block

3.51.2 Functionality

I103EF is a function block with defined functions for earth fault indications in monitor direction. This block includes the *FunctionType* parameter, and the information number parameter is defined for each output signal.

3.51.3 Signals

Table 168: I103EF Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of status reporting
51_EFFW	BOOLEAN	0	Information number 51, earth-fault forward
52_EFREV	BOOLEAN	0	Information number 52, earth-fault reverse

3.51.4 Settings

Table 169: I103EF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	160	Function type (1-255)

3.52 Function status fault protection for IEC 60870-5-103 I103FLTPROT

3.52.1 Function block

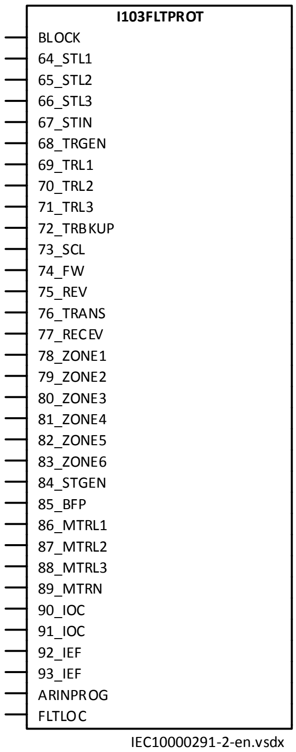


Figure 91: Function block

3.52.2 Functionality

I103FLTPROT is used for fault indications in monitor direction. Each input on the function block is specific for a certain fault type and therefore must be connected to a correspondent signal present in the configuration. For example, 68_TRGEN represents the General Trip of the device, and therefore must be connected to the general trip signal SMPPTRC_TRIP or equivalent.

The delay observed in the protocol is the time difference in between the signal that is triggering the Disturbance Recorder and the respective configured signal to the IEC 60870-5-103 I103FLTPROT.

3.52.3 Signals

Table 170: I103FLTPROT Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of status reporting.
64_STL1	BOOLEAN	0	Information number 64, start phase L1
65_STL2	BOOLEAN	0	Information number 65, start phase L2
66_STL3	BOOLEAN	0	Information number 66, start phase L3
67_STIN	BOOLEAN	0	Information number 67, start residual current IN
68_TRGEN	BOOLEAN	0	Information number 68, trip general
69_TRL1	BOOLEAN	0	Information number 69, trip phase L1
70_TRL2	BOOLEAN	0	Information number 70, trip phase L2
71_TRL3	BOOLEAN	0	Information number 71, trip phase L3
72_TRBKUP	BOOLEAN	0	Information number 72, back up trip I>>
73_SCL	REAL	0	Information number 73, fault location in ohm
74_FW	BOOLEAN	0	Information number 74, forward/line
75_REV	BOOLEAN	0	Information number 75, reverse/busbar
76_TRANS	BOOLEAN	0	Information number 76, signal transmitted
77_RECEV	BOOLEAN	0	Information number 77, signal received
78_ZONE1	BOOLEAN	0	Information number 78, zone 1
79_ZONE2	BOOLEAN	0	Information number 79, zone 2
80_ZONE3	BOOLEAN	0	Information number 80, zone 3
81_ZONE4	BOOLEAN	0	Information number 81, zone 4
82_ZONE5	BOOLEAN	0	Information number 82, zone 5
84_STGEN	BOOLEAN	0	Information number 84, start general
85_BFP	BOOLEAN	0	Information number 85, breaker failure
86_MTRL1	BOOLEAN	0	Information number 86, trip measuring system phase L1
87_MTRL2	BOOLEAN	0	Information number 87, trip measuring system phase L2
88_MTRL3	BOOLEAN	0	Information number 88, trip measuring system phase L3
89_MTRN	BOOLEAN	0	Information number 89, trip measuring system neutral N
90_IOC	BOOLEAN	0	Information number 90, over current trip, stage low

Table continues on next page

Name	Type	Default	Description
91_IOC	BOOLEAN	0	Information number 91, over current trip, stage high
92_IEF	BOOLEAN	0	Information number 92, earth-fault trip, stage low
93_IEF	BOOLEAN	0	Information number 93, earth-fault trip, stage high
ARINPROG	BOOLEAN	0	Autorecloser in progress (SMBRREC- INPROGR)
FLTLOC	BOOLEAN	0	Faultlocator faultlocation valid (LMBRFLO-CALCMADE)

ARINPROG

Input signal `ARINPROG` shall be connected to the autorecloser output signal `ACTIVE`, which indicates that the reclosing is started and the sequence is ongoing. The purpose of the ARINPROGRESS input is to establish the base time for the relative timestamps. While ARINPROGRESS is asserted, a new fault does not reset the base for the relative time reported for trip indications, and all timestamps will be relative to last fault with ARINPROGRESS deasserted.

FLTLOC

Input signal `FLTLOC` shall be connected to the fault locator output signal `CALCMADE`, the trigger to send the 73_SCL value.

3.52.4 Settings

Table 171: I103FLTPROT Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	128	Function type (1-255)

3.53 IED status for IEC 60870-5-103 I103IED

3.53.1 Function block

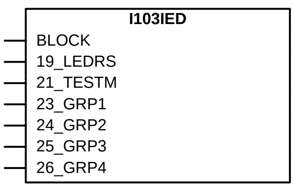


Figure 92: Function block

3.53.2 Functionality

I103IED is a function block with defined IED functions in monitor direction. This block uses parameter as *FunctionType*, and information number parameter is defined for each input signal.

3.53.3 Signals

Table 172: I103IED Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of status reporting
19_LEDRS	BOOLEAN	0	Information number 19, reset LEDs
21_TESTM	BOOLEAN	0	Information number 21, test mode is active
23_GRP1	BOOLEAN	0	Information number 23, setting group 1 is active
24_GRP2	BOOLEAN	0	Information number 24, setting group 2 is active
25_GRP3	BOOLEAN	0	Information number 25, setting group 3 is active
26_GRP4	BOOLEAN	0	Information number 26, setting group 4 is active

3.53.4 Settings

Table 173: I103IED Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	1	Function type (1-255)

3.54 Supervison status for IEC 60870-5-103 I103SUPERV

3.54.1 Function block

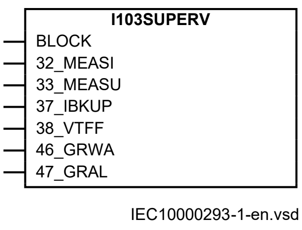


Figure 93: Function block

3.54.2 Functionality

I103SUPERV is a function block with defined functions for supervision indications in monitor direction. This block includes the *FunctionType* parameter, and the information number parameter is defined for each output signal.

3.54.3 Signals

Table 174: I103SUPERV Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of status reporting
32_MEASI	BOOLEAN	0	Information number 32, measurand supervision of I
33_MEASU	BOOLEAN	0	Information number 33, measurand supervision of U
37_IBKUP	BOOLEAN	0	Information number 37, I high-high back-up protection
38_VTFF	BOOLEAN	0	Information number 38, fuse failure VT
46_GRWA	BOOLEAN	0	Information number 46, group warning
47_GRAL	BOOLEAN	0	Information number 47, group alarm

3.54.4 Settings

Table 175: I103SUPERV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	1	Function type (1-255)

3.55 Status for user defined signals for IEC 60870-5-103 I103USRDEF

3.55.1 Function block

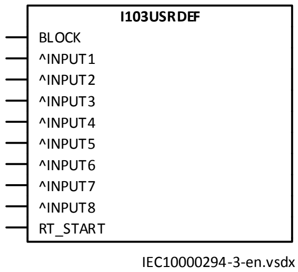


Figure 94: Function block

3.55.2 Functionality

I103USRDEF is a function blocks with user defined input signals in monitor direction. These function blocks include the *FunctionType* parameter for each block in the private range, and the information number parameter for each input signal.

I103USRDEF can be mapped to the INF that are not supported directly by specific function blocks, for example, INF17, INF18, INF20 or INF35. After connecting the appropriate signals to the I103USRDEF inputs, the user must also set the *InfNo_x* values in the settings

I103USRDEF: 1					
FunctionType		5		1	255
NAME1		INPUT1			13 character(s
InfNo_1		**17**		1	255
NAME2		INPUT2			13 character(s
InfNo_2		**18**		1	255
NAME3		INPUT3			13 character(s
InfNo_3		**20**		1	255
NAME4		INPUT4			13 character(s
InfNo_4		**35**		1	255

Figure 95: I103USRDEF example settings

3.55.3 Signals

Table 176: I103USRDEF Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of status reporting
INPUT1	BOOLEAN	0	Binary signal Input 1
INPUT2	BOOLEAN	0	Binary signal input 2
INPUT3	BOOLEAN	0	Binary signal input 3
INPUT4	BOOLEAN	0	Binary signal input 4
INPUT5	BOOLEAN	0	Binary signal input 5
INPUT6	BOOLEAN	0	Binary signal input 6
INPUT7	BOOLEAN	0	Binary signal input 7
INPUT8	BOOLEAN	0	Binary signal input 8

3.55.4 Settings

Table 177: I103USRDEF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
FunctionType	1 - 255	-	1	5	Function type (1-255)
InfNo_1	1 - 255	-	1	1	Information number for binary input 1 (1-255)
InfNo_2	1 - 255	-	1	2	Information number for binary input 2 (1-255)
InfNo_3	1 - 255	-	1	3	Information number for binary input 3 (1-255)
InfNo_4	1 - 255	-	1	4	Information number for binary input 4 (1-255)
InfNo_5	1 - 255	-	1	5	Information number for binary input 5 (1-255)
InfNo_6	1 - 255	-	1	6	Information number for binary input 6 (1-255)
InfNo_7	1 - 255	-	1	7	Information number for binary input 7 (1-255)
InfNo_8	1 - 255	-	1	8	Information number for binary input 8 (1-255)

3.56 Automation bits AUTOBITS

3.56.1 Function block

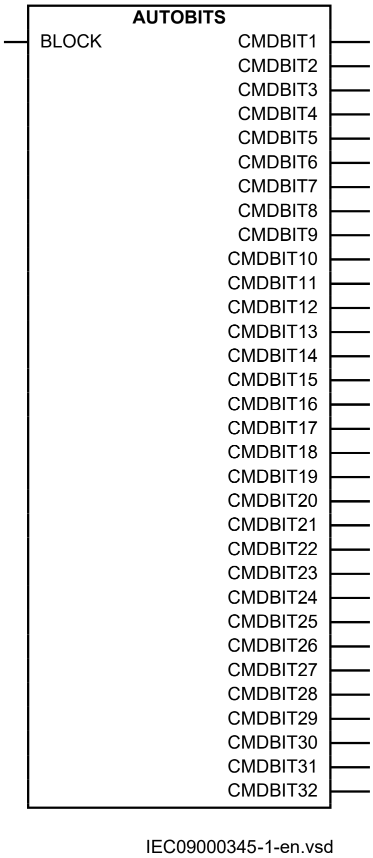


Figure 96: Function block

3.56.2 Functionality

The Automation bits function (AUTOBITS) is used to configure the DNP3 protocol command handling.

3.56.3 Operation principle

Automation bits function (AUTOBITS) has 32 individual outputs which each can be mapped as a Binary Output point in DNP3. The output is operated by a "Object 12" in DNP3. This object contains parameters for control-code, count, on-time and off-time. To operate an AUTOBITS output point, send a control-code of latch-On, latch-Off, pulse-On, pulse-Off, Trip or Close. The remaining parameters are regarded appropriate. For example, pulse-On, on-time=100, off-time=300, count=5 gives 5 positive 100 ms pulses, 300 ms apart.

There is a BLOCK input signal, which disabled the operation of the function, in the same way the setting *Operation*: "On/Off "does. Upon activation of the BLOCK input, all 32 CMDBITxx outputs are set to “0”. The BLOCK acts like an overriding, the function still receives data from the DNP3 master. Upon deactivation of BLOCK, all the 32 CMDBITxx outputs are set by the DNP3 master again, momentarily.

For description of the DNP3 protocol implementation, see the DNP3 communication protocol manual.

3.56.4 Application

The AUTOBITS function block (or the automation bits function block) is used within PCM600 in order to get into the configuration the commands coming through the DNP3 protocol.

See the communication protocol manual for a detailed description of the DNP3 protocol.

3.56.5 Signals

Table 178: AUTOBITS Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function

Table 179: AUTOBITS Output signals

Name	Type	Description
CMDBIT1	BOOLEAN	Command out bit 1
CMDBIT2	BOOLEAN	Command out bit 2
CMDBIT3	BOOLEAN	Command out bit 3
CMDBIT4	BOOLEAN	Command out bit 4
CMDBIT5	BOOLEAN	Command out bit 5
CMDBIT6	BOOLEAN	Command out bit 6
CMDBIT7	BOOLEAN	Command out bit 7
CMDBIT8	BOOLEAN	Command out bit 8
CMDBIT9	BOOLEAN	Command out bit 9
CMDBIT10	BOOLEAN	Command out bit 10
CMDBIT11	BOOLEAN	Command out bit 11
CMDBIT12	BOOLEAN	Command out bit 12
CMDBIT13	BOOLEAN	Command out bit 13

Table continues on next page

Name	Type	Description
CMDBIT14	BOOLEAN	Command out bit 14
CMDBIT15	BOOLEAN	Command out bit 15
CMDBIT16	BOOLEAN	Command out bit 16
CMDBIT17	BOOLEAN	Command out bit 17
CMDBIT18	BOOLEAN	Command out bit 18
CMDBIT19	BOOLEAN	Command out bit 19
CMDBIT20	BOOLEAN	Command out bit 20
CMDBIT21	BOOLEAN	Command out bit 21
CMDBIT22	BOOLEAN	Command out bit 22
CMDBIT23	BOOLEAN	Command out bit 23
CMDBIT24	BOOLEAN	Command out bit 24
CMDBIT25	BOOLEAN	Command out bit 25
CMDBIT26	BOOLEAN	Command out bit 26
CMDBIT27	BOOLEAN	Command out bit 27
CMDBIT28	BOOLEAN	Command out bit 28
CMDBIT29	BOOLEAN	Command out bit 29
CMDBIT30	BOOLEAN	Command out bit 30
CMDBIT31	BOOLEAN	Command out bit 31
CMDBIT32	BOOLEAN	Command out bit 32

3.56.6 Settings

Table 180: AUTOBITS Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off / On

3.57 Configurable logic blocks

3.57.1 Standard configurable logic blocks

A number of logic blocks and timers are available to be used to adapt the configuration to the specific application needs.

- **OR**
- **INVERTER** inverts the input signal

- **PULSETIMER** can be used, for example, for pulse extensions or limiting of operation of outputs
- **GATE** is used for controlling if a signal should be able to pass from the input to the output or not, depending on a setting
- **XOR**
- **LOOPDELAY** used to delay the output signal one execution cycle
- **TIMERSET** has pick-up and drop-out delayed outputs related to the input signal; the timer has a settable time delay
- **AND**
- **SRMEMORY** is a flip-flop that can set or reset an output from two inputs respectively. Each block has two outputs where one is inverted. The memory setting controls if the block after a power interruption should return to the state before the interruption, or be reset. Set input has priority.
- **RSMEMORY** is a flip-flop that can reset or set an output from two inputs respectively. Each block has two outputs where one is inverted. The memory setting controls if the block after a power interruption should return to the state before the interruption, or be reset. Reset input has priority.

3.57.1.1 OR function block

Function block

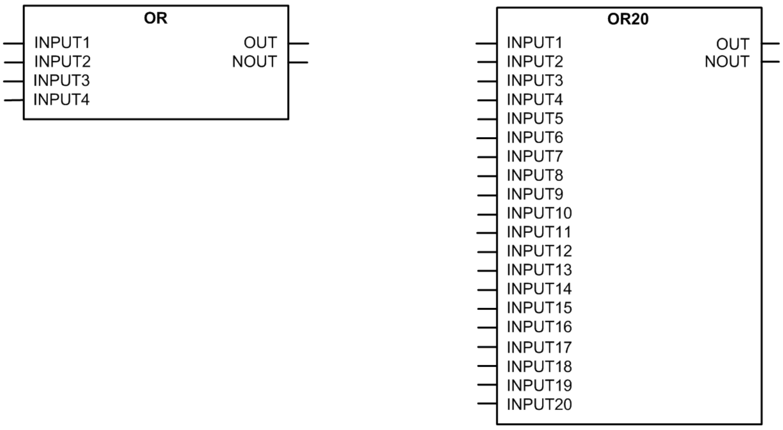


Figure 97: Function block

Functionality

OR and OR20 are used to form general combinatorial expressions with Boolean variables.

The default value in all input is logical FALSE, which makes it possible to use only the required number of inputs and leave the rest disconnected.

OR has six inputs and OR20 has 20 inputs. The output `OUT` has a default value FALSE initially, which suppresses one cycle pulse if the function has been put in the wrong execution order.

Connect at least one output to another function block or to a variable for the function to execute correctly.

Signals

Table 181: OR Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	0	Input signal 1
INPUT2	BOOLEAN	0	Input signal 2
INPUT3	BOOLEAN	0	Input signal 3
INPUT4	BOOLEAN	0	Input signal 4
INPUT5	BOOLEAN	0	Input signal 5
INPUT6	BOOLEAN	0	Input signal 6

Table 182: OR20 Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	0	Input 1
INPUT2	BOOLEAN	0	Input 2
INPUT3	BOOLEAN	0	Input 3
INPUT4	BOOLEAN	0	Input 4
INPUT5	BOOLEAN	0	Input 5
INPUT6	BOOLEAN	0	Input 6
INPUT7	BOOLEAN	0	Input 7
INPUT8	BOOLEAN	0	Input 8
INPUT9	BOOLEAN	0	Input 9
INPUT10	BOOLEAN	0	Input 10
INPUT11	BOOLEAN	0	Input 11
INPUT12	BOOLEAN	0	Input 12
INPUT13	BOOLEAN	0	Input 13
INPUT14	BOOLEAN	0	Input 14

Table continues on next page

Name	Type	Default	Description
INPUT15	BOOLEAN	0	Input 15
INPUT16	BOOLEAN	0	Input 16
INPUT17	BOOLEAN	0	Input 17
INPUT18	BOOLEAN	0	Input 18
INPUT19	BOOLEAN	0	Input 19
INPUT20	BOOLEAN	0	Input 20

Table 183: OR Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

Table 184: OR20 Output signals

Name	Type	Description
OUT	BOOLEAN	Output
NOUT	BOOLEAN	Inverted output

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.1.2 Inverter function block INVERTER

Function block

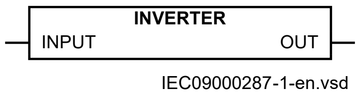


Figure 98: Function block

Signals

Table 185: INVERTER Input signals

Name	Type	Default	Description
INPUT	BOOLEAN	0	Input signal

Table 186: INVERTER Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.1.3 PULSETIMER function block

Function block

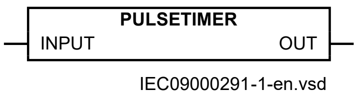


Figure 99: Function block

Functionality

The pulse function can be used, for example for pulse extensions or limiting of operation of outputs. The PULSETIMER has a settable length.

Signals

Table 187: PULSETIMER Input signals

Name	Type	Default	Description
INPUT	BOOLEAN	0	Input signal

Table 188: PULSETIMER Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

Settings

Table 189: PULSETIMER Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
t	0.000 - 90000.000	s	0.001	0.010	Pulse time length

3.57.1.4 Controllable gate function block GATE

Function block

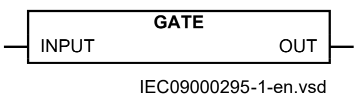


Figure 100: Function block

Functionality

The GATE function block is used for controlling if a signal should pass from the input to the output or not, depending on setting.

Signals

Table 190: GATE Input signals

Name	Type	Default	Description
INPUT	BOOLEAN	0	Input signal

Table 191: GATE Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

Settings

Table 192: GATE Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On

3.57.1.5 Exclusive OR function block XOR

Function block

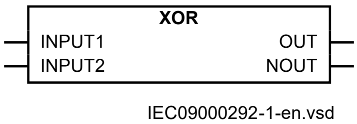


Figure 101: Function block

Functionality

The exclusive OR function (XOR) is used to generate combinatory expressions with Boolean variables. XOR has two inputs and two outputs. One of the outputs is inverted. The output signal is 1 if the input signals are different and 0 if they are the same.

Signals

Table 193: XOR Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	0	Input signal 1
INPUT2	BOOLEAN	0	Input signal 2

Table 194: XOR Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.1.6 Loop delay function block LOOPDELAY

Function block

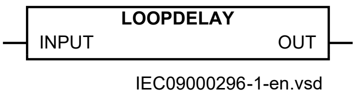


Figure 102: Function block

Functionality

The Logic loop delay function block (LOOPDELAY) function is used to delay the output signal one execution cycle.

Signals

Table 195: LOOPDELAY Input signals

Name	Type	Default	Description
INPUT	BOOLEAN	0	Input signal

Table 196: LOOPDELAY Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal, signal is delayed one execution cycle

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.1.7 Timer function block TIMERSET

Function block

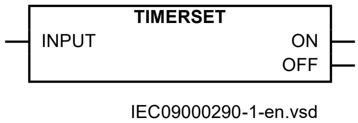


Figure 103: Function block

Functionality

The function block TIMERSET has pick-up and drop-out delayed outputs related to the input signal. The timer has a settable time delay, *t*.

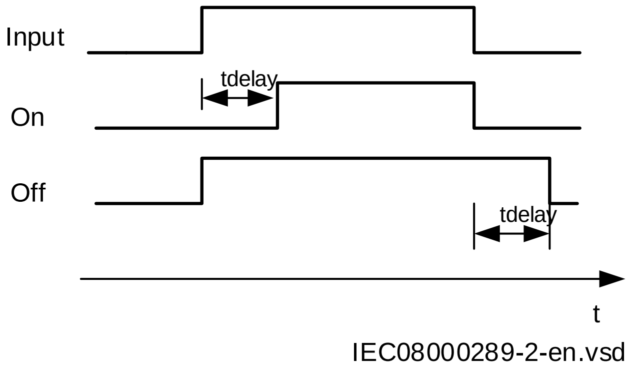


Figure 104: TIMERSET Status diagram

Signals

Table 197: TIMERSET Input signals

Name	Type	Default	Description
INPUT	BOOLEAN	0	Input signal

Table 198: TIMERSET Output signals

Name	Type	Description
ON	BOOLEAN	Output signal, pick-up delayed
OFF	BOOLEAN	Output signal, drop-out delayed

Settings

Table 199: TIMERSET Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On
t	0.000 - 90000.000	s	0.001	0.000	Delay for settable timer n

3.57.1.8 AND function block

Function block

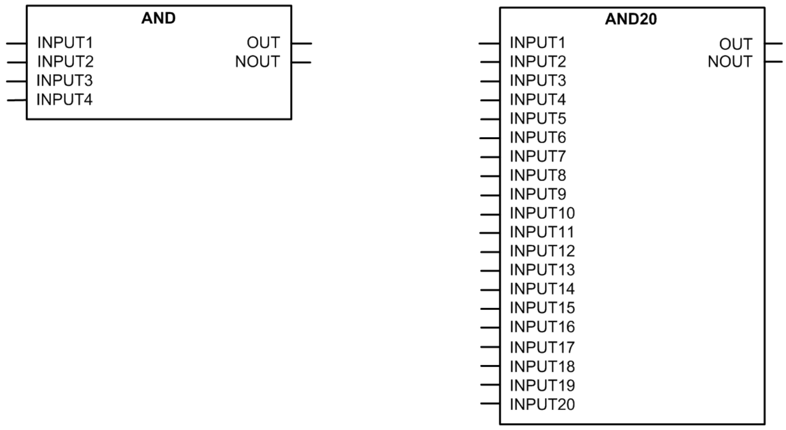


Figure 105: Function block

Functionality

AND and AND20 are used to form general combinatory expressions with Boolean variables.

The default value in all input is logical TRUE, which makes it possible to use only the required number of inputs and leave the rest disconnected.

AND has four inputs and AND20 has 20 inputs. The output `OUT` has a default value FALSE initially, which suppresses one cycle pulse if the function has been put in the wrong execution order.

Connect at least one output to another function block or to a variable for the function to execute correctly.

Signals

Table 200: AND Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	1	Input signal 1
INPUT2	BOOLEAN	1	Input signal 2
INPUT3	BOOLEAN	1	Input signal 3
INPUT4	BOOLEAN	1	Input signal 4

Table 201: AND20 Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	1	Input 1
INPUT2	BOOLEAN	1	Input 2
INPUT3	BOOLEAN	1	Input 3
INPUT4	BOOLEAN	1	Input 4
INPUT5	BOOLEAN	1	Input 5
INPUT6	BOOLEAN	1	Input 6
INPUT7	BOOLEAN	1	Input 7
INPUT8	BOOLEAN	1	Input 8
INPUT9	BOOLEAN	1	Input 9
INPUT10	BOOLEAN	1	Input 10
INPUT11	BOOLEAN	1	Input 11
INPUT12	BOOLEAN	1	Input 12
INPUT13	BOOLEAN	1	Input 13
INPUT14	BOOLEAN	1	Input 14
INPUT15	BOOLEAN	1	Input 15
INPUT16	BOOLEAN	1	Input 16
INPUT17	BOOLEAN	1	Input 17
INPUT18	BOOLEAN	1	Input 18
INPUT19	BOOLEAN	1	Input 19
INPUT20	BOOLEAN	1	Input 20

Table 202: AND Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

Table 203: AND20 Output signals

Name	Type	Description
OUT	BOOLEAN	Output
NOUT	BOOLEAN	Inverted output

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.1.9 Set-reset memory function block SRMEMORY

Function block

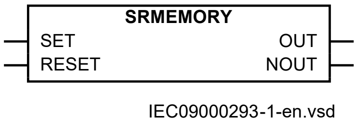


Figure 106: Function block

Functionality

The Set-Reset function SRMEMORY is a flip-flop with memory that can set or reset an output from two inputs respectively. Each SRMEMORY function block has two outputs, where one is inverted. The memory setting controls if the flip-flop after a power interruption returns the state it had before or if it is reset. For a Set-Reset flip-flop, `SET` input has higher priority over `RESET` input.

Table 204: Truth table for the Set-Reset (SRMEMORY) function block

SET	RESET	OUT	NOUT
1	0	1	0
0	1	0	1
1	1	1	0
0	0	0	1

Signals

Table 205: SRMEMORY Input signals

Name	Type	Default	Description
SET	BOOLEAN	0	Input signal to set
RESET	BOOLEAN	0	Input signal to reset

Table 206: SRMEMORY Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

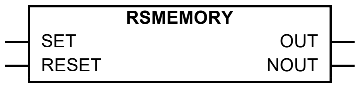
Settings

Table 207: SRMEMORY Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Memory	Off On	-	-	On	Operating mode of the memory function

3.57.1.10 Reset-set with memory function block RSMEMORY

Function block



IEC09000294-1-en.vsd

Figure 107: Function block

Functionality

The Reset-set with memory function block (RSMEMORY) is a flip-flop with memory that can reset or set an output from two inputs respectively. Each RSMEMORY function block has two outputs, where one is inverted. The memory setting controls if the flip-flop after a power interruption returns the state it had before or if it is reset. For a Reset-Set flip-flop, `RESET` input has higher priority over `SET` input.

Table 208: Truth table for RSMEMORY function block

SET	RESET	OUT	NOUT
0	0	Last value	Inverted last value
0	1	0	1
1	0	1	0
1	1	0	1

Signals

Table 209: RSMEMORY Input signals

Name	Type	Default	Description
SET	BOOLEAN	0	Input signal to set
RESET	BOOLEAN	0	Input signal to reset

Table 210: RSMEMORY Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

Settings

Table 211: RSMEMORY Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Memory	Off On	-	-	On	Operating mode of the memory function

3.57.1.11 Equality check for real signals EQR

Function block

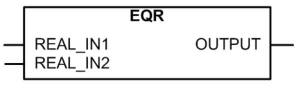


Figure 108: Function block

Functionality

The EQR function block compares the real inputs `REAL_IN1` and `REAL_IN2` and activates the binary output `OUTPUT`, if `REAL_IN1` is equal to `REAL_IN2`.

If `REAL_IN1` == `REAL_IN2`, `OUTPUT` = 1, else `OUTPUT` = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 212: EQR Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 213: EQR Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.12 Equality check for integer signals EQI

Function block

Figure 109: Function block

Functionality

The EQI function compares the integer inputs `INT_IN1` and `INT_IN2` and activates the binary output `OUTPUT`, if `INT_IN1` is equal to `INT_IN2`.

If `INT_IN1` = `INT_IN2`, `OUTPUT` = 1, else `OUTPUT` = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 214: EQI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 215: EQI Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.13 Greater than check for real signals GTR

Function block

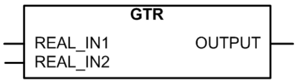


Figure 110: Function block

Functionality

The function compares the real inputs REAL_IN1 and REAL_IN2 and activates the binary output OUTPUT, if REAL_IN1 is greater than REAL_IN2.

If REAL_IN1 > REAL_IN2, OUTPUT = 1, else OUTPUT = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 216: GTR Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 217: GTR Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.14 Greater than check for integer signals GTI

Function block

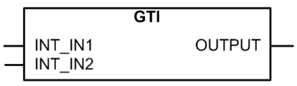


Figure 111: Function block

Functionality

The function compares the integer inputs INT_IN1 and INT_IN2 and activates the binary output OUTPUT, if INT_IN1 is greater than INT_IN2.

If `INT_IN1` > `INT_IN2`, `OUTPUT` = 1, else `OUTPUT` = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 218: GTI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 219: GTI Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.15 Greater than or equal check for real signals GER

Function block

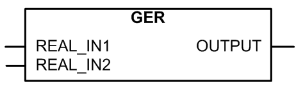


Figure 112: Function block

Functionality

The function compares the real inputs `REAL_IN1` and `REAL_IN2` and activates the binary output `OUTPUT`, if `REAL_IN1` is greater than or equal to `REAL_IN2`.

If `REAL_IN1` ≥ `REAL_IN2`, `OUTPUT` = 1, else `OUTPUT` = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 220: GER Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 221: GER Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.16 Greater than or equal check for integer signals GEI

Function block

Figure 113: Function block

Functionality

The function compares the integer inputs INT_IN1 and INT_IN2 and activates the binary output OUTPUT, if INT_IN1 is greater than or equal to INT_IN2.

If INT_IN1 ≥ INT_IN2, OUTPUT = 1, else OUTPUT = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 222: GEI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 223: GEI Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.17 Less than check for real signals LTR

Function block

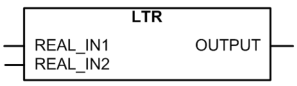


Figure 114: Function block

Functionality

The function compares the real inputs REAL_IN1 and REAL_IN2 and activates the binary output OUTPUT, if REAL_IN1 is less than REAL_IN2.

If REAL_IN1 < REAL_IN2, OUTPUT = 1, else OUTPUT = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 224: LTR Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 225: LTR Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.18 Less than check for integer signals LTI

Function block

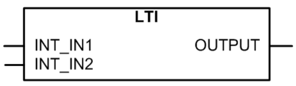


Figure 115: Function block

Functionality

The function compares the integer inputs INT_IN1 and INT_IN2 and activates the binary output OUTPUT, if INT_IN1 is less than INT_IN2.

If INT_IN1 < INT_IN2, OUTPUT = 1, else OUTPUT = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 226: LTI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 227: LTI Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.19 Less than or equal check for real signals LER

Function block

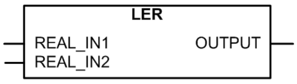


Figure 116: Function block

Functionality

The function compares the real inputs REAL_IN1 and REAL_IN2 and activates the binary output OUTPUT, if REAL_IN1 is less than or equal to REAL_IN2.

If REAL_IN1 ≤ REAL_IN2, OUTPUT = 1, else OUTPUT = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 228: LER Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 229: LER Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.20 Less than or equal check for integer signals LEI

Function block

Figure 117: Function block

Functionality

The function compares the integer inputs INT_IN1 and INT_IN2 and activates the binary output OUTPUT, if INT_IN1 is less than or equal to INT_IN2.

If INT_IN1 ≤ INT_IN2, OUTPUT = 1, else OUTPUT = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 230: LEI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 231: LEI Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.21 Not equal check for real signals NER

Function block

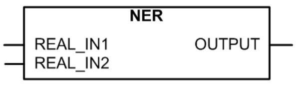


Figure 118: Function block

Functionality

The function compares the real inputs REAL_IN1 and REAL_IN2 and activates the binary output OUTPUT, if REAL_IN1 not equal to REAL_IN2.

If REAL_IN1 ≠ REAL_IN2, OUTPUT = 1, else OUTPUT = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 232: NER Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 233: NER Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.1.22 Not equal check for integer signals NEI

Function block

Figure 119: Function block

Functionality

The function compares the integer inputs INT_IN1 and INT_IN2 and activates the binary output OUTPUT, if INT_IN1 is not equal to INT_IN2.

If INT_IN1 ≠ INT_IN2, OUTPUT = 1, else OUTPUT = 0.

Logic function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have very closely varying values.

Signals

Table 234: NEI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 235: NEI Output signals

Name	Type	Description
OUTPUT	BOOLEAN	Binary output

3.57.2 Configurable logic Q/T

A number of logic blocks and timers with the capability to propagate timestamp and quality of the input signals are available. The function blocks assist the user to adapt the IEDs configuration to the specific application needs.

3.57.2.1 ORQT function block

Function block

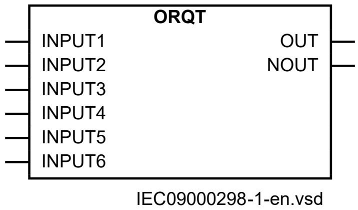


Figure 120: Function block

Functionality

ORQT function block (ORQT) is used to form general combinatory expressions with Boolean variables. ORQT function block has six inputs and two outputs. One of the outputs is inverted.

Signals

Table 236: ORQT Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	0	Input signal 1
INPUT2	BOOLEAN	0	Input signal 2
INPUT3	BOOLEAN	0	Input signal 3
INPUT4	BOOLEAN	0	Input signal 4
INPUT5	BOOLEAN	0	Input signal 5
INPUT6	BOOLEAN	0	Input signal 6

Table 237: ORQT Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.2.2 INVERTERQT function block

Function block

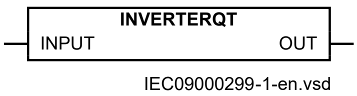


Figure 121: Function block

Signals

Table 238: INVERTERQT Input signals

Name	Type	Default	Description
INPUT	BOOLEAN	0	Input signal

Table 239: INVERTERQT Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.2.3 Pulse timer function block PULSTIMERQT

Function block

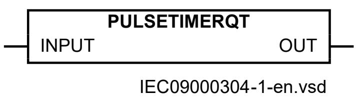


Figure 122: Function block

Functionality

Pulse timer function block (PULSETIMERQT) can be used, for example, for pulse extensions or limiting of operation of outputs. The pulse timer has a settable length and also propagates quality and time.

When the input goes to 1 the output is 1 for the time set by the time delay parameter *t*. Then return to 0.

When the output changes value, the timestamp of the output signal is updated.

The supported “quality” state bits are propagated from the input each execution to the output. A change of these bits does not lead to an updated timestamp on the output.

Signals

Table 240: PULSETIMERQT Input signals

Name	Type	Default	Description
INPUT	BOOLEAN	0	Input signal

Table 241: PULSETIMERQT Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

Settings

Table 242: PULSETIMERQT Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
t	0.000 - 90000.000	s	0.001	0.010	Pulse time length

3.57.2.4 XORQT function block

Function block

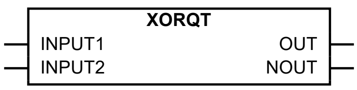


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Figure 123: Function block

Functionality

The exclusive OR function (XORQT) function is used to generate combinatory expressions with Boolean variables. XORQT function has two inputs and two outputs. One of the outputs is inverted. The output signal is 1 if the input signals are different and 0 if they are equal.

Signals

Table 243: XORQT Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	0	Input signal 1
INPUT2	BOOLEAN	0	Input signal 2

Table 244: XORQT Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.2.5 Settable timer function block TIMERSETQT

Function block

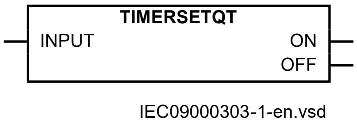

Figure 124: Function block

Functionality

The Settable timer function block (TIMERSETQT) has pick-up and drop-out delayed outputs related to the input signal. The timer has a settable time delay (*t*).

When the output changes value the timestamp of the output signal is updated. The supported “quality” state bits are propagated from the input each execution to the output. A change of these bits does not lead to an updated timestamp on the output.

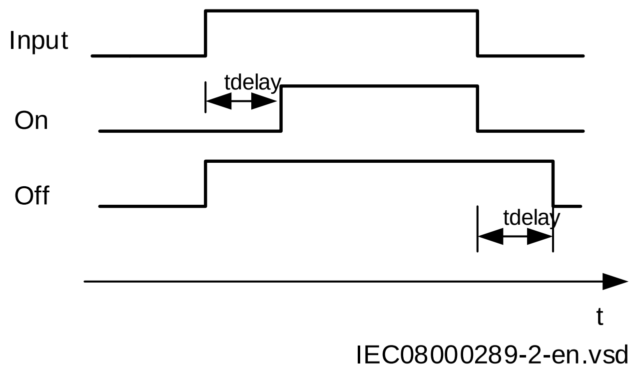

Figure 125: TIMERSETQT function

Signals

Table 245: TIMERSETQT Input signals

Name	Type	Default	Description
INPUT	BOOLEAN	0	Input signal

Table 246: TIMERSETQT Output signals

Name	Type	Description
ON	BOOLEAN	Output signal, pick-up delayed
OFF	BOOLEAN	Output signal, drop-out delayed

Settings

Table 247: TIMERSETQT Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation Off/On
t	0.000 - 90000.000	s	0.001	0.000	Delay for settable timer n

3.57.2.6 ANDQT function block

Function block

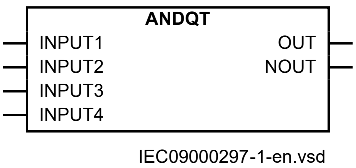

Figure 126: Function block

Functionality

ANDQT function is used to form general combinatory expressions with Boolean variables. ANDQT function block has four inputs and two outputs.

Default value on all four inputs is logical 1 which makes it possible to use only the required number of inputs and leave the rest un-connected. The output `OUT` has an initial default value 0, which suppresses one cycle pulse if the function has been put in the wrong execution order.

Signals

Table 248: ANDQT Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	1	Input signal 1
INPUT2	BOOLEAN	1	Input signal 2
INPUT3	BOOLEAN	1	Input signal 3
INPUT4	BOOLEAN	1	Input signal 4

Table 249: ANDQT Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.2.7 Set-reset function block SRMEMORYQT

Function block

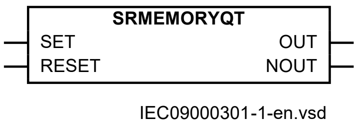

Figure 127: Function block

Functionality

The Set-reset function (SRMEMORYQT) is a flip-flop with memory that can set or reset an output from two inputs respectively. Each SRMEMORYQT function block has two outputs, where one is inverted. The memory setting controls if the flip-flop after a power interruption returns to its previous state or if it is reset. SRMEMORYQT propagates quality and time as well as value.

Table 250: SRMEMORYQT functionality

SET	RESET	OUT	NOUT
1	0	1	0
0	1	0	1
1	1	1	0
0	0	0	1

If *Memory* parameter is "On", the output result is stored in semi-retained memory.

Signals

Table 251: SRMEMORYQT Input signals

Name	Type	Default	Description
SET	BOOLEAN	0	Input signal to set
RESET	BOOLEAN	0	Input signal to reset

Table 252: SRMEMORYQT Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

Settings

Table 253: SRMEMORYQT Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Memory	Off On	-	-	On	Operating mode of the memory function

3.57.2.8 Reset-set function block RSMEMORYQT

Function block

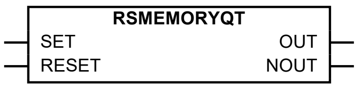

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Figure 128: Function block

Functionality

The Reset-set function (RSMEMORYQT) is a flip-flop with memory that can reset or set an output from two inputs respectively. Each RSMEMORYQT function block has two outputs, where one is inverted. The memory setting controls if the flip-flop after a power interruption returns to its previous state or if it is reset.

Table 254: RSMEMORYQT functionality

SET	RESET	OUT	NOUT
1	0	1	0
0	1	0	1
1	1	0	1
0	0	0	1

Signals

Table 255: RSMEMORYQT Input signals

Name	Type	Default	Description
SET	BOOLEAN	0	Input signal to set
RESET	BOOLEAN	0	Input signal to reset

Table 256: RSMEMORYQT Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
NOUT	BOOLEAN	Inverted output signal

Settings

Table 257: RSMEMORYQT Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Memory	Off On	-	-	On	Operating mode of the memory function

3.57.2.9 INVALIDQT function block

Function block

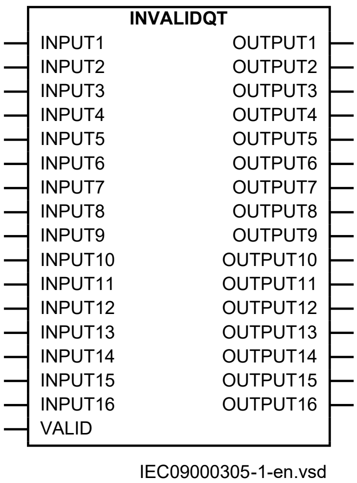


Figure 129: Function block

Functionality

INVALIDQT is a function which sets quality invalid of outputs according to a `VALID` input.

Inputs are copied to outputs. If input VALID is 0, or if its quality invalid bit is set, all outputs' invalid quality bit is set. The timestamp of an output is set to the latest timestamp of INPUT and VALID input.

Signals

Table 258: INVALIDQT Input signals

Name	Type	Default	Description
INPUT1	BOOLEAN	0	Indication input 1
INPUT2	BOOLEAN	0	Indication input 2
INPUT3	BOOLEAN	0	Indication input 3
INPUT4	BOOLEAN	0	Indication input 4
INPUT5	BOOLEAN	0	Indication input 5
INPUT6	BOOLEAN	0	Indication input 6
INPUT7	BOOLEAN	0	Indication input 7
INPUT8	BOOLEAN	0	Indication input 8
INPUT9	BOOLEAN	0	Indication input 9
INPUT10	BOOLEAN	0	Indication input 10
INPUT11	BOOLEAN	0	Indication input 11
INPUT12	BOOLEAN	0	Indication input 12
INPUT13	BOOLEAN	0	Indication input 13
INPUT14	BOOLEAN	0	Indication input 14
INPUT15	BOOLEAN	0	Indication input 15
INPUT16	BOOLEAN	0	Indication input 16
VALID	BOOLEAN	1	Inputs are valid or not

Table 259: INVALIDQT Output signals

Name	Type	Description
OUTPUT1	BOOLEAN	Indication output 1
OUTPUT2	BOOLEAN	Indication output 2
OUTPUT3	BOOLEAN	Indication output 3
OUTPUT4	BOOLEAN	Indication output 4
OUTPUT5	BOOLEAN	Indication output 5
OUTPUT6	BOOLEAN	Indication output 6
OUTPUT7	BOOLEAN	Indication output 7
OUTPUT8	BOOLEAN	Indication output 8
OUTPUT9	BOOLEAN	Indication output 9
OUTPUT10	BOOLEAN	Indication output 10
OUTPUT11	BOOLEAN	Indication output 11
OUTPUT12	BOOLEAN	Indication output 12
OUTPUT13	BOOLEAN	Indication output 13
Table continues on next page		

Name	Type	Description
OUTPUT14	BOOLEAN	Indication output 14
OUTPUT15	BOOLEAN	Indication output 15
OUTPUT16	BOOLEAN	Indication output 16

Settings

The function does not have any parameters available in LHMI or PCM600.

3.57.3 Application

A set of standard logic blocks, like AND or OR, and timers are available for adapting the IED configuration to the specific application needs. Additional logic blocks that have the capability to propagate timestamp and quality beside the normal logical function are also available. Those blocks have a designation including the letters QT, for example, ANDQT or ORQT.

3.57.4 Technical data

Table 260: Configurable logic blocks

Logic block	Quantity with cycle time			Range or value	Accuracy
	fast	medium	normal		
AND	60	60	160	-	-
B16I	5	5	-	-	-
GATE	10	10	20	-	-
IB16A	5	5	-	-	-
INVERTER	30	30	80	-	-
ITOR	10	10	10	-	-
LOOPDELAY	10	10	20	-	-
MINMAXR	5	10	5	-	-
OR	60	60	160	-	-
PULSETIMER	10	10	20	(0.000–90000.000) s	± 0.5% ± 25 ms
RSMEMORY	10	10	20	-	-
RTOI	10	10	10		
SRMEMORY	10	10	20	-	-
SWITCHI	10	10	10	-	-
SWITCHR	10	10	10	-	-
TIMERSET	10	10	20	(0.000–90000.000) s	± 0.5% ± 25 ms
XOR	10	10	20	-	-

Table 261: Configurable logic Q/T

Logic block	Quantity with cycle time		Range or value	Accuracy
	medium	normal		
ANDQT	20	100	-	-
INVALIDQT	6	6	-	-
INVERTERQT	20	100	-	-
ORQT	20	100	-	-
PULSETIMERQT	10	30	(0.000-90000.000) s	± 0.5% ± 25 ms
RSMEMORYQT	10	30	-	-
SRMEMORYQT	10	30	-	-
TIMERSETQT	10	30	(0.000-90000.000) s	± 0.5% ± 25 ms
XORQT	10	30	-	-

3.58 Boolean 16 to integer conversion B16I

3.58.1 Function block

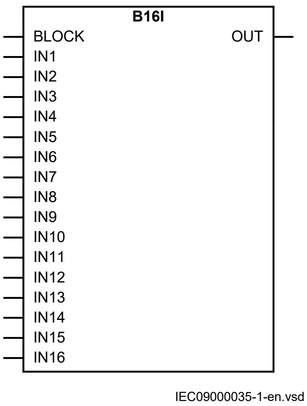


Figure 130: Function block

3.58.2 Functionality

Boolean 16 to integer conversion function (B16I) is used to transform a set of 16 binary (logical) signals into an integer.

3.58.3 Operation principle

Boolean 16 to integer conversion function (B16I) is used to transform a set of 16 binary (logical) signals into an integer. The BLOCK input freezes the output at the last value.

3.58.4 Signals

Table 262: B16I Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
IN1	BOOLEAN	0	Input 1
IN2	BOOLEAN	0	Input 2
IN3	BOOLEAN	0	Input 3
IN4	BOOLEAN	0	Input 4
IN5	BOOLEAN	0	Input 5
IN6	BOOLEAN	0	Input 6
IN7	BOOLEAN	0	Input 7
IN8	BOOLEAN	0	Input 8
IN9	BOOLEAN	0	Input 9
IN10	BOOLEAN	0	Input 10
IN11	BOOLEAN	0	Input 11
IN12	BOOLEAN	0	Input 12
IN13	BOOLEAN	0	Input 13
IN14	BOOLEAN	0	Input 14
IN15	BOOLEAN	0	Input 15
IN16	BOOLEAN	0	Input 16

Table 263: B16I Output signals

Name	Type	Description
OUT	INTEGER	Output value

3.58.5 Settings

The function does not have any parameters available in LHMI or PCM600.

3.58.6 Monitored data

Table 264: B16I Monitored data

Name	Type	Values (Range)	Unit	Description
OUT	INTEGER	-	-	Output value

3.59 Integer to boolean 16 conversion IB16A

3.59.1 Function block

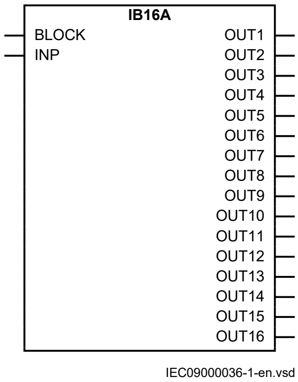


Figure 131: Function block

3.59.2 Functionality

Integer to boolean 16 conversion function (IB16A) is used to transform an integer into a set of 16 binary (logical) signals.

3.59.3 Operation principle

Integer to boolean 16 conversion function (IB16A) is used to transform an integer into a set of 16 binary (logical) signals. IB16A function is designed for receiving the integer input locally. The BLOCK input freezes the logical outputs at the last value.

3.59.4 Signals

Table 265: IB16A Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
INP	INTEGER	0	Integer Input

Table 266: IB16A Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1
OUT2	BOOLEAN	Output 2
OUT3	BOOLEAN	Output 3
Table continues on next page		

Name	Type	Description
OUT4	BOOLEAN	Output 4
OUT5	BOOLEAN	Output 5
OUT6	BOOLEAN	Output 6
OUT7	BOOLEAN	Output 7
OUT8	BOOLEAN	Output 8
OUT9	BOOLEAN	Output 9
OUT10	BOOLEAN	Output 10
OUT11	BOOLEAN	Output 11
OUT12	BOOLEAN	Output 12
OUT13	BOOLEAN	Output 13
OUT14	BOOLEAN	Output 14
OUT15	BOOLEAN	Output 15
OUT16	BOOLEAN	Output 16

3.59.5 Settings

The function does not have any parameters available in LHMI or PCM600.

3.60 Additional arithmetic and logic functions

3.60.1 Additional arithmetic and logic functions

The additional arithmetic or logic functions are used in the ACT level as a connection between function blocks.

The available arithmetic functions are integer addition, integer division, integer multiplication, integer subtraction, real addition, real division, real multiplication, real subtraction, integer to real conversion, real to integer conversion and ten input real minimum or maximum functionalities.

The available logic functions are two-input integer switch and two-input real switch functionalities.

3.60.2 ADDI function block

3.60.2.1 Function block

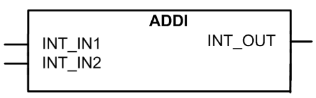


Figure 132: Function block

3.60.2.2 Functionality

ADDI integer adding block adds the integer inputs INT_IN1 and INT_IN2 together. ADDI executes the equation:

$$INT\_OUT = INT\_IN1 + INT\_IN2$$

(Equation 3)

3.60.2.3 Signals

Table 267: ADDI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 268: ADDI Output signals

Name	Type	Description
INT_OUT	INTEGER	Integer output

3.60.3 ADDR function block

3.60.3.1 Function block

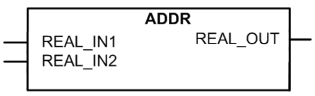


Figure 133: Function block

3.60.3.2 Functionality

ADDR real adding block adds the real inputs REAL_IN1 and REAL_IN2 together. ADDR executes the equation:

$$REAL\_OUT = REAL\_IN1 + REAL\_IN2$$

(Equation 4)

3.60.3.3 Signals

Table 269: ADDR Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 270: ADDR Output signals

Name	Type	Description
REAL_OUT	REAL	Real output

3.60.4 DIVI function block

3.60.4.1 Function block

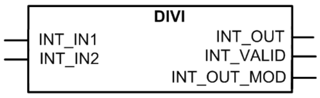


Figure 134: Function block

3.60.4.2 Functionality

DIVI integer division block divides the `INT_IN1` input by `INT_IN2`. The output of the division, the module of division `INT_OUT_MOD` and the validity of integer division in case of division by zero `INT_VALID`.

DIVI executes two equations

$$INT\_OUT = \frac{INT\_IN1}{INT\_IN2}$$

(Equation 5)

$$INT\_OUT\_MOD = MOD\left(\frac{INT\_IN1}{INT\_IN2}\right)$$

(Equation 6)

Table 271: INT_VALID behavior

Input INT_IN2	Output INT_VALID
Zero	FALSE
Lower or higher than zero	TRUE

3.60.4.3 Signals

Table 272: DIVI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 273: DIVI Output signals

Name	Type	Description
INT_OUT	INTEGER	Integer output
INT_VALID	BOOLEAN	Integer output validity
INT_OUT_MOD	INTEGER	Integer output division modulo

3.60.4.4 Technical revision history

Table 274: DIVI technical revision history

Technical revision	Change
B	Inputs INT_IN1, INT_IN2 and outputs INT_OUT, INT_VALID and INT_OUT_MOD are made visible in the Signal Matrix tool (SMT) of PCM600.

3.60.5 DIVR function block

3.60.5.1 Function block

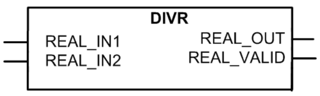


Figure 135: Function block

3.60.5.2 Functionality

DIVR real division block divides the REAL_IN1 input by REAL_IN2. The outputs are the division and the division validity in case of division by zero REAL_VALID.

DIVR executes an equation

$$REAL\_OUT = \frac{REAL\_IN1}{REAL\_IN2}$$

(Equation 7)

Table 275: REAL_VALID behavior

Input REAL_IN2	Output REAL_VALID
Zero	FALSE
Lower or higher than zero	TRUE

3.60.5.3 Signals

Table 276: DIVR Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 277: DIVR Output signals

Name	Type	Description
REAL_OUT	REAL	Real output
REAL_VALID	BOOLEAN	Real output validity

3.60.5.4 Technical revision history

Table 278: DIVR technical revision history

Technical revision	Change
B	Inputs REAL_IN1, REAL_IN2 and outputs REAL_OUT and REAL_VALID are made visible in the Signal Matrix tool (SMT) of PCM600.

3.60.6 MULI function block

3.60.6.1 Function block

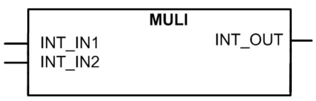


Figure 136: Function block

3.60.6.2 Functionality

MULI integer multiplication block multiplies the integer input INT_IN1 with the INT_IN2 integer input.

MULI executes the equation

$$INT\_OUT = INT\_IN1 \cdot INT\_IN2$$

(Equation 8)

3.60.6.3 Signals

Table 279: MULI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 280: MULI Output signals

Name	Type	Description
INT_OUT	INTEGER	Integer output

3.60.7 MULR function block

3.60.7.1 Function block

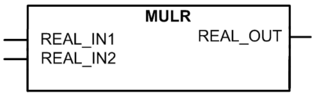


Figure 137: Function block

3.60.7.2 Functionality

MULR real multiplication block multiplies the real input `REAL_IN1` with the real input `REAL_IN2`.

MULR executes the equation:

$$REAL\_OUT = REAL\_IN1 \cdot REAL\_IN2$$

(Equation 9)

3.60.7.3 Signals

Table 281: MULR Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 282: MULR Output signals

Name	Type	Description
REAL_OUT	REAL	Real output

3.60.8 SUBI function block

3.60.8.1 Function block

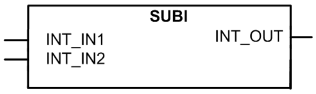


Figure 138: Function block

3.60.8.2 Functionality

SUBI integer subtracting block subtracts the integer input `INT_IN2` from the `INT_IN1` integer input.

SUBI executes the equation:

$$INT\_OUT = INT\_IN1 - INT\_IN2$$

(Equation 10)

3.60.8.3 Signals

Table 283: SUBI Input signals

Name	Type	Default	Description
INT_IN1	INTEGER	0	Integer input 1
INT_IN2	INTEGER	0	Integer input 2

Table 284: SUBI Output signals

Name	Type	Description
INT_OUT	INTEGER	Integer output

3.60.9 SUBR function block

3.60.9.1 Function block

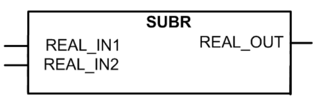


Figure 139: Function block

3.60.9.2 Functionality

SUBR real subtracting block subtracts the real input REAL_IN2 from the real input REAL_IN1.

SUBR executes the equation:

$$REAL\_OUT = REAL\_IN1 - REAL\_IN2$$

(Equation 11)

3.60.9.3 Signals

Table 285: SUBR Input signals

Name	Type	Default	Description
REAL_IN1	REAL	0.0	Real input 1
REAL_IN2	REAL	0.0	Real input 2

Table 286: SUBR Output signals

Name	Type	Description
REAL_OUT	REAL	Real output

3.60.10 ITOR function block

3.60.10.1 Function block

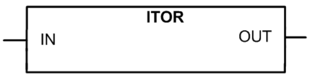


Figure 140: Function block

3.60.10.2 Functionality

ITOR integer to real conversion block converts the integer input IN to the real value output OUT.

3.60.10.3 Signals

Table 287: ITOR Input signals

Name	Type	Default	Description
IN	INTEGER	0	Integer input

Table 288: ITOR Output signals

Name	Type	Description
OUT	REAL	Real outpout

3.60.11 RTOI function block

3.60.11.1 Function block

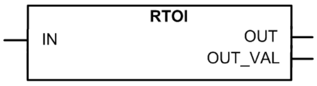


Figure 141: Function block

3.60.11.2 Functionality

RTOI real to integer conversion block converts the real input `IN` to the integer value output `OUT` with the validity information `OUT_VAL` as the real value can exceed the integer size.

Table 289: RTOI OUT_VAL logic

Value of OUT_VAL	Description
TRUE	Integer conversion valid
FALSE	Absolute real input size exceeds the maximum integer size

3.60.11.3 Signals

Table 290: RTOI Input signals

Name	Type	Default	Description
INT	REAL	0.0	Real input

Table 291: RTOI Output signals

Name	Type	Description
OUT	INTEGER	Integer output
OUT_VAL	BOOLEAN	Output conversion validity

3.60.11.4 Technical revision history

Table 292: RTOI technical revision history

Technical revision	Change
B	Input IN and outputs OUT and OUT_VAL are made visible in the Signal Matrix tool (SMT) of PCM600.

3.60.12 MINMAXR function block

3.60.12.1 Function block

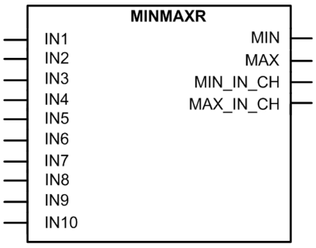


Figure 142: Function block

3.60.12.2 Functionality

MINMAXR minimum and maximum value selector from the real input signals finds the minimum and maximum value from the ten inputs and gives the quantities of these to the outputs MIN and MAX as well as the channel number that has the absolute minimum and maximum values MIN_IN_CH and MAX_IN_CH. When using less than ten inputs, the last connected input should be connected to all the rest open inputs for correct operation.

3.60.12.3 Signals

Table 293: MINMAXR Input signals

Name	Type	Default	Description
IN1	REAL	0.0	input channel1
IN2	REAL	0.0	input channel2
IN3	REAL	0.0	input channel3
IN4	REAL	0.0	input channel4
IN5	REAL	0.0	input channel5
IN6	REAL	0.0	input channel6
IN7	REAL	0.0	input channel7

Table continues on next page

Name	Type	Default	Description
IN8	REAL	0.0	input channel8
IN9	REAL	0.0	input channel9
IN10	REAL	0.0	input channel10

Table 294: MINMAXR Output signals

Name	Type	Description
MIN	REAL	Minimum value of the inputs
MAX	REAL	Maximum value of the inputs
MIN_IN_CH	INTEGER	Channel number having the minimum value
MAX_IN_CH	INTEGER	Channel number having the maximum value

3.60.13 SWITCHI function block

3.60.13.1 Function block

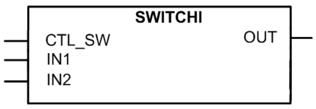


Figure 143: Function block

3.60.13.2 Functionality

SWITCHI integer switching block, operated by the `CTL_SW` input, selects the output `OUT` between the inputs `IN1` and `IN2`.

Table 295: SWITCHI output logic

CTL_SW	OUT
FALSE	IN2
TRUE	IN1

3.60.13.3 Signals

Table 296: SWITCHI Input signals

Name	Type	Default	Description
CTL_SW	BOOLEAN	1	Control Switch
IN1	INTEGER	0	Integer input 1
IN2	INTEGER	0	Integer input 2

Table 297: SWITCHI Output signals

Name	Type	Description
OUT	INTEGER	Integer switch output

3.60.14 SWITCHR function block

3.60.14.1 Function block

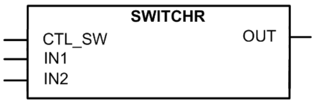


Figure 144: Function block

3.60.14.2 Functionality

SWITCHR real switching block, operated by the `CTL_SW` input, selects the output value `OUT` between the `IN1` and `IN2` inputs.

CTL_SW	OUT
FALSE	IN2
TRUE	IN1

3.60.14.3 Signals

Table 298: SWITCHR Input signals

Name	Type	Default	Description
CTL_SW	BOOLEAN	1	Control Switch
IN1	REAL	0.0	Real input 1
IN2	REAL	0.0	Real input 2

Table 299: SWITCHR Output signals

Name	Type	Description
OUT	REAL	Real switch output

3.61 ETHFRNT function block

Table 300: ETHFRNT Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
IPAddress	0 - 18	IP Address	1	192.168.0.254	IP-Address
IPMask	0 - 18	IP Address	1	255.255.255.0	IP-Mask

3.62 ETHLAN1 function block

Table 301: ETHLAN1 Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
IPAddress	0 - 18	IP Address	1	192.168.2.10	IP-Address
IPMask	0 - 18	IP Address	1	255.255.255.0	IP-Mask

3.63 GATEWAY function block

Table 302: GATEWAY Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
GWAddress	0 - 18	IP Address	1	0.0.0.0	Gateway address

3.64 SYSTEMTIME function block

Table 303: SYSTEMTIME Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
SystemTime		-		2008-01-01 00:00:00	System time

3.65 WEBSERVER function block

Table 304: WEBSERVER Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	Off	Operation On/Off
Write mode	Writing disabled Writing enabled	-	-	Writing disabled	Writing of settings enabled
Session timeout	2 - 60	Min	1	3	Session timeout

Section 4 Protection functions

4.1 Three-phase current protection

4.1.1 Three-phase non-directional overcurrent protection PHxPTOC

4.1.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase non-directional overcurrent protection - Low stage	PHLPTOC	3I>	51P-1
Three-phase non-directional overcurrent protection - High stage	PHHPTOC	3I>>	51P-2
Three-phase non-directional overcurrent protection - Instantaneous stage	PHIPTOC	3I>>>	50P/51P

4.1.1.2 Function block

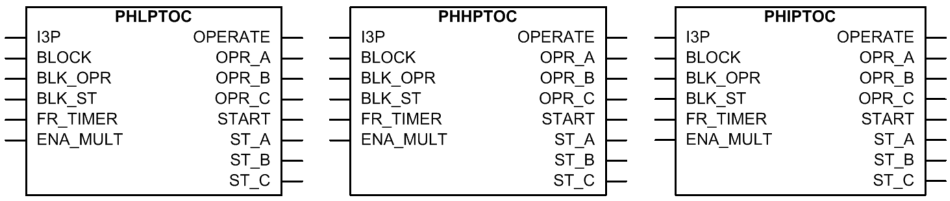


Figure 145: Function block

4.1.1.3 Functionality

The three-phase overcurrent protection PHxPTOC is used as one-phase, two-phase or three-phase non-directional overcurrent and short-circuit protection for feeders.

The function starts when the current exceeds the set limit. The operate time characteristics for low stage PHLPTOC and high stage PHHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).The instantaneous stage PHIPTOC always operates with the DT characteristic.

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of three-phase non-directional overcurrent protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

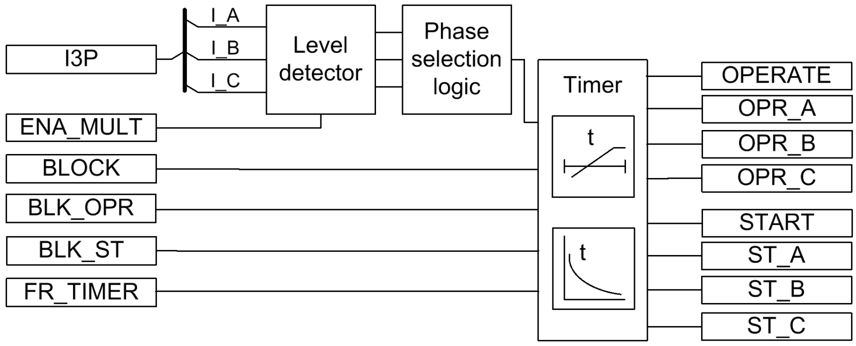


Figure 146: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Level detector

The measured phase currents are compared phasewise to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector reports the exceeding of the value to the phase selection logic. If the ENA_MULT input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

> Do not set the multiplier setting *Start value Mult* higher than necessary. If the value is too high, the function may not operate at all during an inrush followed by a fault, no matter how severe the fault is.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA_MULT input.

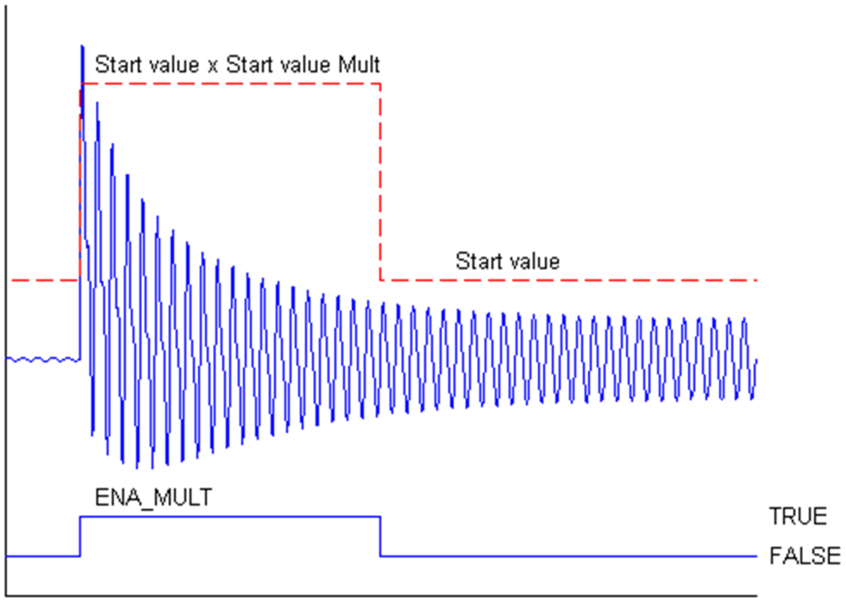


Figure 147: Start value behavior with `ENA_MULT` *input activated*

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of start phases* setting, the phase selection logic activates the timer module.

Timer

Once activated, the timer activates the `START` output. The `ST_A`, `ST_B` and `ST_C` outputs are used to indicate which phases are started. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated. The `OPR_A`, `OPR_B` and `OPR_C` outputs are used to indicate which phases are operated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

4.1.1.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.1.1.6 Measurement modes

The function operates on four alternative measurement modes: "RMS", "DFT", "Peak-to-Peak" and "P-to-P + backup". The measurement mode is selected with the setting *Measurement mode*.

Table 305: Measurement modes supported by PHxPTOC stages

Measurement mode	Supported measurement modes		
	PHLPTOC	PHHPTOC	PHIPTOC
RMS	x	x	
DFT	x	x	
Peak-to-Peak	x	x	
P-to-P + backup			x

For a detailed description of the measurement modes, see the General function block features section in this manual.

4.1.1.7 Timer characteristics

PHxPTOC supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* and *Type of reset curve* settings. When the DT characteristic is selected, it is only affected by the *Operate delay time* and *Reset delay time* settings.

The IED provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The user can choose the DT characteristic by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The following characteristics, which comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages:

Table 306: Timer characteristics supported by different stages

Operating curve type	Supported by	
	PHLPTOC	PHHPTOC
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	x	
(5) ANSI Definite Time	x	x
(6) Long Time Extremely Inverse	x	
(7) Long Time Very Inverse	x	
(8) Long Time Inverse	x	
(9) IEC Normal Inverse	x	x
(10) IEC Very Inverse	x	x
Table continues on next page		

Operating curve type	Supported by	
	PHLPTOC	PHHPTOC
(11) IEC Inverse	x	
(12) IEC Extremely Inverse	x	x
(13) IEC Short Time Inverse	x	
(14) IEC Long Time Inverse	x	
(15) IEC Definite Time	x	x
(17) User programmable	x	x
(18) RI type	x	
(19) RD type	x	

PHIPTOC supports only definite time characteristic.

For a detailed description of timers, see the General function block features section in this manual.

Table 307: Reset time characteristics supported by different stages

Reset curve type	Supported by		
	PHLPTOC	PHHPTOC	Note
(1) Immediate	x	x	Available for all operate time curves
(2) Def time reset	x	x	Available for all operate time curves
(3) Inverse reset	x	x	Available only for ANSI and user programmable curves

The *Type of reset curve* setting does not apply to PHIPTOC or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

4.1.1.8 Application

PHxPTOC is used in several applications in the power system. The applications include but are not limited to:

- Selective overcurrent and short-circuit protection of feeders in distribution and subtransmission systems
- Backup overcurrent and short-circuit protection of power transformers and generators
- Overcurrent and short-circuit protection of various devices connected to the power system, for example shunt capacitor banks, shunt reactors and motors
- General backup protection

PHxPTOC is used for single-phase, two-phase and three-phase non-directional overcurrent and short-circuit protection. Typically, overcurrent protection is used for clearing two and three-phase short circuits. Therefore, the user can choose how many phases, at minimum, must have currents above the start level for the function to operate. When the number of start-phase settings is set to "1 out of 3", the operation of PHxPTOC is enabled with the presence of high current in one-phase.

When the setting is "2 out of 3" or "3 out of 3", single-phase faults are not detected. The setting "3 out of 3" requires the fault to be present in all three phases.

Many applications require several steps using different current start levels and time delays. PHxPTOC consists of three protection stages:

- Low PHLPTOC
- High PHHPTOC
- Instantaneous PHIPTOC.

PHLPTOC is used for overcurrent protection. The function contains several types of time-delay characteristics. PHHPTOC and PHIPTOC are used for fast clearance of very high overcurrent situations.

Transformer and busbar overcurrent protection with reverse blocking principle

By implementing a full set of overcurrent protection stages and blocking channels between the protection stages of the incoming feeders, bus-tie and outgoing feeders, it is possible to speed up the operation of overcurrent protection in the busbar and transformer LV-side faults without impairing the selectivity. Also, the security degree of busbar protection is increased, because there is now a dedicated, selective and fast busbar protection functionality which is based on the blockable overcurrent protection principle. The additional time selective stages on the transformer HV and LV-sides provide increased security degree of backup protection for the transformer, busbar and also for the outgoing feeders.

Depending on the overcurrent stage in question, the selectivity of the scheme in Figure 148 is based on the operating current, operating time or blockings between successive overcurrent stages. With blocking channels, the operating time of the protection can be drastically shortened if compared to the simple time selective protection. In addition to the busbar protection, this blocking principle is applicable for the protection of transformer LV terminals and short lines. The functionality and performance of the proposed overcurrent protections can be summarized as seen in the table.

Table 308: Proposed functionality of numerical transformer and busbar overcurrent protection. DT = definite time, IDMT = inverse definite minimum time

O/C-stage	Operating char.	Selectivity mode	Operation speed	Sensitivity
HV/3I>	DT/IDMT	time selective	low	very high
HV/3I>>	DT	blockable/time selective	high/low	high
HV/3I>>>	DT	current selective	very high	low
LV/3I>	DT/IDMT	time selective	low	very high
LV/3I>>	DT	time selective	low	high
LV/3I>>>	DT	blockable	high	high

In case the bus-tie breaker is open, the operating time of the blockable overcurrent protection is approximately 100 ms (relaying time). When the bus-tie breaker is closed, that is, the fault current flows to the faulted section of the busbar from two directions, the operation time becomes as follows: first the bus-tie relay unit trips the tie breaker in the above 100 ms, which reduces the fault current to a half. After this the incoming feeder relay unit of the faulted bus section trips the breaker in approximately 250 ms (relaying time), which becomes the total fault clearing time in this case.

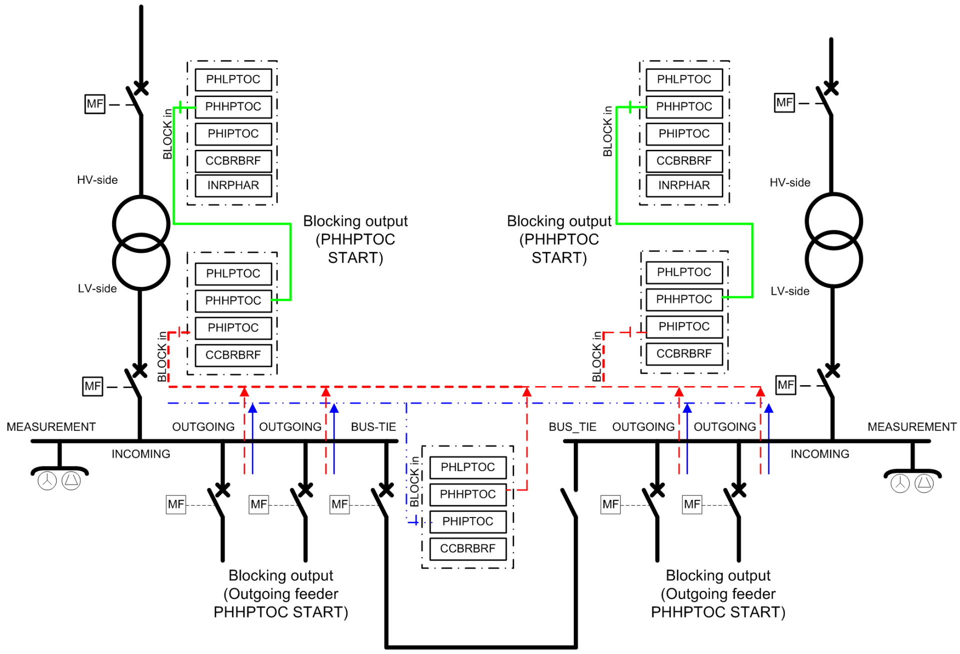


Figure 148: Numerical overcurrent protection functionality for a typical sub-transmission/distribution substation (feeder protection not shown). Blocking output = digital output signal from the start of a protection stage, Blocking in = digital input signal to block the operation of a protection stage

The operating times of the time selective stages are very short, because the grading margins between successive protection stages can be kept short. This is mainly due to the advanced measuring principle allowing a certain degree of CT saturation, good operating accuracy and short retardation times of the numerical units. So, for example, a grading margin of 150 ms in the DT mode of operation can be used, provided that the circuit breaker interrupting time is shorter than 60 ms.

The sensitivity and speed of the current-selective stages become as good as possible due to the fact that the transient overreach is practically zero. Also, the effects of switching inrush currents on the setting values can be reduced by using the IED logic, which recognizes the transformer energizing inrush current and blocks the operation or multiplies the current start value setting of the selected overcurrent stage with a predefined multiplier setting.

Finally, a dependable trip of the overcurrent protection is secured by both a proper selection of the settings and an adequate ability of the measuring transformers to reproduce the fault current. This is important in order to maintain selectivity and also for the protection to operate without additional time delays. For additional information about available measuring modes and current transformer requirements, see the General function block features section in this manual.

Radial outgoing feeder overcurrent protection

The basic requirements for feeder overcurrent protection are adequate sensitivity and operation speed taking into account the minimum and maximum fault current levels along the protected line, selectivity requirements, inrush currents and the thermal and mechanical withstand of the lines to be protected.

In many cases the above requirements can be best fulfilled by using multiple-stage overcurrent units. Figure 149 shows an example of this. A brief coordination study has been carried out between the incoming and outgoing feeders.

The protection scheme is implemented with three-stage numerical overcurrent protection, where the low-set stage PHLPTOC operates in IDMT-mode and the two higher stages PHHPTOC and PHIPTOC in DT-mode. Also the thermal withstand of the line types along the feeder and maximum expected inrush currents of the feeders are shown. Faults occurring near the station where the fault current levels are the highest are cleared rapidly by the instantaneous stage in order to minimize the effects of severe short circuit faults. The influence of the inrush current is taken into consideration by connecting the inrush current detector to the start value multiplying input of the instantaneous stage. By this way the start value is multiplied with a predefined setting during the inrush situation and nuisance tripping can be avoided.

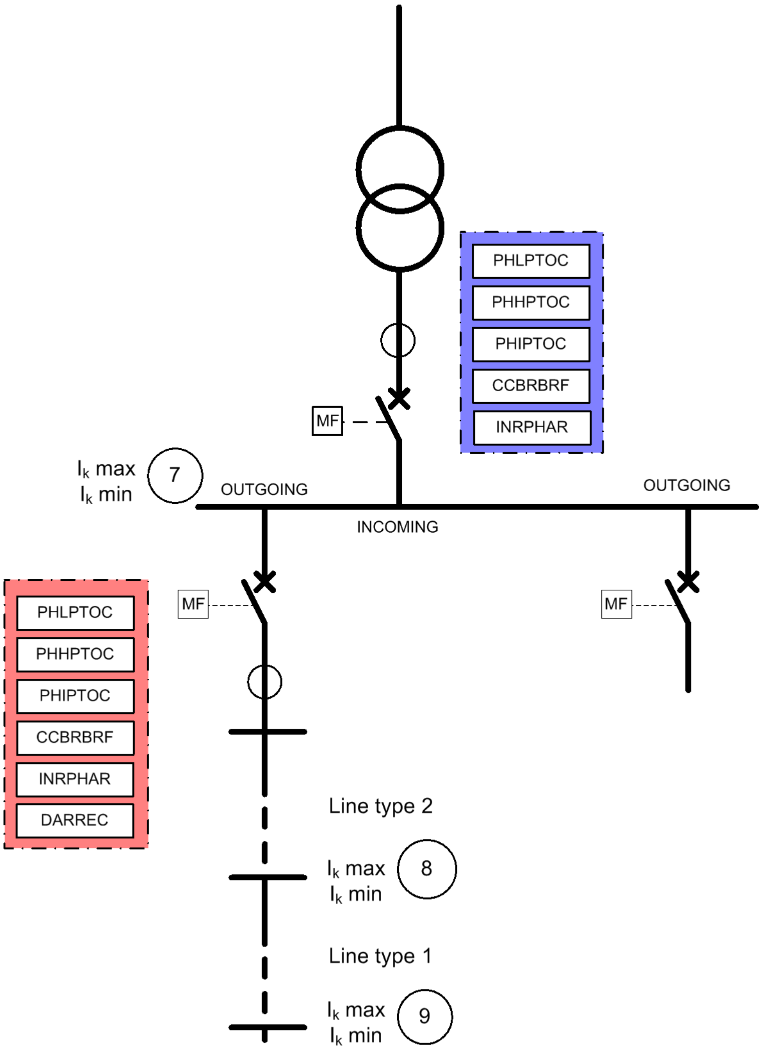


Figure 149: Functionality of numerical multiple-stage overcurrent protection

The coordination plan is an effective tool to study the operation of time selective operation characteristics. All the points mentioned earlier, required to define the overcurrent protection parameters, can be expressed simultaneously in a coordination plan. In Figure 150, the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

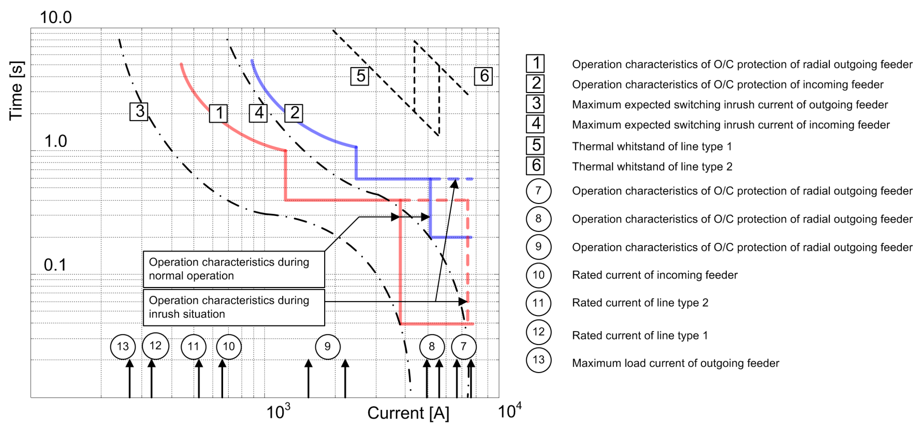


Figure 150: Example coordination of numerical multiple-stage overcurrent protection

For the short circuit protection of motors, the start value is typically set 1.5 times higher than the motor startup current.

4.1.1.9 Signals

Table 309: PHLPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	3-phase current group
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 310: PHHPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	3-phase current group
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 311: PHIPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	3-phase current group
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 312: PHLPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
OPR_A	BOOLEAN	Operated phase A
OPR_B	BOOLEAN	Operated phase B
OPR_C	BOOLEAN	Operated phase C
START	BOOLEAN	Started signal
ST_A	BOOLEAN	Started phase A
ST_B	BOOLEAN	Started phase B
ST_C	BOOLEAN	Started phase C

Table 313: PHHPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
OPR_A	BOOLEAN	Operated phase A
OPR_B	BOOLEAN	Operated phase B
OPR_C	BOOLEAN	Operated phase C
START	BOOLEAN	Started signal
ST_A	BOOLEAN	Started phase A
ST_B	BOOLEAN	Started phase B
ST_C	BOOLEAN	Started phase C

Table 314: PHIPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
OPR_A	BOOLEAN	Operated phase A
OPR_B	BOOLEAN	Operated phase B
OPR_C	BOOLEAN	Operated phase C
START	BOOLEAN	Started signal

Table continues on next page

Name	Type	Description
ST_A	BOOLEAN	Started phase A
ST_B	BOOLEAN	Started phase B
ST_C	BOOLEAN	Started phase C

4.1.1.10 Settings

Table 315: PHLPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.05 - 5.00	pu	0.01	0.05	Start value
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC/ANSI curves
Operating curve type	ANSI Ext. inv. ANSI Very inv. ANSI Norm. inv. ANSI Mod. inv. ANSI Def. Time L.T.E. inv. L.T.V. inv. L.T. inv. IEC Norm. inv. IEC Very inv. IEC inv. IEC Ext. inv. IEC S.T. inv. IEC L.T. inv. IEC Def. Time Programmable RI type RD type	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.04 - 200.00	s	0.01	0.04	Operate delay time

Table 316: PHLPTOC Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type

Table 317: PHLPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Num of start phases	1 out of 3 2 out of 3 3 out of 3	-	-	1 out of 3	Number of phases required for operate activation

Table 318: PHLPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Selects used current measurement mode
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time
Minimum operate time	0.040 - 60.000	s	0.001	0.040	Minimum operate time for IDMT curves

Table 319: PHHPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.10 - 40.00	pu	0.01	0.10	Start value
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC/ANSI curves
Operating curve type	ANSI Ext. inv. ANSI Norm. inv. ANSI Def. Time IEC Norm. inv. IEC Very inv. IEC Ext. inv. IEC Def. Time Programmable	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.02 - 200.00	s	0.01	0.02	Operate delay time

Table 320: PHHPTOC Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type

Table 321: PHHPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Num of start phases	1 out of 3 2 out of 3 3 out of 3	-	-	1 out of 3	Number of phases required for operate activation

Table 322: PHHPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Selects used current measurement mode
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time
Minimum operate time	0.020 - 60.000	s	0.001	0.020	Minimum operate time for IDMT curves

Table 323: PHIPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.10 - 40.00	pu	0.01	0.10	Start value
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Operate delay time	0.02 - 200.00	s	0.01	0.02	Operate delay time

Table 324: PHIPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Num of start phases	1 out of 3 2 out of 3 3 out of 3	-	-	1 out of 3	Number of phases required for operate activation

Table 325: PHIPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.1.1.11 Measured values

Table 326: PHLPTOC Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Current amplitude (DFT) phase A
I_AMPL_B	REAL	0	Current amplitude (DFT) phase B
I_AMPL_C	REAL	0	Current amplitude (DFT) phase C
I_RMS_A	REAL	0	Current amptitude (RMS) phase A
I_RMS_B	REAL	0	Current amplitude (RMS) phase B
I_RMS_C	REAL	0	Current amplitude (RMS) phase C
I_PTOP_A	REAL	0	Current amplitude (PTOP) phase A
I_PTOP_B	REAL	0	Current amplitude (PTOP) phase B
I_PTOP_C	REAL	0	Current amplitude (PTOP) phase C
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 327: PHHPTOC Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Current amplitude (DFT) phase A
I_AMPL_B	REAL	0	Current amplitude (DFT) phase B
I_AMPL_C	REAL	0	Current amplitude (DFT) phase C
I_RMS_A	REAL	0	Current amptitude (RMS) phase A
I_RMS_B	REAL	0	Current amplitude (RMS) phase B
I_RMS_C	REAL	0	Current amplitude (RMS) phase C
I_PTOP_A	REAL	0	Current amplitude (PTOP) phase A
I_PTOP_B	REAL	0	Current amplitude (PTOP) phase B
I_PTOP_C	REAL	0	Current amplitude (PTOP) phase C
I_PEAK_A	REAL	0	Current peak magnitude phase A
I_PEAK_B	REAL	0	Current peak magnitude phase B
I_PEAK_C	REAL	0	Current peak magnitude phase C
Table continues on next page			

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 328: PHIPTOC Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Current amplitude (DFT) phase A
I_AMPL_B	REAL	0	Current amplitude (DFT) phase B
I_AMPL_C	REAL	0	Current amplitude (DFT) phase C
I_RMS_A	REAL	0	Current amptitude (RMS) phase A
I_RMS_B	REAL	0	Current amplitude (RMS) phase B
I_RMS_C	REAL	0	Current amplitude (RMS) phase C
I_PTOP_A	REAL	0	Current amplitude (PTOP) phase A
I_PTOP_B	REAL	0	Current amplitude (PTOP) phase B
I_PTOP_C	REAL	0	Current amplitude (PTOP) phase C
I_PEAK_A	REAL	0	Current peak magnitude phase A
I_PEAK_B	REAL	0	Current peak magnitude phase B
I_PEAK_C	REAL	0	Current peak magnitude phase C
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

4.1.1.12 Monitored data

Table 329: PHLPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase A
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase B
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase C
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Started phase A
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Started phase B
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Started phase C
START_DUR	REAL	-	%	Ratio of start time / operate time
INVAL_CRV	BOOLEAN	0=FALSE 1=TRUE	-	Invalid curve parameters

Table 330: PHHPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase A
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase B
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase C
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Started phase A
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Started phase B
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Started phase C
START_DUR	REAL	-	%	Ratio of start time / operate time
INVAL_CRV	BOOLEAN	0=FALSE 1=TRUE	-	Invalid curve parameters

Table 331: PHIPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase A
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase B
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase C
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Started phase A
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Started phase B
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Started phase C
START_DUR	REAL	-	%	Ratio of start time / operate time

4.1.1.13 Technical data

Table 332: PHxPTOC Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
	PHLPTOC	±1.5% of the set value or ±0.002 × I_n
	PHHPTOC and PHIPTOC	±1.5% of set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n)
Start time 1)2)	PHIPTOC: I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	Typically 17 ms (±5 ms) Typically 10 ms (±5 ms)
	PHHPTOC: I_{Fault} = 2 × set *Start value*	Typically 19 ms (±5 ms)
	PHLPTOC: I_{Fault} = 2 × set *Start value*	Typically 23 ms (±15 ms)
Reset time		<45 ms
Reset ratio		Typically 0.96
Retardation time		<30 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms 3)
Suppression of harmonics		RMS: No suppression DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression P-to-P+backup: No suppression

1) *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 50 Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20

4.1.1.14 Technical revision history

Table 333: PHHPTOC technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

Table 334: PHLPTOC technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for *Time multiplier* setting.

4.1.2 Three-phase directional overcurrent protection DPHxPDOC

4.1.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase directional overcurrent protection - Low stage	DPHLPDOC	3I> ->	67-1
Three-phase directional overcurrent protection - High stage	DPHHPDOC	3I>> ->	67-2

4.1.2.2 Function block

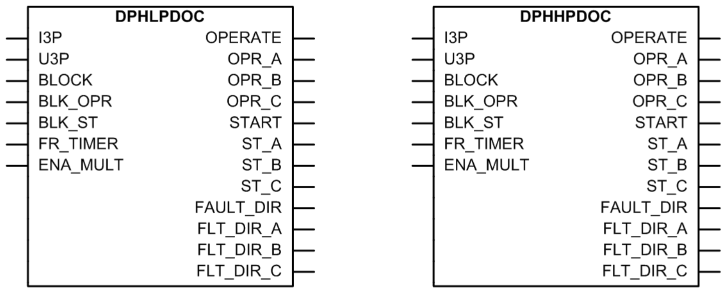


Figure 151: Function block

4.1.2.3 Functionality

The three-phase overcurrent protection DPHxPDOC is used as one-phase, two-phase or three-phase directional overcurrent and short-circuit protection for feeders.

DPHxPDOC starts up when the value of the current exceeds the set limit and directional criterion is fulfilled. The operate time characteristics for low stage DPHLPDOC and high stage DPHHPDOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of directional overcurrent protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

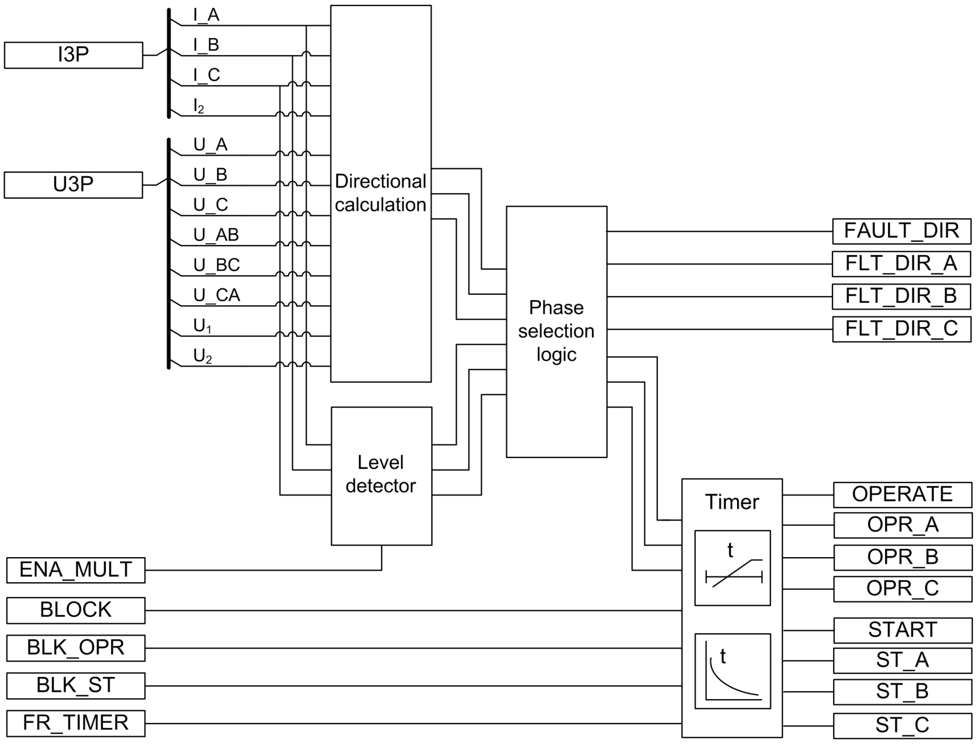


Figure 152: Functional module diagram

Directional calculation

The directional calculation compares the current phasors to the polarizing phasor. A suitable polarization quantity can be selected from the different polarization quantities, which are the positive sequence voltage, negative sequence voltage, self-polarizing (faulted) voltage and cross-polarizing voltages (healthy voltages). The polarizing method is defined with the *Pol quantity* setting.

Table 335: Polarizing quantities

Polarizing quantity	Description
Pos. seq. volt	Positive sequence voltage
Neg. seq. volt	Negative sequence voltage
Self pol	Self polarization
Cross pol	Cross polarization

The directional operation can be selected with the *Directional mode* setting. The user can select either "Non-directional", "Forward" or "Reverse" operation. By setting the value of *Allow Non Dir* to "Allowed", the non-directional operation is allowed when the directional information is invalid.

The *Characteristic angle* setting is used to turn the directional characteristic. The value of *Characteristic angle* should be chosen in such a way that all the faults in the operating direction are seen in the operating zone and all the faults in the opposite direction are seen in the non-operating zone. The value of *Characteristic angle* depends on the network configuration.

Reliable operation requires both the operating and polarizing quantities to exceed certain minimum amplitude levels. The minimum amplitude level for the operating quantity (current) is set with the *Min operate current* setting. The minimum amplitude level for the polarizing quantity (voltage) is set with the *Min operate voltage* setting. If the amplitude level of the operating quantity or polarizing quantity is below the set level, the direction information of the corresponding phase is set to "Unknown".

The polarizing quantity validity can remain valid even if the amplitude of the polarizing quantity falls below the value of the *Min operate voltage* setting. In this case, the directional information is provided by a special memory function for a time defined with the *Voltage Mem time* setting.

DPHxPDOC is provided with a memory function to secure a reliable and correct directional IED operation in case of a close short circuit or an earth fault characterized by an extremely low voltage. At sudden loss of the polarization quantity, the angle difference is calculated on the basis of a fictive voltage. The fictive voltage is calculated using the polarizing quantity measured before the fault occurred. The memory function enables the function to operate up to a maximum of three seconds after a total loss of voltage. This time can be set with the *Voltage Mem time* setting.

The value for the *Min operate voltage* setting should be carefully selected since the accuracy in low signal levels is strongly affected by the measuring device accuracy.

When the voltage of one or more phases falls below *Min operate voltage* at a close fault, the corresponding phase-related fictive voltage is used to determine the phase angle. The measured voltage is applied again as soon as the voltage rises above *Min operate voltage*. The fictive voltage is also discarded if the measured voltage stays below *Min operate voltage* for longer than *Voltage Mem time* or if the fault current disappears while the fictive voltage is in use. When the voltage is below *Min operate voltage* and hysteresis and the fictive voltage is unusable, the fault direction cannot be determined. The fictive voltage can be unusable for three reasons:

- The fictive voltage is discarded after *Voltage Mem time*
- The phase angle cannot be reliably measured before the fault situation.
- When the used *Pol quantity* setting is "Neg. seq. volt.", the measured negative-sequence voltage before the fault is often too low for the fictive voltage function.

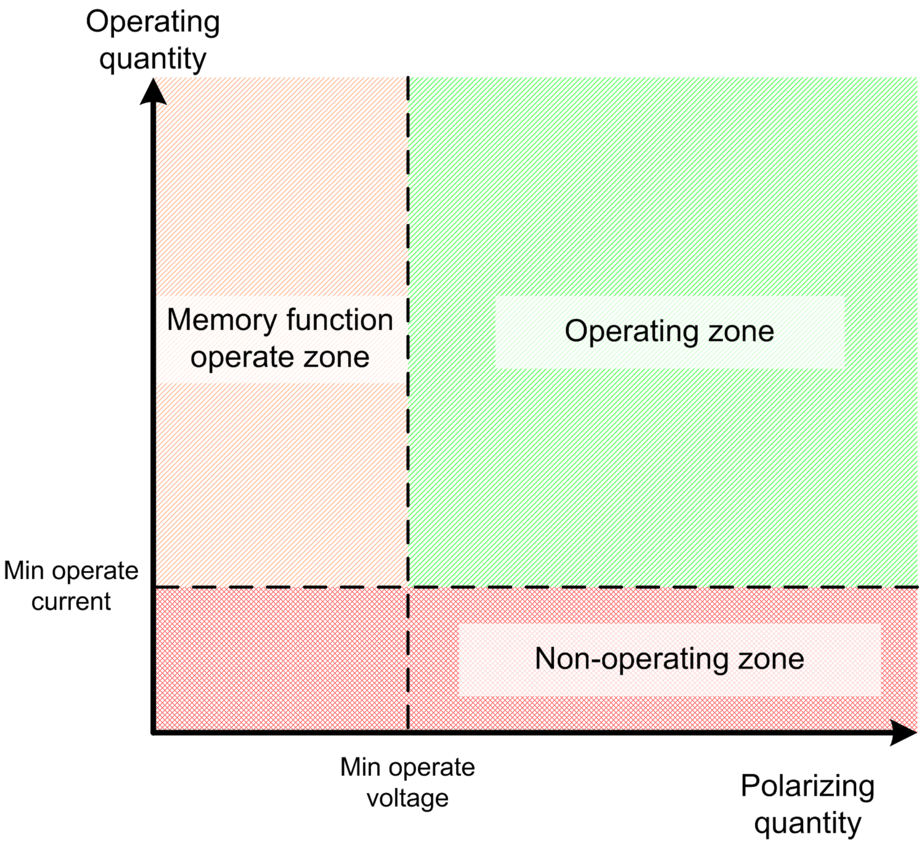


Figure 153: Operating zones at minimum magnitude levels

Level detector

The measured phase currents are compared phasewise to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector reports the exceeding of the value to the phase selection logic. If the `ENA_MULT` input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

Do not set the multiplier setting *Start value Mult* higher than necessary. If the value is too high, the function may not operate at all during an inrush followed by a fault, no matter how severe the fault is.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the `ENA_MULT` input.

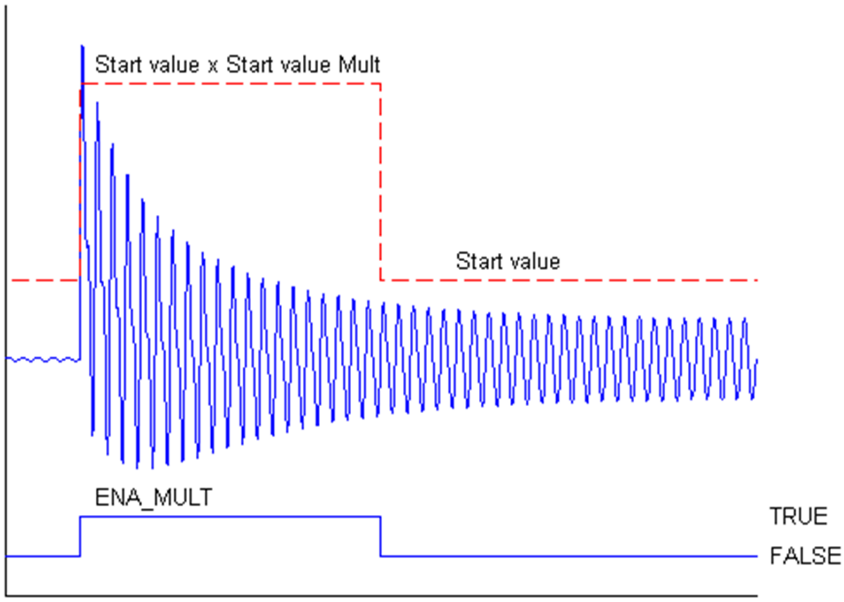


Figure 154: Start value behavior with `ENA_MULT` *input activated*

Phase selection logic

If the fault criteria are fulfilled in the level detector and the directional calculation, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of start phases* setting, the phase selection logic activates the timer module.

The phase selection logic provides also information about phase specific fault directions. The FLT_DIR_A output indicates the direction of the fault in phase A. Similarly, the FLT_DIR_B output indicates the direction of the fault in phase B. The direction of the fault in phase C is indicated by the FLT_DIR_C output. The general fault direction information is provided by the FAULT_DIR output.

Timer

Once activated, the timer activates the START output. The ST_A, ST_B and ST_C outputs are used to indicate which phases are started. When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated. The OPR_A, OPR_B and OPR_C outputs are used to indicate which phases are operated.

DPHxPDOC can be blocked from BLOCK, the binary input. Activation of BLOCK input deactivates all outputs and resets internal timers. The start signals from the function can be blocked from BLK_ST, the binary input. The operate signals from the function can be blocked from BLK_OPR, the binary input. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input signal.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The angle values available at the input monitor data view are in radians.

4.1.2.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.1.2.6 Measuring modes

The function operates on three alternative measurement modes: “RMS”, “DFT” and “Peak-to-Peak” . The measurement mode is selected with the *Measurement mode* setting.

Table 336: Measurement modes supported by DPHxPDOC stages

Measurement mode	Supported measurement modes	
	DPHLPDOC	DPHHPDOC
RMS	x	x
DFT	x	x
Peak-to-Peak	x	x

4.1.2.7 Directional overcurrent characteristics

The forward and reverse sectors are defined separately. The forward operation area is limited with the *Min forward angle* and *Max forward angle* settings. The reverse operation area is limited with the *Min reverse angle* and *Max reverse angle* settings.

The sector limits are always given as positive degree values.

In the forward operation area, the *Max forward angle* setting gives the counterclockwise sector and the *Min forward angle* setting gives the corresponding clockwise sector, measured from the *Characteristic angle* setting.

In the backward operation area, the *Max reverse angle* setting gives the counterclockwise sector and the *Min reverse angle* setting gives the corresponding clockwise sector, a measurement from the *Characteristic angle* setting that has been rotated 180 degrees.

Relay characteristic angle (RCA) is set positive if the operating current lags the polarizing quantity and negative if the operating current leads the polarizing quantity.

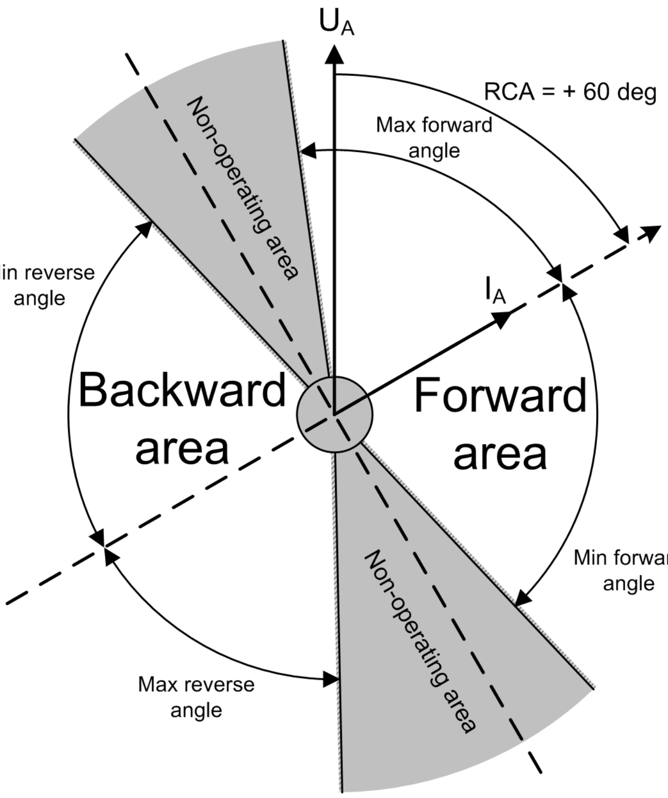


Figure 155: Configurable operating sectors

Table 337: Momentary per phase direction value for monitored data view

Criterion for per phase direction information	The value for DIR_A/_B/_C
The ANGLE_X is not in any of the defined sectors, or the direction cannot be defined due too low amplitude	0 = unknown
The ANGLE_X is in the forward sector	1 = forward
The ANGLE_X is in the reverse sector	2 = backward
(The ANGLE_X is in both forward and reverse sectors, that is, when the sectors are overlapping)	3 = both

Table 338: Momentary phase combined direction value for monitored data view

Criterion for phase combined direction information	The value for DIRECTION
The direction information (DIR_X) for all phases is unknown	0 = unknown
The direction information (DIR_X) for at least one phase is forward, none being in reverse	1 = forward
The direction information (DIR_X) for at least one phase is reverse, none being in forward	2 = backward
The direction information (DIR_X) for some phase is forward and for some phase is reverse	3 = both

FAULT_DIR gives the detected direction of the fault during fault situations, that is, when the START output is active.

Self-polarizing as polarizing method

Table 339: Equations for calculating angle difference for self-polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{U}_A$	$ANGLE\_A = \varphi(\underline{U}_A) - \varphi(\underline{I}_A) - \varphi_{RCA}$
B	$\underline{I}_B$	$\underline{U}_B$	$ANGLE\_B = \varphi(\underline{U}_B) - \varphi(\underline{I}_B) - \varphi_{RCA}$
C	$\underline{I}_C$	$\underline{U}_C$	$ANGLE\_C = \varphi(\underline{U}_C) - \varphi(\underline{I}_C) - \varphi_{RCA}$
A - B	$\underline{I}_A - \underline{I}_B$	$\underline{U}_{AB}$	$ANGLE\_A = \varphi(\underline{U}_{AB}) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA}$
B - C	$\underline{I}_B - \underline{I}_C$	$\underline{U}_{BC}$	$ANGLE\_B = \varphi(\underline{U}_{BC}) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA}$
C - A	$\underline{I}_C - \underline{I}_A$	$\underline{U}_{CA}$	$ANGLE\_C = \varphi(\underline{U}_{CA}) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA}$

In an example case of the phasors in a single-phase earth fault where the faulted phase is phase A, the angle difference between the polarizing quantity U_A and operating quantity I_A is marked as φ. In the self-polarization method, there is no need to rotate the polarizing quantity.

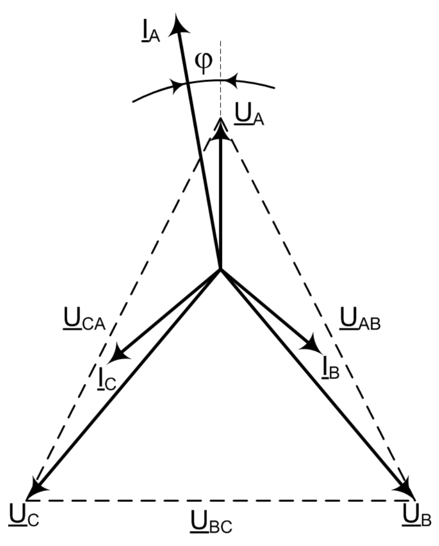


Figure 156: Single-phase earth fault, phase A

In an example case of a two-phase short-circuit failure where the fault is between phases B and C, the angle difference is measured between the polarizing quantity U_{BC} and operating quantity $\underline{I}_B$ - $\underline{I}_C$ in the self-polarizing method.

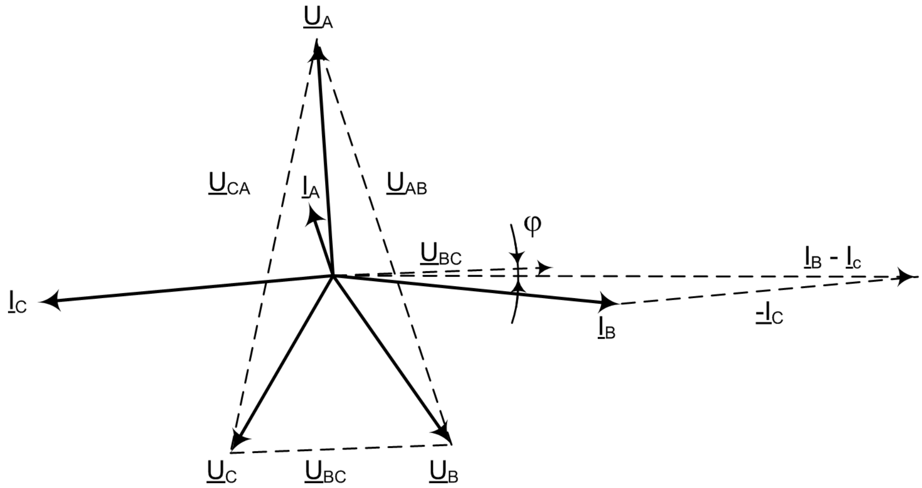


Figure 157: Two-phase short circuit, short circuit is between phases B and C

Cross-polarizing as polarizing quantity

Table 340: Equations for calculating angle difference for cross-polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{U}_{BC}$	$ANGLE\_A = \varphi(\underline{U}_{BC}) - \varphi(\underline{I}_A) - \varphi_{RCA} + 90^o$
B	$\underline{I}_B$	$\underline{U}_{CA}$	$ANGLE\_B = \varphi(\underline{U}_{CA}) - \varphi(\underline{I}_B) - \varphi_{RCA} + 90^o$
C	$\underline{I}_C$	$\underline{U}_{AB}$	$ANGLE\_C = \varphi(\underline{U}_{AB}) - \varphi(\underline{I}_C) - \varphi_{RCA} + 90^o$
A - B	$\underline{I}_A$ - $\underline{I}_B$	$\underline{U}_{BC}$ - $\underline{U}_{CA}$	$ANGLE\_A = \varphi(\underline{U}_{BC} - \underline{U}_{CA}) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA} + 90^o$
B - C	$\underline{I}_B$ - $\underline{I}_C$	$\underline{U}_{CA}$ - $\underline{U}_{AB}$	$ANGLE\_B = \varphi(\underline{U}_{CA} - \underline{U}_{AB}) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA} + 90^o$
C - A	$\underline{I}_C$ - $\underline{I}_A$	$\underline{U}_{AB}$ - $\underline{U}_{BC}$	$ANGLE\_C = \varphi(\underline{U}_{AB} - \underline{U}_{BC}) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 90^o$

The angle difference between the polarizing quantity U_{BC} and operating quantity I_A is marked as φ in an example of the phasors in a single-phase earth fault where the faulted phase is phase A. The polarizing quantity is rotated with 90 degrees. The characteristic angle is assumed to be ~ 0 degrees.

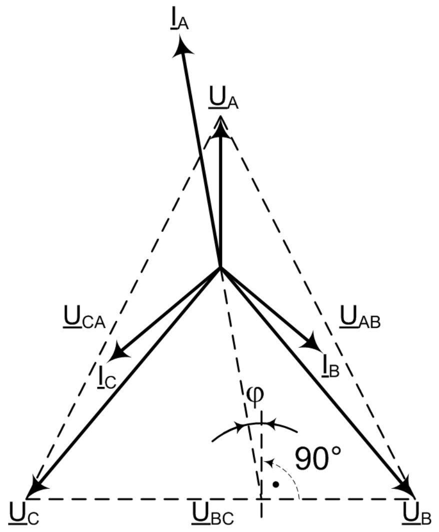


Figure 158: Single-phase earth fault, phase A

In an example of the phasors in a two-phase short-circuit failure where the fault is between the phases B and C, the angle difference is measured between the polarizing quantity $\underline{U}_{AB}$ and operating quantity $\underline{I}_B$ - $\underline{I}_C$ marked as φ.

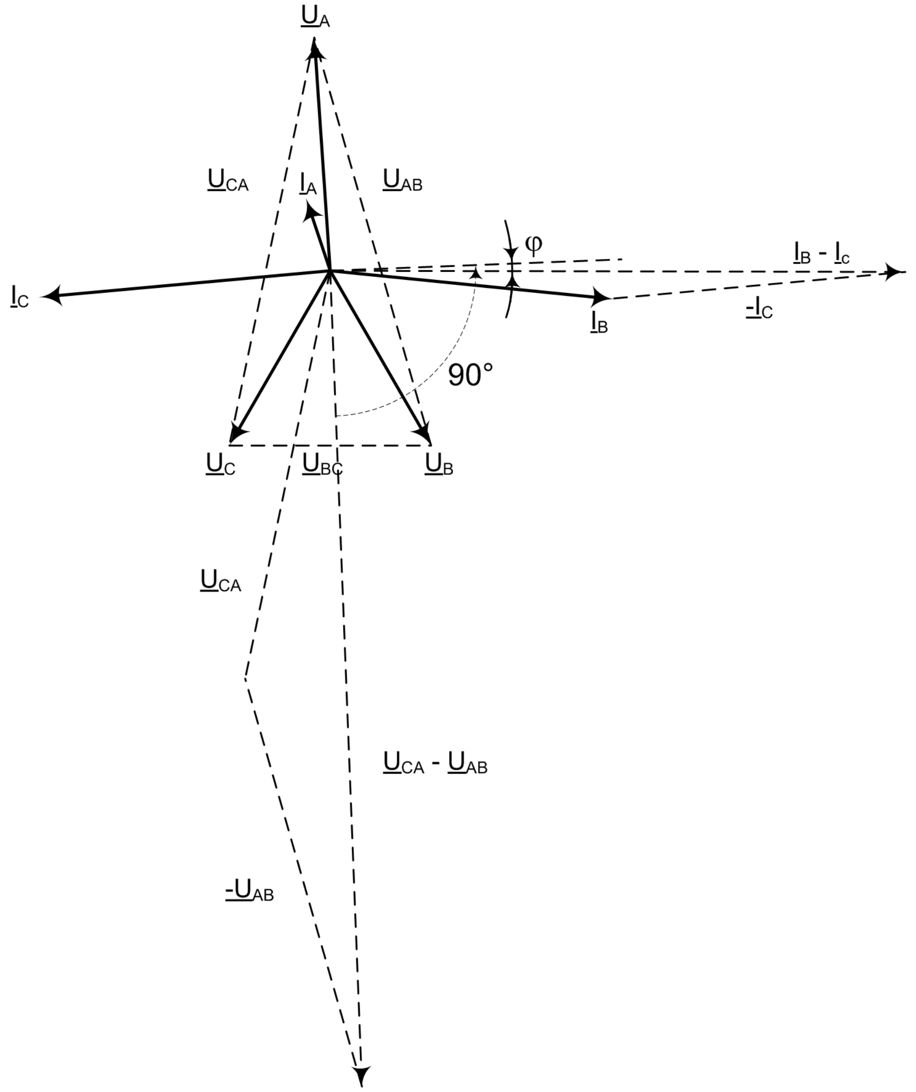


Figure 159: Two-phase short circuit, short circuit is between phases B and C

The equations are valid when network rotating direction is counter-clockwise, that is, ABC. If the network rotating direction is reversed, 180 degrees is added to the calculated angle difference. This is done automatically with a system parameter *Phase rotation*.

Negative sequence voltage as polarizing quantity

When the negative voltage is used as the polarizing quantity, the angle difference between the operating and polarizing quantity is calculated with the same formula for all fault types:

$$ANGLE\_X = \varphi(-\underline{U}_2) - \varphi(\underline{I}_2) - \varphi_{RCA}$$

(Equation 12)

This means that the actuating polarizing quantity is -$\underline{U}_2$.

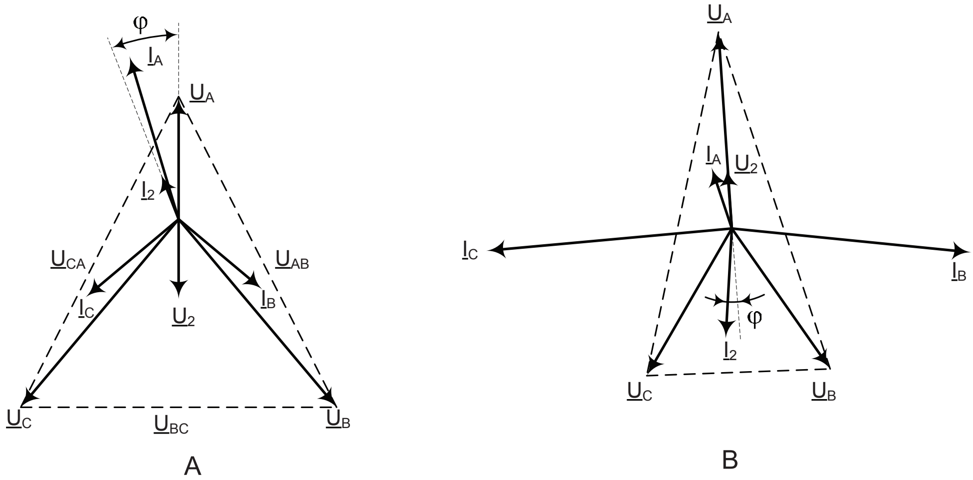


Figure 160: Phasors in a single-phase earth fault, phases A-N, and two-phase short circuit, phases B and C, when the actuating polarizing quantity is the negative-sequence voltage -U2

Positive sequence voltage as polarizing quantity

Table 341: Equations for calculating angle difference for positive-sequence quantity polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{U}_1$	$ANGLE\_A = \varphi(\underline{U}_1) - \varphi(\underline{I}_A) - \varphi_{RCA}$
B	$\underline{I}_B$	$\underline{U}_1$	$ANGLE\_B = \varphi(\underline{U}_1) - \varphi(\underline{I}_B) - \varphi_{RCA} - 120^\circ$
C	$\underline{I}_C$	$\underline{U}_1$	$ANGLE\_C = \varphi(\underline{U}_1) - \varphi(\underline{I}_C) - \varphi_{RCA} + 120^\circ$
A - B	$\underline{I}_A$ - $\underline{I}_B$	$\underline{U}_1$	$ANGLE\_A = \varphi(\underline{U}_1) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA} + 30^\circ$
B - C	$\underline{I}_B$ - $\underline{I}_C$	$\underline{U}_1$	$ANGLE\_B = \varphi(\underline{U}_1) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA} - 90^\circ$
C - A	$\underline{I}_C$ - $\underline{I}_A$	$\underline{U}_1$	$ANGLE\_C = \varphi(\underline{U}_1) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 150^\circ$

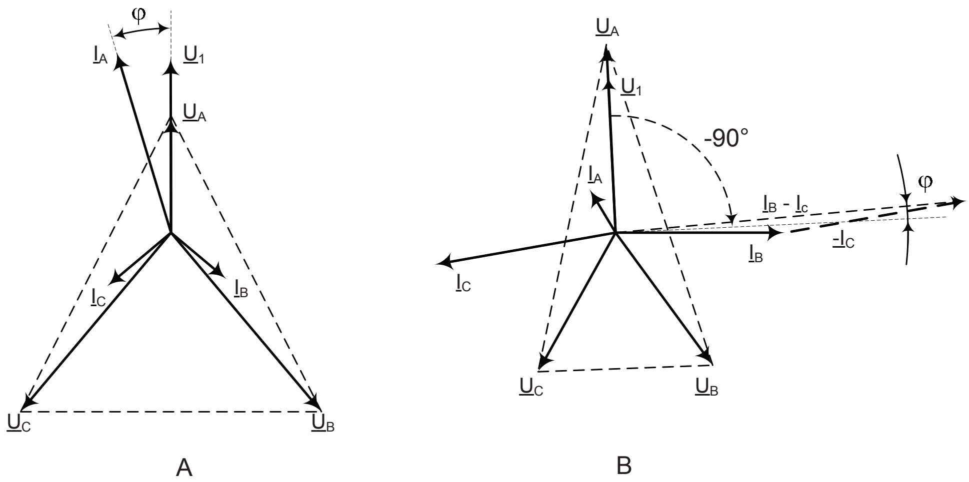


Figure 161: Phasors in a single-phase earth fault, phase A to ground, and a two-phase short circuit, phases B-C, are short-circuited when the polarizing quantity is the positive-sequence voltage U_1

Network rotation direction

Typically, the network rotating direction is counter-clockwise and defined as "ABC". If the network rotating direction is reversed, meaning clockwise, that is, "ACB", the equations for calculating the angle difference needs to be changed. The network rotating direction is defined with a system parameter *Phase rotation*. The change in the network rotating direction affects the phase-to-phase voltages polarization method where the calculated angle difference needs to be rotated 180 degrees. Also, when the sequence components are used, which are, the positive sequence voltage or negative sequence voltage components, the calculation of the components are affected but the angle difference calculation remains the same. When the phase-to-ground voltages are used as the polarizing method, the network rotating direction change has no effect on the direction calculation.

The network rotating direction is set in the IED using the parameter in the HMI menu: **Configuration/System/Phase rotation**. The default parameter value is "ABC".

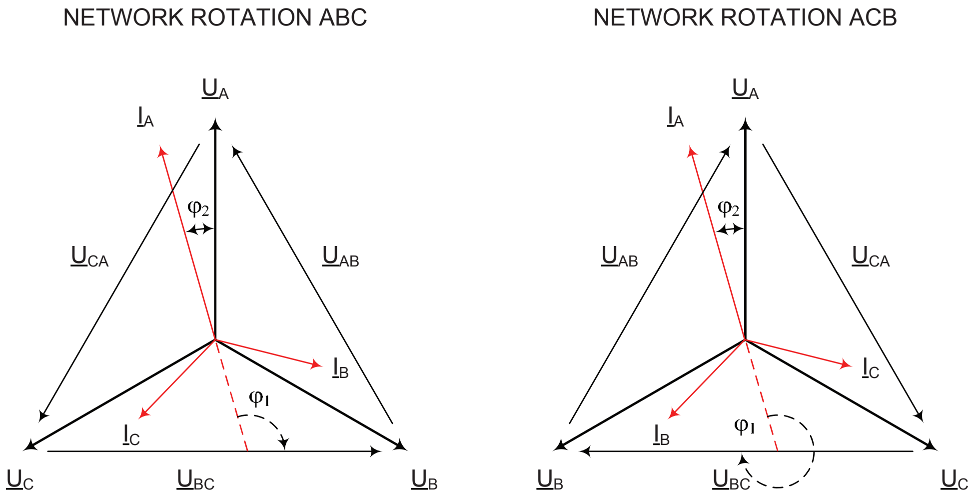


Figure 162: Examples of network rotating direction

4.1.2.8 Application

DPHxPDOC is used as short-circuit protection in three-phase distribution or sub transmission networks operating at 50 or 60 Hz.

In radial networks, phase overcurrent IEDs are often sufficient for the short circuit protection of lines, transformers and other equipment. The current-time characteristic should be chosen according to the common practice in the network. It is recommended to use the same current-time characteristic for all overcurrent IEDs in the network. This includes the overcurrent protection of transformers and other equipment.

The phase overcurrent protection can also be used in closed ring systems as short circuit protection. Because the setting of a phase overcurrent protection system in closed ring networks can be complicated, a large number of fault current calculations are needed. There are situations with no possibility to have the selectivity with a protection system based on overcurrent IEDs in a closed ring system.

In some applications, the possibility of obtaining the selectivity can be improved significantly if DPHxPDOC is used. This can also be done in the closed ring networks and radial networks with the generation connected to the remote in the system thus giving fault current infeed in reverse direction. Directional overcurrent IEDs are also used to have a selective protection scheme, for example in case of parallel distribution lines or power transformers fed by the same single source. In ring connected supply feeders between substations or feeders with two feeding sources, DPHxPDOC is also used.

Parallel lines or transformers

When the lines are connected in parallel and if a fault occurs in one of the lines, it is practical to have DPHxPDOC to detect the direction of the fault. Otherwise, there is a risk that the fault situation in one part of the feeding system can de-energize the whole system connected to the LV side.

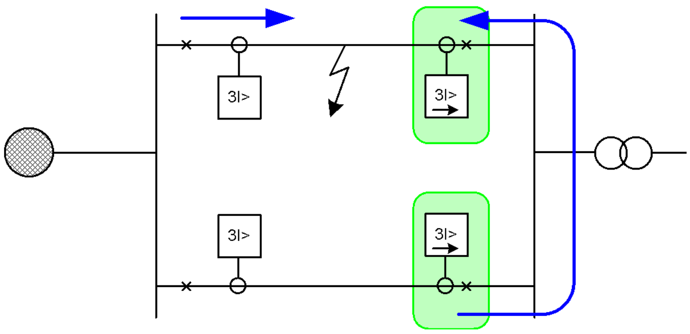


Figure 163: Overcurrent protection of parallel lines using directional IEDs

DPHxPDOC can be used for parallel operating transformer applications. In these applications, there is a possibility that the fault current can also be fed from the LV-side up to the HV-side. Therefore, the transformer is also equipped with directional overcurrent protection.

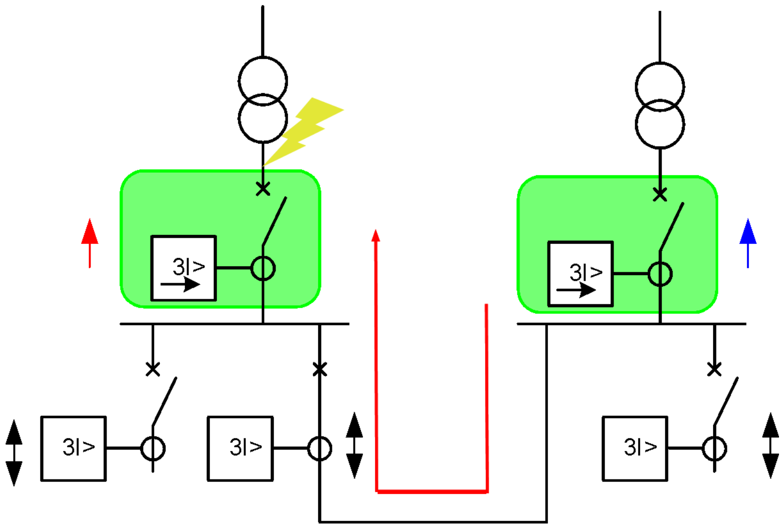


Figure 164: Overcurrent protection of parallel operating transformers

Closed ring network topology

The closed ring network topology is used in applications where electricity distribution for the consumers is secured during network fault situations. The power is fed at least from two directions which means that the current direction can be varied. The time grading between the network level stages is challenging without unnecessary delays in the time settings. In this case, it is practical to use the directional overcurrent IEDs to achieve a selective protection scheme. Directional overcurrent functions can be used in closed ring applications. The arrows define the operating direction of the directional functionality. The double arrows define the non-directional functionality where faults can be detected in both directions.

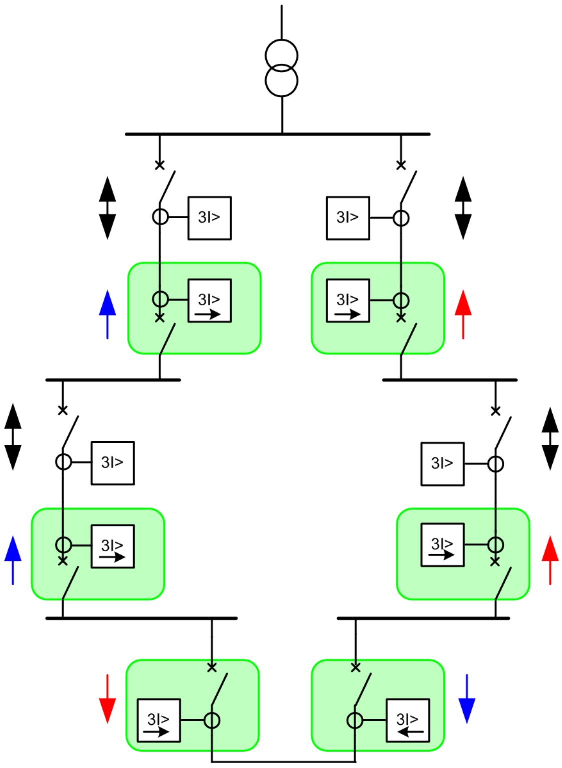


Figure 165: Closed ring network topology where feeding lines are protected with directional overcurrent IEDs

4.1.2.9 Signals

Table 342: DPHLPDOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	3-phase current group
U3P	GROUP SIGNAL	-	3-phase voltage group
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 343: DPHHPDOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	3-phase current group
U3P	GROUP SIGNAL	-	3-phase voltage group
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 344: DPHLPDOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
OPR_A	BOOLEAN	Operated phase A
OPR_B	BOOLEAN	Operated phase B
OPR_C	BOOLEAN	Operated phase C
START	BOOLEAN	Started signal
ST_A	BOOLEAN	Started phase A
ST_B	BOOLEAN	Started phase B
ST_C	BOOLEAN	Started phase C
FAULT_DIR	INTEGER	Detected fault direction, general
FLT_DIR_A	INTEGER	Detected fault direction, phase A
FLT_DIR_B	INTEGER	Detected fault direction, phase B
FLT_DIR_C	INTEGER	Detected fault direction, phase C

Table 345: DPHHPDOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
OPR_A	BOOLEAN	Operated phase A
OPR_B	BOOLEAN	Operated phase B
OPR_C	BOOLEAN	Operated phase C
START	BOOLEAN	Started signal
ST_A	BOOLEAN	Started phase A
ST_B	BOOLEAN	Started phase B
ST_C	BOOLEAN	Started phase C
FAULT_DIR	INTEGER	Detected fault direction, general
FLT_DIR_A	INTEGER	Detected fault direction, phase A
FLT_DIR_B	INTEGER	Detected fault direction, phase B
FLT_DIR_C	INTEGER	Detected fault direction, phase C

4.1.2.10 Settings

Table 346: DPHLPDOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Directional mode	Non-directional Forward Reverse	-	-	Forward	Directional mode
Start value	0.05 - 5.00	pu	0.01	0.05	Start value
Characteristic angle	-179 - 180	Deg	1	0	Characteristic angle
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC/ANSI curves
Operating curve type	ANSI Ext. inv. ANSI Very inv. ANSI Norm. inv. ANSI Mod. inv. ANSI Def. Time L.T.E. inv. L.T.V. inv. L.T. inv. IEC Norm. inv. IEC Very inv. IEC inv. IEC Ext. inv. IEC S.T. inv. IEC L.T. inv. IEC Def. Time Programmable RI type RD type	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.04 - 200.00	s	0.01	0.04	Operate delay time

Table 347: DPHLPDOC Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Pol quantity	Pos. seq. volt. Self pol Neg. seq. volt. Cross Pol	-	-	Cross Pol	Reference quantity used to determine fault direction
Max forward angle	45 - 135	Deg	5	90	Maximum phase angle in forward direction
Min forward angle	45 - 135	Deg	5	90	Minimum phase angle in forward direction
Max reverse angle	45 - 135	Deg	5	90	Maximum phase angle in reverse direction
Min reverse angle	45 - 135	Deg	5	90	Minimum phase angle in reverse direction
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type

Table 348: *DPHLPDOC Non group settings (basic)*

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Num of start phases	1 out of 3 2 out of 3 3 out of 3	-	-	1 out of 3	Number of phases required for operate activation

Table 349: *DPHLPDOC Non group settings (advanced)*

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Selects used current measurement mode
Min operate current	0.01 - 1.00	pu	0.01	0.01	Minimum operating current to allow directional criteria
Min operate voltage	0.01 - 1.00	pu	0.01	0.01	Minimum operating voltage to allow directional criteria
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time
Minimum operate time	0.040 - 60.000	s	0.001	0.040	Minimum operate time for IDMT curves
Voltage Mem time	0 - 3000	ms	1	40	Voltage memory time
Allow Non Dir	Not allowed Allowed	-	-	Not allowed	Allows prot activation as non-dir when dir info is invalid

Table 350: *DPHHPDOC Group settings (basic)*

Name	Values (Range)	Unit	Step	Default	Description
Directional mode	Non-directional Forward Reverse	-	-	Forward	Directional mode
Start value	0.10 - 40.00	pu	0.01	0.10	Start value
Characteristic angle	-179 - 180	Deg	1	0	Characteristic angle
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC/ANSI curves
Operating curve type	ANSI Ext. inv. ANSI Norm. inv. ANSI Def. Time IEC Norm. inv. IEC Very inv. IEC Ext. inv. IEC Def. Time Programmable	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.04 - 200.00	s	0.01	0.04	Operate delay time

Table 351: DPHHPDOC Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Pol quantity	Pos. seq. volt. Self pol Neg. seq. volt. Cross Pol	-	-	Cross Pol	Reference quantity used to determine fault direction
Max forward angle	45 - 135	Deg	5	90	Maximum phase angle in forward direction
Min forward angle	45 - 135	Deg	5	90	Minimum phase angle in forward direction
Max reverse angle	45 - 135	Deg	5	90	Maximum phase angle in reverse direction
Min reverse angle	45 - 135	Deg	5	90	Minimum phase angle in reverse direction
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type

Table 352: DPHHPDOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Num of start phases	1 out of 3 2 out of 3 3 out of 3	-	-	1 out of 3	Number of phases required for operate activation

Table 353: DPHHPDOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Selects used current measurement mode
Min operate current	0.01 - 1.00	pu	0.01	0.01	Minimum operating current to allow directional criteria

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Min operate voltage	0.01 - 1.00	pu	0.01	0.01	Minimum operating voltage to allow directional criteria
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time
Minimum operate time	0.040 - 60.000	s	0.001	0.040	Minimum operate time for IDMT curves
Voltage Mem time	0 - 3000	ms	1	40	Voltage memory time
Allow Non Dir	Not allowed Allowed	-	-	Not allowed	Allows prot activation as non-dir when dir info is invalid

4.1.2.11 Measured values

Table 354: DPHLPDOC Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Current amplitude (DFT) phase A
I_AMPL_B	REAL	0	Current amplitude (DFT) phase B
I_AMPL_C	REAL	0	Current amplitude (DFT) phase C
I_ANGL_A	REAL	0	Current phase angle phase A
I_ANGL_B	REAL	0	Current phase angle phase B
I_ANGL_C	REAL	0	Current phase angle phase C
I_RMS_A	REAL	0	Current amptitude (RMS) phase A
I_RMS_B	REAL	0	Current amplitude (RMS) phase B
I_RMS_C	REAL	0	Current amplitude (RMS) phase C
I_PTOP_A	REAL	0	Current amplitude (PTOP) phase A
I_PTOP_B	REAL	0	Current amplitude (PTOP) phase B
I_PTOP_C	REAL	0	Current amplitude (PTOP) phase C
I2_AMPL	REAL	0	Negative phase sequence current amplitude
I2_ANGL	REAL	0	Negative phase sequence current angle
U_AMPL_A	REAL	0	Polarizing phase-to-ground voltage amplitude
U_AMPL_B	REAL	0	Polarizing phase-to-ground voltage amplitude
U_AMPL_C	REAL	0	Polarizing phase-to-ground voltage amplitude
U_ANGL_A	REAL	0	Polarizing phase-to-ground voltage phase angle
U_ANGL_B	REAL	0	Polarizing phase-toground voltage phase angle
U_ANGL_C	REAL	0	Polarizing phase-toground voltage phase angle
Table continues on next page			

Name	Type	Default	Description
U_AMPL_AB	REAL	0	Polarizing phase-to-phase voltage amplitude
U_AMPL_BC	REAL	0	Polarizing phase-to-phase voltage amplitude
U_AMPL_CA	REAL	0	Polarizing phase-to-phase voltage amplitude
U_ANGL_AB	REAL	0	Polarizing phase-to-phase voltage phase angle
U_ANGL_BC	REAL	0	Polarizing phase-to-phase voltage phase angle
U_ANGL_CA	REAL	0	Polarizing phase-to-phase voltage phase angle
U1_AMPL	REAL	0	Polarizing positive sequence voltage amplitude
U1_ANGL	REAL	0	Polarizing positive sequence voltage phase angle
U2_AMPL	REAL	0	Polarizing negative sequence voltage amplitude
U2_ANGL	REAL	0	Polarizing negative sequence voltage phase angle
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 355: DPHHPDOC Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Current amplitude (DFT) phase A
I_AMPL_B	REAL	0	Current amplitude (DFT) phase B
I_AMPL_C	REAL	0	Current amplitude (DFT) phase C
I_ANGL_A	REAL	0	Current phase angle phase A
I_ANGL_B	REAL	0	Current phase angle phase B
I_ANGL_C	REAL	0	Current phase angle phase C
I_RMS_A	REAL	0	Current amptitude (RMS) phase A
I_RMS_B	REAL	0	Current amplitude (RMS) phase B
I_RMS_C	REAL	0	Current amplitude (RMS) phase C
I_PTOP_A	REAL	0	Current amplitude (PTOP) phase A
I_PTOP_B	REAL	0	Current amplitude (PTOP) phase B
I_PTOP_C	REAL	0	Current amplitude (PTOP) phase C
I_PEAK_A	REAL	0	Current peak magnitude phase A
I_PEAK_B	REAL	0	Current peak magnitude phase B
I_PEAK_C	REAL	0	Current peak magnitude phase C
I2_AMPL	REAL	0	Negative phase sequence current amplitude
I2_ANGL	REAL	0	Negative phase sequence current angle
U_AMPL_A	REAL	0	Polarizing phase-to-ground voltage amplitude
U_AMPL_B	REAL	0	Polarizing phase-to-ground voltage amplitude
U_AMPL_C	REAL	0	Polarizing phase-to-ground voltage amplitude

Table continues on next page

Name	Type	Default	Description
U_ANGL_A	REAL	0	Polarizing phase-to-ground voltage phase angle
U_ANGL_B	REAL	0	Polarizing phase-toground voltage phase angle
U_ANGL_C	REAL	0	Polarizing phase-toground voltage phase angle
U_AMPL_AB	REAL	0	Polarizing phase-to-phase voltage amplitude
U_AMPL_BC	REAL	0	Polarizing phase-to-phase voltage amplitude
U_AMPL_CA	REAL	0	Polarizing phase-to-phase voltage amplitude
U_ANGL_AB	REAL	0	Polarizing phase-to-phase voltage phase angle
U_ANGL_BC	REAL	0	Polarizing phase-to-phase voltage phase angle
U_ANGL_CA	REAL	0	Polarizing phase-to-phase voltage phase angle
U1_AMPL	REAL	0	Polarizing positive sequence voltage amplitude
U1_ANGL	REAL	0	Polarizing positive sequence voltage phase angle
U2_AMPL	REAL	0	Polarizing negative sequence voltage amplitude
U2_ANGL	REAL	0	Polarizing negative sequence voltage phase angle
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

4.1.2.12 Monitored data

Table 356: DPHLPDOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase A
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase B
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase C
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Started phase A
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Started phase B
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Started phase C
FLT_DIR_A	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Detected fault direction, phase A
FLT_DIR_B	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Detected fault direction, phase B

Table continues on next page

Name	Type	Values (Range)	Unit	Description
FLT_DIR_C	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Detected fault direction, phase C
DIRECTION	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information, general
DIR_A	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information, phase A
DIR_B	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information, phase B
DIR_C	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information, phase C
ANGLE_A	REAL	-	deg	Calculated angle difference, phase A
ANGLE_B	REAL	-	deg	Calculated angle difference, phase B
ANGLE_C	REAL	-	deg	Calculated angle difference, phase C
START_DUR	REAL	-	%	Ratio of start time / operate time
INVAL_CRV	BOOLEAN	0=FALSE 1=TRUE	-	Invalid curve parameters

Table 357: DPHHPDOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase A
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase B
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase C
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Started phase A
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Started phase B
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Started phase C
FLT_DIR_A	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Detected fault direction, phase A

Table continues on next page

Name	Type	Values (Range)	Unit	Description
FLT_DIR_B	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Detected fault direction, phase B
FLT_DIR_C	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Detected fault direction, phase C
DIRECTION	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information, general
DIR_A	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information, phase A
DIR_B	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information, phase B
DIR_C	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information, phase C
ANGLE_A	REAL	-	deg	Calculated angle difference, phase A
ANGLE_B	REAL	-	deg	Calculated angle difference, phase B
ANGLE_C	REAL	-	deg	Calculated angle difference, phase C
START_DUR	REAL	-	%	Ratio of start time / operate time
INVAL_CRV	BOOLEAN	0=FALSE 1=TRUE	-	Invalid curve parameters

4.1.2.13 Technical data

Table 358: DPHxPDOC Technical data

Characteristic		Value
Operation accuracy		At the frequency f = f_n
	DPHLPDOC	Current: ±1.5% of the set value or ±0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n Phase angle: ±2°
	DPHHPDOC	Current: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n) Voltage: ±1.5% of the set value or ±0.002 × U_n Phase angle: ±2°
Start time1)2)	I_{Fault} = 2.0 × set *Start value*	Typically 24 ms (±15 ms)
Reset time		<40 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms3)
Suppression of harmonics		RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression P-to-P+backup: No suppression

1) *Measurement mode* = default (depends of stage), current before fault = 0.0 × I_n, f_n = 50 Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20

4.1.2.14 Technical revision history

Table 359: DPHHPDOC technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

Table 360: DPHLPDOC technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

4.1.3 Voltage-dependent overcurrent protection PHPVOC

4.1.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage-dependent overcurrent protection	PHPVOC	I(U)>	51V

4.1.3.2 Function block

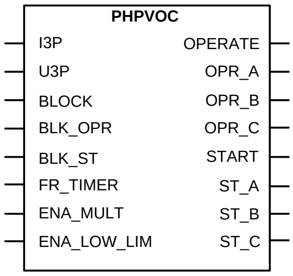


Figure 166: Function block

4.1.3.3 Functionality

The voltage-dependent overcurrent protection function PHPVOC is used for single-phase, two-phase or three-phase voltage-dependent time overcurrent protection of generators against overcurrent and short circuit conditions.

PHPVOC starts when the input phase current exceeds a limit which is dynamically calculated based on the measured terminal voltages. The operating characteristics can be selected to be either inverse definite minimum time IDMT or definite time DT.

PHPVOC contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHPVOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

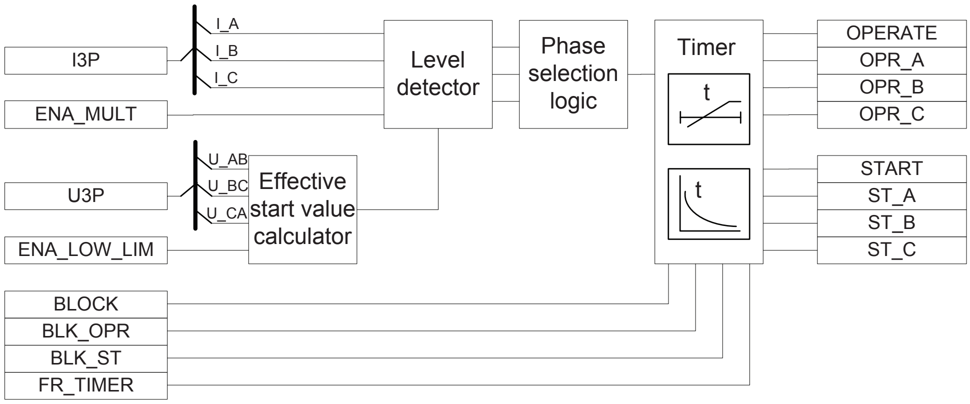


Figure 167: Functional module diagram

Effective start value calculator

The normal starting current above which the overcurrent protection starts is set through the *Start value* setting. The effective start value of the current may need to be changed during certain conditions like magnetizing inrush or when the terminal voltages drop due to a fault. Hence, the effective start value calculator module dynamically calculates the effective start value above which the overcurrent protection starts.

Four methods of calculating the effective start value are provided in PHPVOC. These can be chosen with the *Control mode* setting to be either "Voltage control", "Input control", "Volt & Input Ctrl" or "No Volt dependency" mode.

The calculated effective start value per phase, `EFF_ST_VAL_A`, `EFF_ST_VAL_B`, `EFF_ST_VAL_C`, is available in the monitored data view and is used by the level detector module.

All three phase-to-phase voltages should be available for the function to operate properly.

Voltage control mode

In the voltage control mode, the effective start value is calculated based on the magnitude of input voltages `U_AB`, `U_BC` and `U_CA`. The voltage dependency is phase sensitive, which means that the magnitude of one input voltage controls the start value of only the corresponding phase, that is, the magnitude of voltage inputs `U_AB`, `U_BC` and `U_CA` independently control the current start values of phases A, B and C respectively.

Two voltage control characteristics, voltage step and voltage slope, can be achieved with the *Voltage high limit* and *Voltage low limit* settings.

The voltage step characteristic is achieved with the *Voltage high limit* setting being equal to the *Voltage low limit* setting. The effective start value is calculated based on the equations.

If U < *Voltage high limit*:
Effective start value = *Start value low*

(Equation 13)

If U ≥ *Voltage high limit*:
Effective start value = *Start value*

(Equation 14)

Here U represents the measured input voltage. This voltage step characteristic is graphically represented.

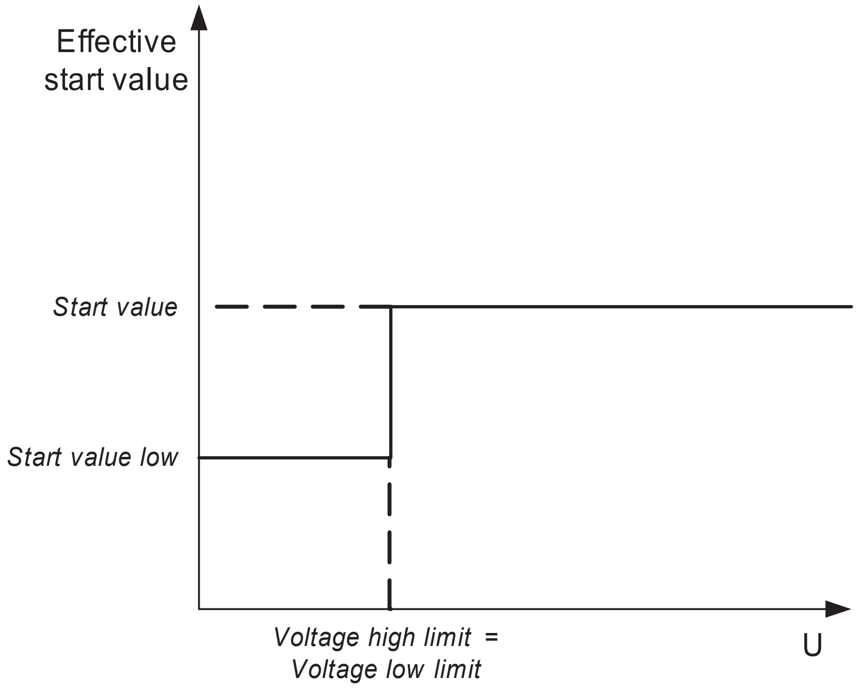


Figure 168: Effective start value for voltage step characteristic

The voltage slope characteristic is achieved by assigning different values to *Voltage high limit* and *Voltage low limit*. The effective start value calculation is based on the equations.

If U < *Voltage low limit*:
Effective start value = *Start value low*

(Equation 15)

If *Voltage low limit* ≤ U < *Voltage high limit*:

$$\text{Effective start value} = \text{Start value} - \left[\left(\frac{\text{Start value} - \text{Start value low}}{\text{Voltage high limit} - \text{Voltage low limit}}\right) \times (\text{Voltage high limit} - U)\right]$$

(Equation 16)

If U ≥ *Voltage high limit*:

Effective start value = *Start value*

(Equation 17)

Here U represents the measured input voltage. The voltage slope characteristic is graphically represented.

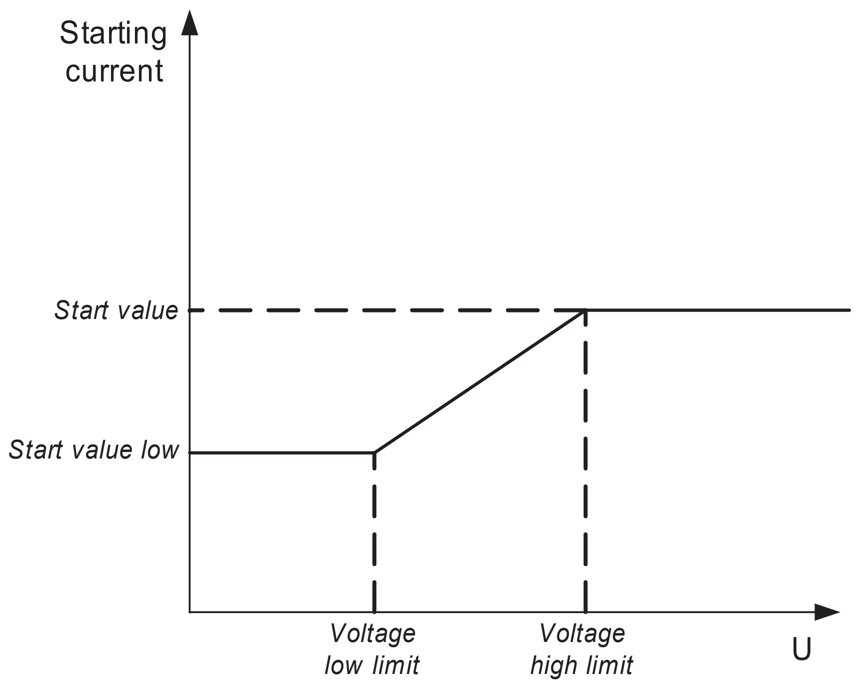


Figure 169: Effective start value or voltage slope characteristic

To achieve the voltage slope characteristics, *Voltage high limit* must always be set to a value greater than *Voltage low limit*.
If *Voltage high limit* is lesser than *Voltage low limit*,the voltage step characteristic is active with *Voltage low limit* being the cutoff value.

The value of the setting *Start value* should always be greater than the setting *Start value low*. Otherwise, *Start value low* is used as the effective start value.

External input control mode

The external input control mode is used to enable voltage control from an external application. If *Control mode* is set to the "Input Control" mode, the effective start value for all phases is influenced by the status of the binary input ENA_LOW_LIM.

$$\begin{aligned}&\text{If } ENA\_LOW\_LIM \text{ is } TRUE:\\&\text{Effective start value} = \text{Start value low}\end{aligned}$$

(Equation 18)

$$\begin{aligned}&\text{If } ENA\_LOW\_LIM \text{ is } FALSE:\\&\text{Effective start value} = \text{Start value}\end{aligned}$$

(Equation 19)

Voltage and input control mode

If *Control mode* is set to "Voltage and input Ctrl", both the "Voltage control" and "Input control" modes are used. However, the input control functionality is dominant over the voltage control mode when ENA_LOW_LIM is active.

No voltage dependency mode

When *Control mode* is set to "No Volt dependency", the effective start value has no voltage dependency and the function acts as a normal time overcurrent function with effective start value being equal to the *Start value* setting.

Level detector

The measured phase currents are compared phasewise to the calculated effective start value. If the measured value exceeds the calculated effective start value, the level detector reports the exceeding value to the phase selection logic. If the ENA_MULT input is active, the effective start value is multiplied by the *Start value Mult* setting.

Do not set the multiplier *Start value Mult* setting higher than necessary. If the value is too high, the function may not operate at all during an inrush followed by a fault, no matter how severe the fault is.

The start value multiplication is normally done when the inrush detection function INRPHAR is connected to the ENA_MULT input.

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of start phases* setting, the phase selection logic activates the timer module.

Timer

Once activated, the Timer module activates the START output. The output signals ST_A, ST_B and ST_C are used to indicate which of the phases are started.

Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated. The outputs OPR_A, OPR_B and OPR_C are used to indicate which of the phases are operated.

When the user programmable IDMT curve is selected, the operation time characteristics are defined by the settings *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operating delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The *Time multiplier* is used for scaling the IDMT operate and reset times.

The *Minimum operate time* setting defines the minimum desired operating time for IDMT operation. The setting is applicable only when the IDMT curves are used.

Though the *Time multiplier* and *Minimum operate time* settings are common for different IDMT curves, the operating time essentially depends upon the type of IDMT curve chosen.

The timer calculates the start duration value START_DUR which indicates the percentage ratio of the start situation and the set operating time. This output is available in the monitored data view.

The binary input BLOCK is used to completely block the module. Activating the BLOCK input deactivates all binary outputs and resets the internal timers. The binary input BLK_ST is used to block the activation of the START signal. The binary input BLK_OPR is used to block the OPERATE signal. The operation timer counting can be frozen on the prevailing value by activation of the FR_TIMER input.

4.1.3.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.1.3.6 Application

The voltage-dependent overcurrent protection is used as a backup protection for the generators and system from damage due to the phase faults which are not cleared by primary protection and associated breakers.

In case of a short circuit, the sustained fault current of the generator, determined by the machine synchronous reactance, could be well below the full-load current. Also, if the generator excitation power is fed from the generator terminals, a voltage drop due to a short circuit also leads to low fault current. Hence, the primary protection, like normal overcurrent protection, might not detect this kind of fault situation. In some cases, the automatic voltage regulator AVR can help maintain high fault currents by controlling the generator excitation system. But if the AVR is out of service or if there is an internal fault in the operation of AVR, the low fault currents can go unnoticed and therefore a voltage-depended overcurrent protection should be used for backup.

Two voltage control characteristics, voltage step and voltage slope, are available in PHPVOC. The choice is made based on the system conditions and the level of protection to be provided.

The voltage step characteristic is applied to generators used in industrial systems. Under closeup fault conditions when the generator terminal voltages drop below the settable threshold value, a new start value of the current well below the normal load current is selected. The control voltage setting should be such that PHPVOC does not trip under the highest loading conditions to which the system can be subjected. Choosing too high a value for the control voltage may allow an undesired operation of the function during wide-area disturbances. When the terminal voltage of the generator is above the control voltage value, normal start value is used. This ensures that PHPVOC does not operate during normal overloads when the generator terminal voltages are maintained near the normal levels.

Voltage slope characteristic is often used as an alternative to impedance protection on small to medium (5-150 MVA) size generators to provide backup to the differential protection. Other applications of the voltage slope characteristic protection exist in networks to provide better coordination and fault detection than plain overcurrent protection. The voltage slope method provides an improved sensitivity of overcurrent operation by making the overcurrent start value proportional to the terminal voltage. The current start value varies correspondingly with the generator terminal voltages between the set voltage high limit and voltage low limit, thus ensuring the operation of PHPVOC despite of the drop in fault current value.

The operation of PHPVOC should be time-graded with respect to the main protection scheme to ensure that PHPVOC does not operate before the main protection.

4.1.3.7 Signals

Table 361: PHPVOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
U3P	GROUP SIGNAL	-	Group signal for voltage inputs
BLOCK	BOOLEAN	0	Block all binary outputs by resetting timers
BLK_ST	BOOLEAN	0	Block start outputs
BLK_OPR	BOOLEAN	0	Block operate outputs
FR_TIMER	BOOLEAN	0	Freeze internal operate timer count
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier
ENA_LOW_LIM	BOOLEAN	0	Enable signal for voltage dependent lower start value

Table 362: PHPVOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
OPR_A	BOOLEAN	Operate signal for phase A
OPR_B	BOOLEAN	Operate signal for phase B
OPR_C	BOOLEAN	Operate signal for phase C
START	BOOLEAN	Started
ST_A	BOOLEAN	Start signal for phase A
ST_B	BOOLEAN	Start signal for phase B
ST_C	BOOLEAN	Start signal for phase C

4.1.3.8 Settings

Table 363: PHPVOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.05 - 5.00	pu	0.01	0.05	Start value
Start value low	0.05 - 1.00	pu	0.01	0.05	Lower start value based on voltage control
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Voltage high limit	0.01 - 1.00	pu	0.01	1.00	Voltage high limit for voltage control
Voltage low limit	0.01 - 1.00	pu	0.01	1.00	Voltage low limit for voltage control
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC / ANSI curves
Operating curve type	ANSI Ext. inv. ANSI Very inv. ANSI Norm. inv. ANSI Mod. inv. ANSI Def. Time L.T.E. inv. L.T.V. inv. L.T. inv. IEC Norm. inv. IEC Very inv. IEC inv. IEC Ext. inv. IEC S.T. inv. IEC L.T. inv. IEC Def. Time Programmable RI type RD type	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.04 - 200.00	s	0.01	0.04	Operate delay time

Table 364: PHPVOC Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type

Table 365: PHPVOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On
Num of start phases	1 out of 3 2 out of 3 3 out of 3	-	-	1 out of 3	Number of phases required for operate activation

Table 366: PHPVOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Current measurement mode
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Control mode	Voltage control Input control Voltage & Input Ctrl No Volt dependency	-	-	Voltage control	Type of control
Reset delay time	0.00 - 60.00	s	0.01	0.02	Reset delay time
Minimum operate time	0.04 - 60.00	s	0.01	0.04	Minimum operate time for IDMT curves

4.1.3.9 Measured values

Table 367: PHPVOC Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0.0	Current amptitude (DFT) phase 1
I_AMPL_B	REAL	0.0	Current amptitude (DFT) phase 2
I_AMPL_C	REAL	0.0	Current amptitude (DFT) phase 3
I_RMS_A	REAL	0.0	Current amptitude (RMS) phase 1
I_RMS_B	REAL	0.0	Current amptitude (RMS) phase 2
I_RMS_C	REAL	0.0	Current amptitude (RMS) phase 3
I_PTOP_A	REAL	0.0	Current amptitude (PTOP) phase 1
I_PTOP_B	REAL	0.0	Current amptitude (PTOP) phase 2
I_PTOP_C	REAL	0.0	Current amptitude (PTOP) phase 3
U_AMPL_AB	REAL	0.0	Voltage amplitude (DFT) phase to phase AB
U_AMPL_BC	REAL	0.0	Voltage amplitude (DFT) phase to phase BC
U_AMPL_CA	REAL	0.0	Voltage amplitude (DFT) phase to phase CA
BLOCK	BOOLEAN	0	Block all binary outputs by resetting timers
BLK_ST	BOOLEAN	0	Block start outputs
BLK_OPR	BOOLEAN	0	Block operate outputs
Table continues on next page			

Name	Type	Default	Description
FR_TIMER	BOOLEAN	0	Freeze internal operate timer count
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier
ENA_LOW_LIM	BOOLEAN	0	Enable signal for voltage dependent lower start value

4.1.3.10 Monitored data

Table 368: PHPVOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for phase A
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for phase B
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for phase C
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for phase A
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for phase B
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for phase C
EFF_ST_VAL_A	REAL	-	A	Effective start value for phase A
EFF_ST_VAL_B	REAL	-	A	Effective start value for phase B
EFF_ST_VAL_C	REAL	-	A	Effective start value for phase C
START_DUR	REAL	-	%	Start duration

4.1.3.11 Technical data

Table 369: PHPVOC Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	Current: ±1.5% of the set value or ±0.002 × I_n
	Voltage: ±1.5% of the set value or ±0.002 × U_n
Start time [1)2)]	Typically 20 ms (±10 ms)
Reset time	<45 ms
Reset ratio	Typically 0.96
Table continues on next page	

Characteristic	Value
Operate time accuracy in definite time mode	±1.0% of the set value of ±20 ms
Operate time accuracy in inverse time mode	±5.0% of the set value of ±20 ms
Suppression of harmonics	-50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Measurement mode = default, current before fault = 0.0 × I_n, f_n = 50 Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements.
2) Includes the delay of the signal output contact.

4.1.3.12 Technical revision history

Table 370: PHPVOC technical revision history

Technical revision	Change
B	Internal improvements

4.1.4 Three-phase thermal overload protection for overhead lines and cables T1PTTR

4.1.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase thermal overload protection for overhead lines and cables	T1PTTR	3Ith>	49F

4.1.4.2 Function block

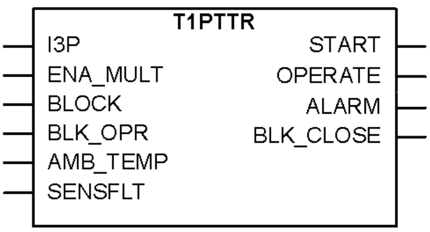


Figure 170: Function block

4.1.4.3 Functionality

The increased utilization of power systems closer to the thermal limits has generated a need for a thermal overload function also for power lines.

A thermal overload is in some cases not detected by other protection functions, and the introduction of the thermal overload function T1PTTR allows the protected circuit to operate closer to the thermal limits.

An alarm level gives an early warning to allow operators to take action before the line trips. The early warning is based on the three-phase current measuring function using a thermal model with first order thermal loss with the settable time constant. If the temperature rise continues the function will operate based on the thermal model of the line.

Re-energizing of the line after the thermal overload operation can be inhibited during the time the cooling of the line is in progress. The cooling of the line is estimated by the thermal model.

4.1.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of three-phase thermal protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

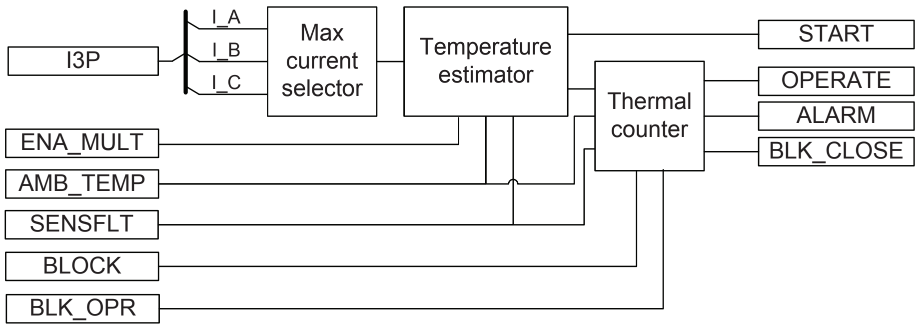


Figure 171: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Max current selector

The max current selector of the function continuously checks the highest measured TRMS phase current value. The selector reports the highest value to the temperature estimator.

Temperature estimator

The final temperature rise is calculated from the highest of the three-phase currents according to the expression:

$$\Theta_{final} = \left(\frac{I}{I_{ref}} \right)^2 \cdot T_{ref}$$

(Equation 20)

I	the largest phase current
I_{ref}	set *Current reference*
T_{ref}	set *Temperature rise*

The ambient temperature is added to the calculated final temperature rise estimation, and the ambient temperature value used in the calculation is also available in the monitored data as `TEMP_AMB` in degrees. If the final temperature estimation is larger than the set *Maximum temperature*, the `START` output is activated.

Current reference and *Temperature rise* setting values are used in the final temperature estimation together with the ambient temperature. It is suggested to set these values to the maximum steady state current allowed for the line or cable under emergency operation for a few hours per years. Current values with the corresponding conductor temperatures are given in cable manuals. These values are given for conditions such as ground temperatures, ambient air temperature, the way of cable laying and ground thermal resistivity.

Thermal counter

The actual temperature at the actual execution cycle is calculated as:

$$\Theta_n = \Theta_{n-1} + \left(\Theta_{final} - \Theta_{n-1}\right) \cdot \left(1 - e^{-\frac{\Delta t}{\tau}}\right)$$

(Equation 21)

Θ_n	calculated present temperature
Θ_{n-1}	calculated temperature at previous time step
Θ_{final}	calculated final temperature with actual current
Δt	time step between calculation of actual temperature
τ	thermal time constant for the protected device (line or cable), set *Time constant*

The actual temperature of the protected component (line or cable) is calculated by adding the ambient temperature to the calculated temperature, as shown above. The ambient temperature can be given a constant value. The calculated component temperature can be monitored as it is exported from the function as a real figure.

When the component temperature reaches the set alarm level *Alarm value*, the output signal `ALARM` is set. When the component temperature reaches the set trip level *Maximum temperature*, the `OPERATE` output is activated. The `OPERATE` signal pulse length is fixed to 100 ms

There is also a calculation of the present time to operation with the present current. This is only calculated if the final temperature is calculated to be above the operation temperature. The value is available in the monitored data view as T_OPERATE in minutes.

$$t_{operate} = -\tau \cdot \ln\left(\frac{\Theta_{final} - \Theta_{operate}}{\Theta_{final} - \Theta_{n}}\right)$$

(Equation 22)

Caused by the thermal overload protection function, there can be a lockout to reconnect the tripped circuit after operating. The lockout output BLK_CLOSE is activated at the same time when the OPERATE output is activated and is not reset until the device temperature has cooled down below the set value of the *Reclose temperature* setting. The time to lockout release T_ENA_CLOSE is also calculated and is available in the monitored data view in minutes. The *Maximum temperature* value must be set at least two degrees above the set value of *Reclose temperature*.

The time to lockout release is calculated, that is, the calculation of the cooling time to a set value. The calculated temperature can be reset to its initial value (the *Initial temperature* setting) via a control parameter that is located under the clear menu. This is useful during testing when secondary injected current has given a calculated false temperature level.

$$t_{lockout\_release} = -\tau \cdot \ln\left(\frac{\Theta_{final} - \Theta_{lockout\_release}}{\Theta_{final} - \Theta_{n}}\right)$$

(Equation 23)

Here the final temperature is equal to the set or measured ambient temperature.

In some applications, the measured current can involve a number of parallel lines. This is often used for cable lines where one bay connects several parallel cables. By setting the *Current multiplier* parameter to the number of parallel lines (cables), the actual current on one line is used in the protection algorithm. To activate this option, the ENA_MULT input must be activated.

The validity of operation of the RTD sensor is obtained from the SENFLT input. In case of any errors or malfunctioning in the RTD output, T1PTTR takes the temperature value from the *Env temperature Set* setting.

By setting the *Sensor available* setting to “Yes,” the external sensor is enabled to measure the ambient temperature. When *Sensor available* is set to “No,” the *Env temperature Set* setting is used to define the ambient temperature.

The temperature calculation is initiated from the value defined with the *Initial temperature* setting parameter. This is done in case the IED is powered up, the function is turned "Off" and back "On" or reset through the Clear menu. The temperature is also stored in the nonvolatile memory and restored in case the IED is restarted.

The thermal time constant of the protected circuit is given in minutes with the *Time constant* setting. Please see cable manufacturers manuals for further details.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_OPR can be used to block the operate signals.

4.1.4.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.1.4.6 Application

The lines and cables in the power system are constructed for a certain maximum load current level. If the current exceeds this level, the losses will be higher than expected. As a consequence, the temperature of the conductors will increase. If the temperature of the lines and cables reaches too high values, it can cause a risk of damages by, for example, the following ways:

- The sag of overhead lines can reach an unacceptable value.
- If the temperature of conductors, for example aluminium conductors, becomes too high, the material will be destroyed.
- In cables the insulation can be damaged as a consequence of overtemperature, and therefore phase-to-phase or phase-to-earth faults can occur.

In stressed situations in the power system, the lines and cables may be required to be overloaded for a limited time. This should be done without any risk for the above-mentioned risks.

The thermal overload protection provides information that makes temporary overloading of cables and lines possible. The thermal overload protection estimates the conductor temperature continuously. This estimation is made by using a thermal model of the line/cable that is based on the current measurement.

If the temperature of the protected object reaches a set warning level, a signal is given to the operator. This enables actions in the power system to be done before dangerous temperatures are reached. If the temperature continues to increase to the maximum allowed temperature value, the protection initiates a trip of the protected line.

4.1.4.7 Signals

Table 371: T1PTTR Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
AMB_TEMP	REAL	0	Ambient temperature from external temperature sensor
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Block of operate output
ENA_MULT	BOOLEAN	0	Enable current multiplier
SENSFLT	BOOLEAN	0	Validity status of ambient temperature sensor
RESET	BOOLEAN	0	Reset of internal thermal load counter

Table 372: T1PTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal
START	BOOLEAN	Start Signal
ALARM	BOOLEAN	Alarm signal
BLK_CLOSE	BOOLEAN	Thermal overload indicator. To inhibit reclose

4.1.4.8 Settings

Table 373: T1PTTR Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Alarm value	20.0 - 150.0	Deg	0.1	80.0	Temperature level for start (alarm)
Env temperature Set	-50 - 100	Deg	1	40	Ambient temperature used when Sensor available is set to Off
Maximum temperature	20.0 - 200.0	Deg	0.1	90.0	Temperature level for operate
Reclose temperature	20.0 - 150.0	Deg	0.1	70.0	Temperature for reset of block reclose after operate
Temperature rise	0.0 - 200.0	Deg	0.1	75.0	End temperature rise above ambient
Time constant	1 - 1000	Min	1	45	Time constant of the line in minutes.

Table 374: T1PTTR Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Current reference	0.05 - 4.00	pu	0.01	1.00	The load current leading to Temperature raise temperature
Current multiplier	1 - 5	-	1	1	Current multiplier when function is used for parallel lines

Table 375: T1PTTR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Sensor available	No Yes	-	-	No	External temperature sensor available

Table 376: T1PTTR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Initial temperature	-50.0 - 100.0	Deg	0.1	0.0	Temperature raise above ambient temperature at startup

4.1.4.9 Measured values

Table 377: T1PTTR Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0	Current amplitude (RMS) phase A
I_RMS_B	REAL	0	Current amplitude (RMS) phase B
I_RMS_C	REAL	0	Current amplitude (RMS) phase C
AMB_TEMP	REAL	0	Ambient temperature from external temperature sensor
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Block of operate output
ENA_MULT	BOOLEAN	0	Enable current multiplier
SENSFLT	BOOLEAN	0	Validity status of ambient temperature sensor
RESET	BOOLEAN	0	Reset of internal thermal load counter

4.1.4.10 Monitored data

Table 378: T1PTTR Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal
T_OPERATE	INTEGER	-	Minutes	Estimated time to operate
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
BLK_CLOSE	BOOLEAN	0=FALSE 1=TRUE	-	Thermal overload indicator to inhibit reclose
T_ENA_CLOSE	INTEGER	-	-	Estimated time to reset of block reclose
TEMP	REAL	-	-	Calculated temperature of the device
TEMP_AMB	REAL	-	-	Ambient temperature used in the calculations
TEMP_RL	REAL	-	-	Temperature relative to operate temperature

4.1.4.11 Technical data

Table 379: T1PTTR Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	Current measurement: ±0.5% of the set value or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Operate time accuracy[1)]	±2.0% or ±0.50 s

1) Overload current > 1.2 × Operate level temperature, *Current reference* > 0.50 pu

4.1.4.12 Technical revision history

Table 380: T1PTTR technical revision history

Technical revision	Change
B	Output TEMP_RL is added Internal improvements

4.1.5 Three-phase thermal overload protection, two time constants T2PTTR

4.1.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase thermal overload protection, two time constants	T2PTTR	3Ith>T/G	49T/G

4.1.5.2 Function block

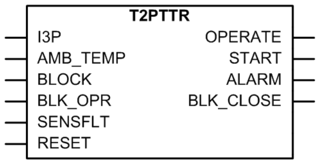


Figure 172: Function block

4.1.5.3 Functionality

The three-phase thermal overload, two time constant protection function T2PTTR protects the transformer mainly from short-time overloads. The transformer is protected from long-time overloads with the oil temperature detector included in its equipment.

The alarm signal gives an early warning to allow the operators to take action before the transformer trips. The early warning is based on the three-phase current measuring function using a thermal model with two settable time constants. If the temperature rise continues, T2PTTR operates based on the thermal model of the transformer.

After a thermal overload operation, the re-energizing of the transformer is inhibited during the transformer cooling time. The transformer cooling is estimated with a thermal model.

4.1.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of three-phase thermal overload, two time constant protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

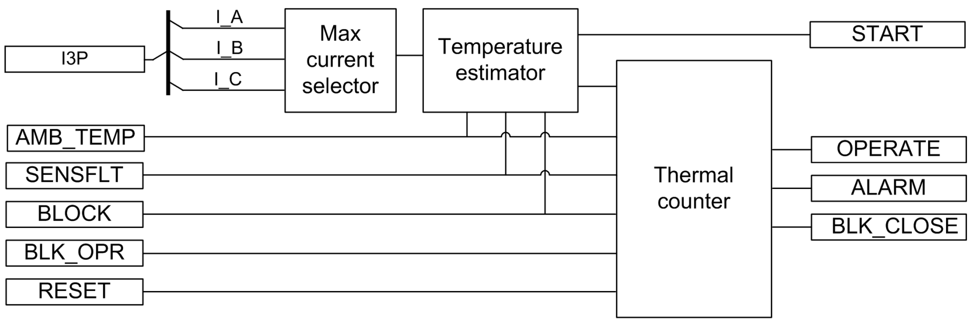


Figure 173: Functional module diagram. I_A, I_B and I_C represent phase currents.

Max current selector

The max current selector of the function continuously checks the highest measured TRMS phase current value. The selector reports the highest value to the thermal counter.

Temperature estimator

The final temperature rise is calculated from the highest of the three-phase currents according to the expression:

$$\Theta_{final} = \left(\frac{I}{I_{ref}} \right)^2 \cdot T_{ref}$$

(Equation 24)

I	highest measured phase current
I_{ref}	the set value of the *Current reference* setting
T_{ref}	the set value of the *Temperature rise* setting (temperature rise (°C) with the steady-state current I_{ref}

The ambient temperature is added to the calculated final temperature rise estimation, and the ambient temperature value used in the calculation is also available in the monitored data as `TEMP_AMB` in degrees. If the total value of temperature is higher than the set operating temperature level, the `START` output is activated.

The *Current reference* setting is a steady-state current that gives the steady-state end temperature value *Temperature rise*. It gives a setting value corresponding to the rated power of the transformer.

The *Temperature rise* setting is used when the value of the reference temperature rise corresponds to the *Current reference* value. The temperature values with the corresponding transformer load currents are usually given by transformer manufacturers.

Thermal counter

T2PTTR applies the thermal model of two time constants for temperature measurement. The temperature rise in degrees Celsius (°C) is calculated from the highest of the three-phase currents according to the expression:

$$\Delta\Theta = \left[p * \left(\frac{I}{I_{ref}} \right)^2 * T_{ref} \right] \cdot \left(1 - e^{-\frac{\Delta t}{\tau 1}} \right) + \left[(1-p) \cdot \left(\frac{I}{I_{ref}} \right)^2 \cdot T_{ref} \right] \cdot \left(1 - e^{-\frac{\Delta t}{\tau 2}} \right)$$

(Equation 25)

ΔΘ	calculated temperature rise (°C) in transformer
I	measured phase current with the highest TRMS value
Iref	the set value of the *Current reference* setting (rated current of the protected object)
Tref	the set value of the *Temperature rise* setting (temperature rise setting (°C) with the steady-state current I_{ref})
p	the set value of the *p-factor* setting (weighting factor for the short time constant)
Δt	time step between the calculation of the actual temperature
τ_1	the set value of the *Short time constant* setting (the short heating / cooling time constant)
τ_2	the set value of the *Long time constant* setting (the long heating / cooling time constant)

The warming and cooling following the two time-constant thermal curve is a characteristic of transformers. The thermal time constants of the protected transformer are given in seconds with the *Short time constant* and *Long time constant* settings. The *Short time constant* setting describes the warming of the transformer with respect to windings. The *Long time constant* setting describes the warming of the transformer with respect to the oil. Using the two time-constant model, the IED is able to follow both fast and slow changes in the temperature of the protected object.

The *p-factor* setting is the weighting factor between *Short time constant* τ_1 and *Long time constant* τ_2. The higher the value of the *p-factor* setting, the larger is the share of the steep part of the heating curve. When p=1, only *Short-time constant* is used. When p = 0, only *Long time constant* is used.

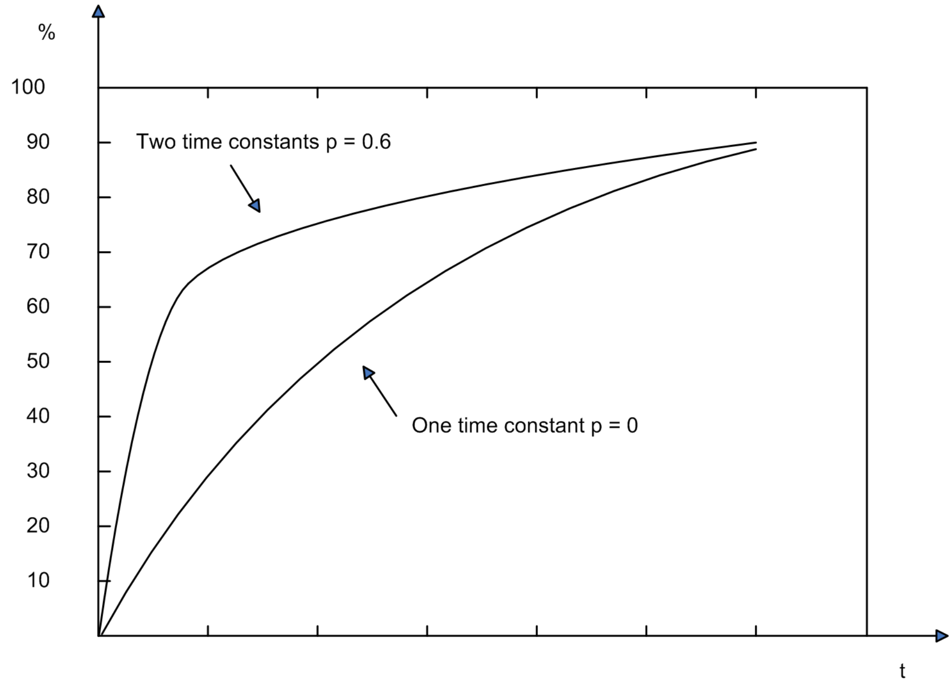


Figure 174: Effect of the Weighting factor p factor and the difference between the two time constants and one time constant models

The actual temperature of the transformer is calculated by adding the ambient temperature to the calculated temperature.

$$\Theta = \Delta\Theta + \Theta_{amb}$$

(Equation 26)

Θ	temperature in transformer (°C)
$\Delta\Theta$	calculated temperature rise (°C) in transformer
Θ_{amb}	set *Env temperature Set*

The validity of operation of the RTD sensor is obtained from the SENFLT input. In case of any errors or malfunctioning in the RTD output, T2PTTR takes the temperature value from the *Env temperature Set* setting.

By setting the *Sensor available* setting to "Yes," the external sensor is enabled to measure the ambient temperature. When *Sensor available* is set to "No," the *Env temperature Set* setting is used to define the ambient temperature.

The temperature calculation is initiated from the value defined with the *Initial temperature* setting. This is done when the IED is powered up, the function is turned off and back on or it is reset through the Clear menu or through the RESET input. The temperature is stored in a nonvolatile memory and restored if the IED is restarted.

The *Max temperature* setting defines the maximum temperature of the transformer in degrees Celsius (°C). The value of the *Max temperature* setting is usually given by transformer manufacturers. The actual alarm, operating and lockout temperatures for T2PTTR are given as a percentage value of the *Max temperature* setting.

When the transformer temperature reaches the alarm level defined with the *Alarm temperature* setting, the `ALARM` output signal is set. When the transformer temperature reaches the trip level value defined with the *Operate temperature* setting, the `OPERATE` output is activated. The `OPERATE` output is deactivated when the value of the measured current falls below 10 percent of the *Current Reference* value or the calculated temperature value falls below *Operate temperature*.

There is also a calculation of the present time to operation with the present current. `T_OPERATE` is only calculated if the final temperature is calculated to be above the operation temperature. The value is available in the monitored data view.

After operating, there can be a lockout to reconnect the tripped circuit due to the thermal overload protection function. The `BLK_CLOSE` lockout output is activated when the device temperature is above the *Reclose temperature* lockout release temperature setting value. The time to lockout release `T_ENA_CLOSE` is also calculated. The value is available in the monitored data view.

4.1.5.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.1.5.6 Application

The transformers in a power system are constructed for a certain maximum load current level. If the current exceeds this level, the losses are higher than expected. This results in a rise in transformer temperature. If the temperature rise is too high, the equipment is damaged:

- Insulation within the transformer ages faster, which in turn increases the risk of internal phase-to-phase or phase-to-earth faults.
- Possible hotspots forming within the transformer degrade the quality of the transformer oil.

During stressed situations in power systems, it is required to overload the transformers for a limited time without any risks. The thermal overload protection provides information and makes temporary overloading of transformers possible.

The permissible load level of a power transformer is highly dependent on the transformer cooling system. The two main principles are:

- ONAN: The air is naturally circulated to the coolers without fans, and the oil is naturally circulated without pumps.
- OFAF: The coolers have fans to force air for cooling, and pumps to force the circulation of the transformer oil.

The protection has several parameter sets located in the setting groups, for example one for a non-forced cooling and one for a forced cooling situation. Both the permissive steady-state loading level as well as the thermal time constant are influenced by the transformer cooling system. The active setting group can be changed by a parameter, or through a binary input if the binary input is enabled for it. This feature can be used for transformers where forced cooling is taken out of operation or extra cooling is switched on. The parameters can also be changed when a fan or pump fails to operate.

The thermal overload protection continuously estimates the internal heat content, that is, the temperature of the transformer. This estimation is made by using a thermal model of the transformer which is based on the current measurement.

If the heat content of the protected transformer reaches the set alarm level, a signal is given to the operator. This enables the action that needs to be taken in the power systems before the temperature reaches a high value. If the temperature continues to rise to the trip value, the protection initiates the trip of the protected transformer.

After the trip, the transformer needs to cool down to a temperature level where the transformer can be taken into service again. T2PTTR continues to estimate the heat content of the transformer during this cooling period using a set cooling time constant. The energizing of the transformer is blocked until the heat content is reduced to the set level.

The thermal curve of two time constants is typical for a transformer. The thermal time constants of the protected transformer are given in seconds with the *Short time constant* and *Long time constant* settings. If the manufacturer does not state any other value, the *Long time constant* can be set to 4920 s (82 minutes) for a distribution transformer and 7260 s (121 minutes) for a supply transformer. The corresponding *Short time constants* are 306 s (5.1 minutes) and 456 s (7.6 minutes).

If the manufacturer of the power transformer has stated only one, that is, single time constant, it can be converted to two time constants. The single time constant is also used by itself if the *p-factor* setting is set to zero and the time constant value is set to the value of the *Long time constant* setting. The thermal image corresponds to the one time constant model in that case.

Table 381: Conversion table between one and two time constants

Single time constant (min)	*Short time constant* (min)	*Long time constant* (min)	*p-factor*
10	1.1	17	0.4
15	1.6	25	0.4
20	2.1	33	0.4
25	2.6	41	0.4
30	3.1	49	0.4
35	3.6	58	0.4
40	4.1	60	0.4
45	4.8	75	0.4
50	5.1	82	0.4
55	5.6	90	0.4
60	6.1	98	0.4
65	6.7	107	0.4
70	7.2	115	0.4
75	7.8	124	0.4

The default *Max temperature* setting is 105°C. This value is chosen since even though the IEC 60076-7 standard recommends 98°C as the maximum allowable temperature in long-time loading, the standard also states that a transformer can withstand the emergency loading for weeks or even months, which may produce the winding temperature of 140°C. Therefore, 105°C is a safe maximum temperature value for a transformer if the *Max temperature* setting value is not given by the transformer manufacturer.

4.1.5.7 Signals

Table 382: T2PTTR Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
AMB_TEMP	REAL	0	Ambient temperature from external temperature sensor
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Block of operate output
SENSFLT	BOOLEAN	0	Validity status of ambient temperature sensor
RESET	BOOLEAN	0	Reset of internal thermal load counter

Table 383: T2PTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal
START	BOOLEAN	Signal indicating current that will raise temperature above operate level if prolonged
ALARM	BOOLEAN	The calculated temperature is over Alarm level Temperature limit
BLK_CLOSE	BOOLEAN	Thermal overload indicator. To inhibite reclose.

4.1.5.8 Settings

Table 384: T2PTTR Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Temperature rise	0.0 - 200.0	Deg	0.1	78.0	Temperature reference for thermal model
Env temperature Set	-50.0 - 100.0	Deg	0.1	40.0	Ambient temperature used when Sensor available is set to Off
Max temperature	0.0 - 200.0	Deg	0.1	105.0	Maximum temperature allowed for the transformer
Alarm temperature	40.0 - 100.0	%	0.1	90.0	Alarm temperature, percent value
Operate tempetature	80.0 - 120.0	%	0.1	100.0	Operate temperature, percent value
Reclose temperature	40.0 - 100.0	%	0.1	60.0	Reclose temperature after operate, percent value
Weighting factor p	0.00 - 1.00	-	0.01	0.40	Weighting factor of the short time constant
Short time constant	60 - 60000	s	1	450	Short time constant in seconds
Long time constant	60 - 60000	s	1	7200	Long time constant in seconds

Table 385: T2PTTR Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Current reference	0.05 - 4.00	pu	0.01	1.00	The load current leading to Temperature rise temperature

Table 386: T2PTTR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On
Sensor available	No Yes	-	-	No	External temperature sensor availiable

Table 387: T2PTTR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Initial temperature	0.0 - 100.0	%	0.1	80.0	Initial temperature, percent value

4.1.5.9 Measured values

Table 388: T2PTTR Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0	Current amplitude (RMS) phase A
I_RMS_B	REAL	0	Current amplitude (RMS) phase B
I_RMS_C	REAL	0	Current amplitude (RMS) phase C
AMB_TEMP	REAL	0	Ambient temperature from external temperature sensor
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Block of operate output
SENSFLT	BOOLEAN	0	Validity status of ambient temperature sensor
RESET	BOOLEAN	0	Reset of internal thermal load counter

4.1.5.10 Monitored data

Table 389: T2PTTR Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal
T_OPERATE	INTEGER	-	s	Estimated time to operate
START	BOOLEAN	0=FALSE 1=TRUE	-	Signal indicating current that will raise temperature above operate level if prolonged
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	The calculated temperature is over Alarm level Temperature limit
BLK_CLOSE	BOOLEAN	0=FALSE 1=TRUE	-	Thermal overload indicator. To inhibite reclose.
T_ENA_CLOSE	INTEGER	-	s	Estimated time to deactivate BLK_CLOSE in seconds
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
TEMP	REAL	-	-	The calculated temperature of the protected object
TEMP_AMB	REAL	-	-	Ambient temperature used in the calculations
TEMP_RL	REAL	-	-	The calculated temperature of the protected object relative to the operate level

4.1.5.11 Technical data

Table 390: T2PTTR Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	Current measurement: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Operate time accuracy1)	±2.0% or ±1000 ms

1) Overload current > 1.2 × Operate level temperature, *Current reference* > 0.50 pu

4.1.5.12 Technical revision history

Table 391: T2PTTR technical revision history

Technical revision	Change
B	Change in function IEC 60617 and ANSI symbol

4.1.6 Motor load jam protection JAMPTOC

4.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor load jam protection	JAMPTOC	Ist>	51LR

4.1.6.2 Function block

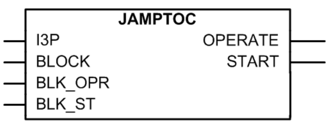


Figure 175: Function block

4.1.6.3 Functionality

The motor load jam protection JAMPTOC is used for protecting the motor in stall or mechanical jam situations during the running state.

When the motor is started, a separate function is used for the startup protection, and JAMPTOC is normally blocked during the startup period. When the motor has passed the starting phase, JAMPTOC monitors the magnitude of phase currents. The function starts when the measured current exceeds the breakdown torque level, that is, above the set limit. The operation characteristic is definite time.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the motor load jam protection can be described with a module diagram. All the modules in the diagram are explained in the next sections.

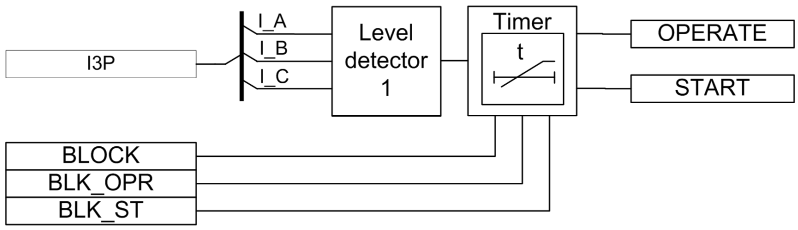


Figure 176: Functional module diagram

Level detector

The measured phase currents are compared to the set *Start value*. The TRMS values of the phase currents are considered for the level detection. The timer module is enabled if at least two of the measured phase currents exceed the set *Start value*.

Timer

Once activated, the timer activates the `START` output and runs until the *Operate delay time* setting value has elapsed. The time characteristics is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated.

When the timer has elapsed but the motor stall condition still exists, the `OPERATE` output remains active until the phase currents values drop below the *Start value*, that is, until the stall condition persists. If the drop-off situation occurs while the operating time is still counting, the reset timer is activated. If the drop-off time exceeds the set *Reset delay time*, the operating timer is reset.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The blocking functionality contains three binary inputs. The BLOCK input blocks the operation of the whole function, and the timers are reset. The BLOCK input can be used to block the protection during a motor start.

The activation of the BLK_ST and BLK_OPR inputs blocks the starting and operating outputs respectively.

4.1.6.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.1.6.6 Application

The motor protection during stall is primarily needed to protect the motor from excessive temperature rise, as the motor draws large currents during the stall phase. This condition causes a temperature rise in the stator windings. Due to reduced speed, the temperature also rises in the rotor. The rotor temperature rise is more critical when the motor stops.

The physical and dielectric insulations of the system deteriorate with age and the deterioration is accelerated by the temperature increase. Insulation life is related to the time interval during which the insulation is maintained at a given temperature.

An induction motor stalls when the load torque value exceeds the breakdown torque value, causing the speed to decrease to zero or to some stable operating point well below the rated speed. This occurs, for example, when the applied shaft load is suddenly increased and is greater than the producing motor torque due to the bearing failures. This condition develops a motor current almost equal to the value of the locked-rotor current.

JAMPTOC is designed to protect the motor in stall or mechanical jam situations during the running state. To provide a good and reliable protection for motors in a stall situation, the temperature effects on the motor have to be kept within the allowed limits.

4.1.6.7 Signals

Table 392: JAMPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	3-phase current group
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs

Table 393: JAMPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started signal

4.1.6.8 Settings

Table 394: JAMPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Start value	0.10 - 10.00	pu	0.01	2.50	Start value
Operate delay time	0.10 - 120.00	s	0.01	2.00	Operate delay time

Table 395: JAMPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Reset delay time	0.000 - 60.000	s	0.001	0.100	Reset delay time

4.1.6.9 Measured values

Table 396: JAMPTOC Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0	Current amptitude (RMS) phase A
I_RMS_B	REAL	0	Current amplitude (RMS) phase B
I_RMS_C	REAL	0	Current amplitude (RMS) phase C
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs

4.1.6.10 Monitored data

Table 397: JAMPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	REAL	-	%	Ratio of start time / operate time

4.1.6.11 Technical data

Table 398: JAMPTOC Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × I_n
Start time[1)2)]	I_{Fault} = 2.0 × set *Start value*	Typically 25 ms (±15ms)
Reset time		<40 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms

1) Current before = 0.0 × I_n, f_n = 50 Hz
2) Includes the delay of the signal output contact

4.1.6.12 Technical revision history

Table 399: JAMPTOC technical revision history

Technical revision	Change
B	Change in function ANSI symbol

4.1.7 Loss of load protection LOFLPTUC

4.1.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Loss of load protection	LOFLPTUC	3I<	37

4.1.7.2 Function block

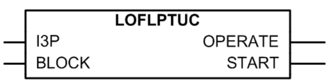


Figure 177: Function block

4.1.7.3 Functionality

The loss of load protection LOFLPTUC is used to detect a sudden load loss which is considered as a fault condition.

LOFLPTUC starts when the current is less than the set limit. It operates with the definite time (DT) characteristics, which means that the function operates after a predefined operate time and resets when the fault current disappears.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.1.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of loss of load protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

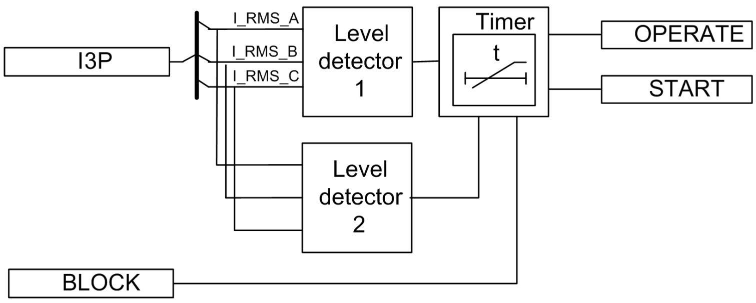


Figure 178: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Level detector 1

This module compares the phase currents (RMS value) to the set *Start value high* setting. If all the phase current values are less than the set *Start value high* value, the loss of load condition is detected and an enable signal is sent to the timer. This signal is disabled after one or several phase currents have exceeded the set *Start value high* value of the element.

Level detector 2

This is a low-current detection module, which monitors the de-energized condition of the motor. It compares the phase currents (RMS value) to the set *Start value low* setting. If any of the phase current values is less than the set *Start value low*, a signal is sent to block the operation of the timer.

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The BLOCK signal blocks the operation of the function and resets the timer.

4.1.7.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.1.7.6 Application

When a motor runs with a load connected, it draws a current equal to a value between the no-load value and the rated current of the motor. The minimum load current can be determined by studying the characteristics of the connected load. When the current drawn by the motor is less than the minimum load current drawn, it can be inferred that the motor is either disconnected from the load or the coupling mechanism is faulty. If the motor is allowed to run in this condition, it may aggravate the fault in the coupling mechanism or harm the personnel handling the machine. Therefore, the motor has to be disconnected from the power supply as soon as the above condition is detected.

LOFLPTUC detects the condition by monitoring the current values and helps disconnect the motor from the power supply instantaneously or after a delay according to the requirement.

When the motor is at standstill, the current will be zero and it is not recommended to activate the trip during this time. The minimum current drawn by the motor when it is connected to the power supply is the no load current, that is, the higher start value current. If the current drawn is below the lower start value current, the motor is disconnected from the power supply. LOFLPTUC detects this condition and interprets that the motor is de-energized and disables the function to prevent unnecessary trip events.

4.1.7.7 Signals

Table 400: LOFLPTUC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
BLOCK	BOOLEAN	0	Block all binary outputs by resetting timers.

Table 401: LOFLPTUC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Loss of load protection operated
START	BOOLEAN	Loss of load protection started

4.1.7.8 Settings

Table 402: LOFLPTUC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value high	0.01 - 1.00	pu	0.01	0.50	Current setting/Start value high
Start value low	0.01 - 0.50	pu	0.01	0.10	Current setting/Start value low
Operate delay time	0.40 - 600.00	s	0.01	2.00	Operate time delay

Table 403: LOFLPTUC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On / Off

Table 404: LOFLPTUC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Reset delay time	0.000 - 60.000	s	0.001	0.020	Time delay to reset

4.1.7.9 Measured values

Table 405: LOFLPTUC Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0	Current amptitude (RMS) phase A
I_RMS_B	REAL	0	Current amptitude (RMS) phase B
I_RMS_C	REAL	0	Current amptitude (RMS) phase C
BLOCK	BOOLEAN	0	Block all binary outputs by resetting timers.

4.1.7.10 Monitored data

Table 406: LOFLPTUC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Loss of load protection operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Loss of load protection started
START_DUR	REAL	-	%	start time / operate time (in %)

4.1.7.11 Technical data

Table 407: LOFLPTUC Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5% of the set value or $\pm 0.002 \times I_n$
Start time[1)]	Typically <330 ms
Reset time	<40 ms
Reset ratio	Typically 0.96
Retardation time	<35 ms
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms

1) Includes the delay of the signal output contact

4.1.8 Motor thermal overload protection MPTTR

4.1.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase thermal overload protection for motors	MPTTR	3Ith>M	49M

4.1.8.2 Function block

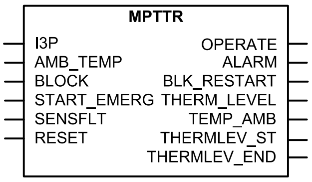


Figure 179: Function block

4.1.8.3 Functionality

The motor thermal overload protection function MPTTR protects the electric motors from overheating. MPTTR models the thermal behavior of motor on the basis of the measured load current and disconnects the motor when the thermal content reaches 100 percent. The thermal overload conditions are the most often encountered abnormal conditions in industrial motor applications. The thermal overload conditions are typically the result of an abnormal rise in the motor running current, which produces an increase in the thermal dissipation of the motor and temperature or reduces cooling. MPTTR prevents an electric motor from drawing excessive current and overheating, which causes the premature insulation failures of the windings and, in worst cases, burning out of the motors.

4.1.8.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the motor thermal overload protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

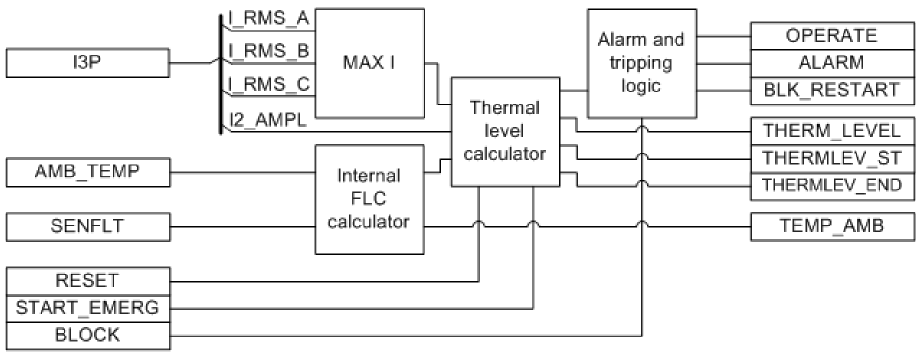


Figure 180: Functional module diagram

Max current selector

The maximum current selector of the function continuously checks the highest measured TRMS phase current value. The selector reports the highest value to the temperature estimator.

Internal FLC calculator

Full load current (FLC) of the motor is defined by the manufacturer at an ambient temperature of 40°C. Special considerations are required with an application where the ambient temperature of a motor exceeds or remains below 40°C. A motor operating at a higher temperature, even if at or below rated load, can subject the motor windings to excessive temperature similar to that resulting from overload operation at normal ambient temperature. The motor rating has to be appropriately reduced for operation in such high ambient temperatures. Similarly, when the ambient temperature is considerably lower than the nominal 40°C, the motor can be slightly overloaded. For calculating thermal level it is better that the FLC values are scaled for different temperatures. The scaled currents are known as internal FLC. An internal FLC is calculated based on the ambient temperature shown in the table. The *Env temperature mode* setting defines whether the thermal level calculations are based on FLC or internal FLC.

When the value of the *Env temperature mode* setting is set to the "FLC Only" mode, no internal FLC is calculated. Instead, the FLC given in the data sheet of the manufacturer is used. When the value of the *Env temperature mode* setting is set to the "Set Amb Temp" mode, the internal FLC is calculated based on the ambient temperature taken as an input through the *Env temperature Set* setting. When the *Env temperature mode* setting is on the "Use RTD" mode, the internal FLC is calculated from temperature data available through resistance temperature detectors (RTDs) using the `AMB_TEMP` input.

Table 408: Modification of internal FLC

Ambient Temperature T_{amb}	Internal FLC
<20°C	FLC x 1.09
20 to <40°C	FLC x (1.18 - T_{amb} x 0.09/20)
40°C	FLC
>40 to 65°C	FLC x (1 –[(T_{amb} -40)/100])
>65°C	FLC x 0.75

The validity of operation of the RTD sensor is obtained from the `SENFLT` input. In case of any errors or malfunctioning in the RTD output, the function takes the value of temperature available from the *Env temperature Set* setting for calculating the internal FLC. The ambient temperature is used for calculating thermal level and it is available in the output data view on the LHMI from the `TEMP_AMB` output in degrees. The activation of the `BLOCK` input does not affect the `TEMP_AMB` output.

Thermal level calculator

The heating of the motor is determined by the square value of the load current. However, in case of unbalanced phase currents, the negative-sequence current also causes additional heating. This is taken into account by means of the *Negative Seq factor* setting.

The thermal load is calculated based on different situations or operations and it also depends on the phase current level. The equations used for the heating calculations are:

$$\theta_B = \left[\left(\frac{I}{k \times I_r} \right)^2 + K_2 \times \left(\frac{I_2}{k \times I_r} \right)^2 \right] \times \left(1 - e^{-t/\tau} \right) \times p\%$$

(Equation 27)

$$\theta_A = \left[\left(\frac{I}{k \times I_r} \right)^2 + K_2 \times \left(\frac{I_2}{k \times I_r} \right)^2 \right] \times \left(1 - e^{-t/\tau}\right) \times 100\%$$

(Equation 28)

I TRMS value of the measured max of phase currents

I_r set rated current, FLC or internal FLC

I_2 measured negative sequence current

k set value of *Overload factor*

K_2 set value of *Negative Seq factor*

p set value of *Weighting factor*

τ time constant

The equation θ_B is used when the values of all the phase currents are below the overload limit, that is, k x I_r. The equation θ_A is used when the value of any one of the phase currents exceeds the overload limit.

During overload condition, the thermal level calculator calculates the value of θ_B in background, and when the overload ends the thermal level is brought linearly from θ_A to θ_B with a speed of 1.66 percent per second. For the motor at standstill, that is, when the current is below the value of 0.12 x I_r, the cooling is expressed as:

$$\theta = \theta_{02} \times e^{\frac{-t}{\tau}}$$

(Equation 29)

θ_{02} initial thermal level when cooling begins

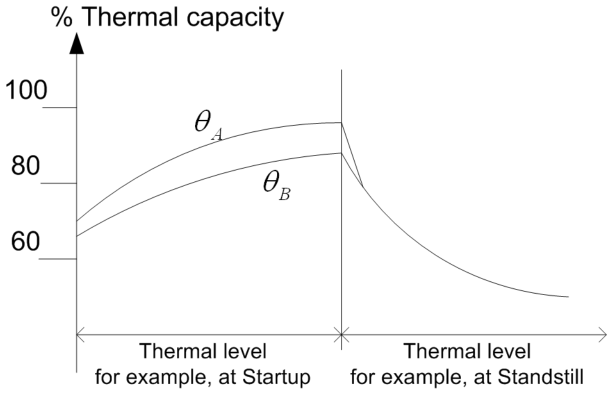


Figure 181: Thermal behavior

The required overload factor and negative sequence current heating effect factor are set by the values of the *Overload factor* and *Negative Seq factor* settings.

In order to accurately calculate the motor thermal condition, different time constants are used in the above equations. These time constants are employed based on different motor running conditions, for example starting, normal or stop, and are set through the *Time constant start*, *Time constant normal* and *Time constant stop* settings. Only one time constant is valid at a time.

Table 409: Time constant and the respective phase current values

Time constant (tau) in use	Phase current
Time constant start	Any current whose value is over 2.5 x I_r
Time constant normal	Any current whose value is over 0.12 x I_r and all currents are below 2.5 x I_r
Time constant stop	All the currents whose values are below 0.12 x I_r

The *Weighting factor p* setting determines the ratio of the thermal increase of the two curves θ_A and θ_B.

The thermal level at the power-up of the IED is defined by the *Initial thermal Val* setting.

The activation of the RESET binary input resets the value of the calculated thermal level to the *Initial thermal Val* setting.

The calculated thermal level, the THERM_LEVEL output, is available in the output data view on the LHMI. The activation of the BLOCK input does not affect the calculated thermal level.

The thermal level at the beginning of the startup condition of a motor and at the end of the startup condition is available in the output data view at the THERMLEV_ST and THERMLEV_END outputs respectively. The activation of the BLOCK input does not have any effect on these outputs.

Alarm and tripping logic

The module generates alarm, restart inhibit and tripping signals.

When the thermal level exceeds the set value of the *Alarm thermal value* setting, the ALARM output is activated. Sometimes a condition arises when it becomes necessary to inhibit the restarting of a motor, for example in case of some extreme starting condition like long starting time. If the thermal content exceeds the set value of the *Restart thermal val* setting, the BLK_RESTART output is activated. The time for the next possible motor startup is available in the monitored data view from the T_ENARESTART output. The T_ENARESTART output estimates the time for the BLK_RESTART deactivation considering as if the motor is stopped. When the thermal content reaches 100 percent, the OPERATE output is activated. The

OPERATE output is deactivated when the value of the measured current falls below 12 percent of the rated current or the thermal content drops below 100 percent.

On the rising edge of the emergency start signal START_EMERG, the thermal level is set to a value below the thermal restart inhibit level. This allows at least one motor startup, even though the thermal level has exceeded the restart inhibit level.

When the thermal content reaches 100 percent, the OPERATE output is activated.

The activation of the BLOCK input blocks the ALARM, BLK_RESTART and OPERATE outputs.

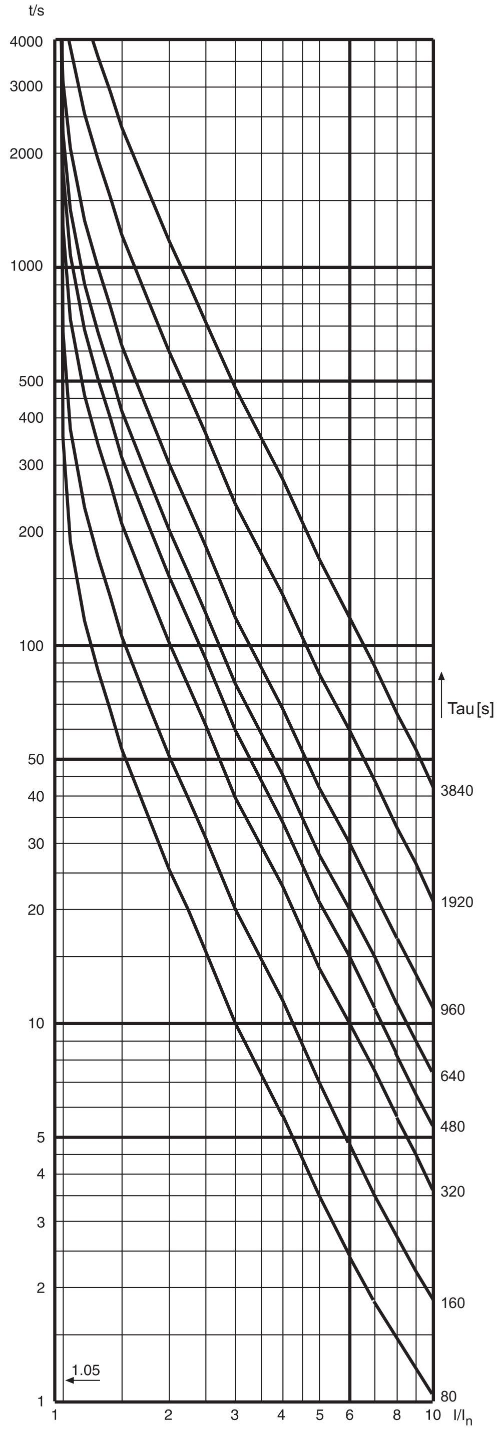


Figure 182: Trip curves when no prior load and p=20...100 %. Overload factor = 1.05.

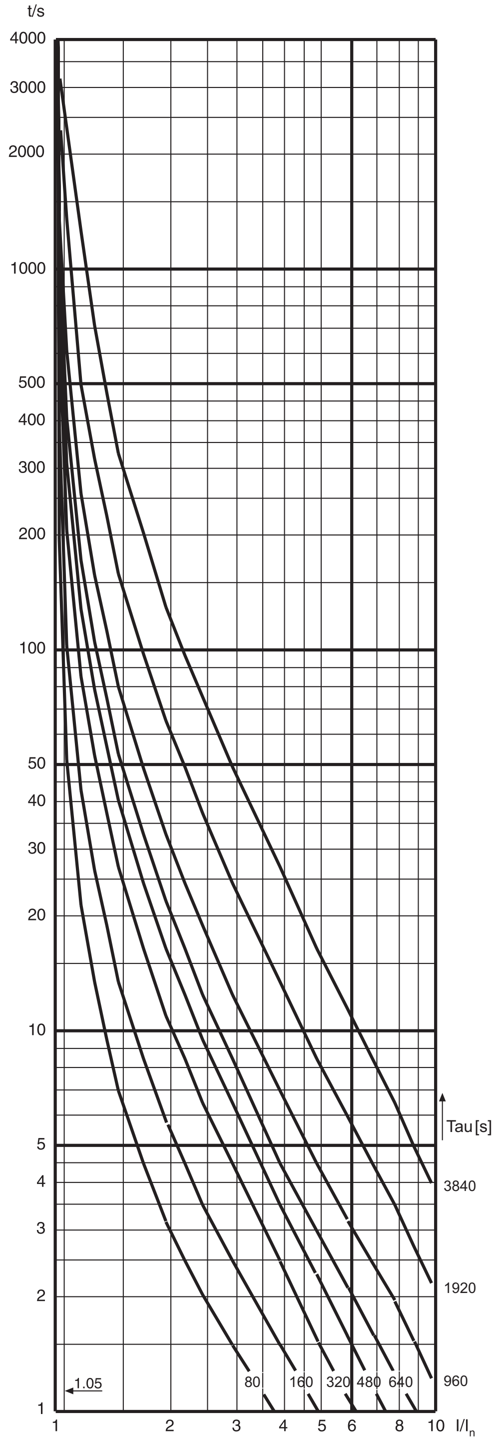


Figure 183: Trip curves at prior load 1 x FLC and p=100 %, Overload factor = 1.05.

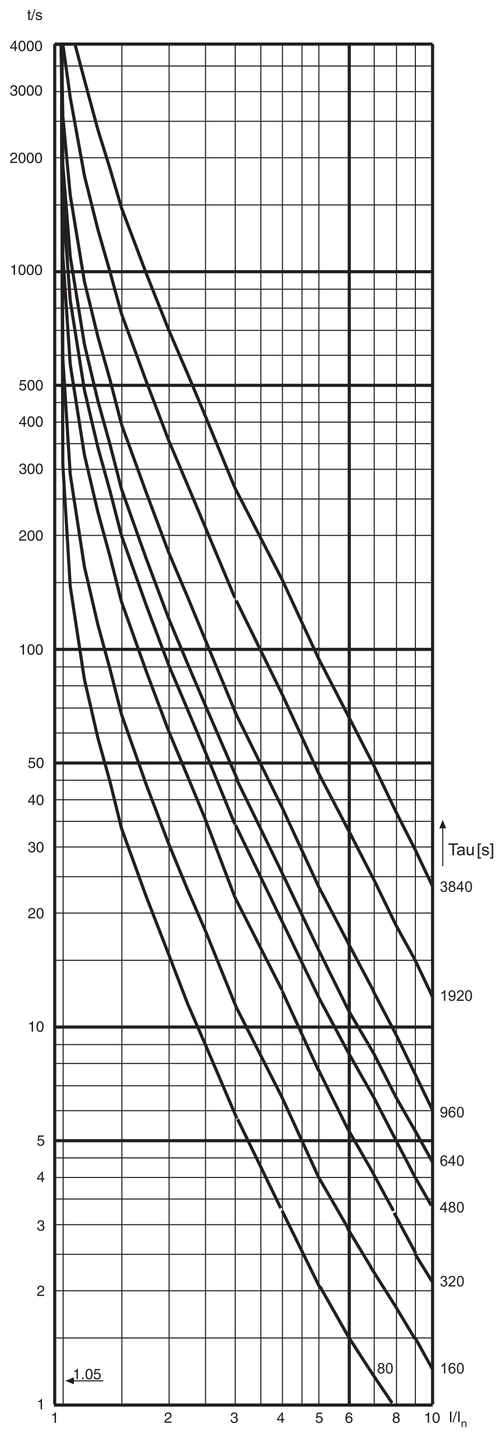


Figure 184: Trip curves at prior load 1 x FLC and p=50 %. Overload factor = 1.05.

4.1.8.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.1.8.6 Application

MPTTR is intended to limit the motor thermal level to predetermined values during the abnormal motor operating conditions. This prevents a premature motor insulation failure.

The abnormal conditions result in overheating and include overload, stalling, failure to start, high ambient temperature, restricted motor ventilation, reduced speed operation, frequent starting or jogging, high or low line voltage or frequency, mechanical failure of the driven load, improper installation and unbalanced line voltage or single phasing. The protection of insulation failure by the implementation of current sensing cannot detect some of these conditions, such as restricted ventilation. Similarly, the protection by sensing temperature alone can be inadequate in cases like frequent starting or jogging. The thermal overload protection addresses these deficiencies to a larger extent by deploying a motor thermal model based on load current.

The thermal load is calculated using the true RMS phase value and negative sequence value of the current. The heating up of the motor is determined by the square value of the load current. However, while calculating the thermal level, the rated current should be re-rated or de-rated depending on the value of the ambient temperature. Apart from current, the rate at which motor heats up or cools is governed by the time constant of the motor. There are two thermal curves: one which characterizes short-time and long-time overloads used for tripping and another which is used for the thermal condition of the motor.

The calculation of thermal load is based on different situations or operations and also depends on the value of phase current level. The equations used for the heating up calculations are:

$$\theta_B = \left[\left(\frac{I}{k \times I_r} \right)^2 + K_2 \times \left(\frac{I_2}{k \times I_r} \right)^2 \right] \times \left(1 - e^{-t/\tau} \right) \times p\%$$

(Equation 30)

$$\theta_A = \left[\left(\frac{I}{k \times I_r} \right)^2 + K_2 \times \left(\frac{I_2}{k \times I_r} \right)^2 \right] \times \left(1 - e^{-t/\tau} \right) \times 100\%$$

(Equation 31)

I	The true RMS value of the measured max of phase currents
In	motor rated current (FLC or internal FLC)
I2	measured negative sequence current
k	set value of *Overload factor*
K2	set value of *Negative Seq factor*
p	set value of *Weighting factor*
τ	time constant

The equation θ_B is used when the values of all the phase currents are below the overload limit, that is, k x In, whereas the equation θ_A is used when the value of any of the phase currents exceeds the overload limit.

During overload condition, the function calculates the θ_B in background when the overload that ends the thermal level is brought linearly from θ_A to θ_B with a speed of 1.66 percent per second. For a motor at standstill the cooling can be expressed as:

$$\theta = \theta_{02} \times e^{\frac{-t}{\tau}}$$

(Equation 32)

θ_{02} initial thermal level when cooling begins

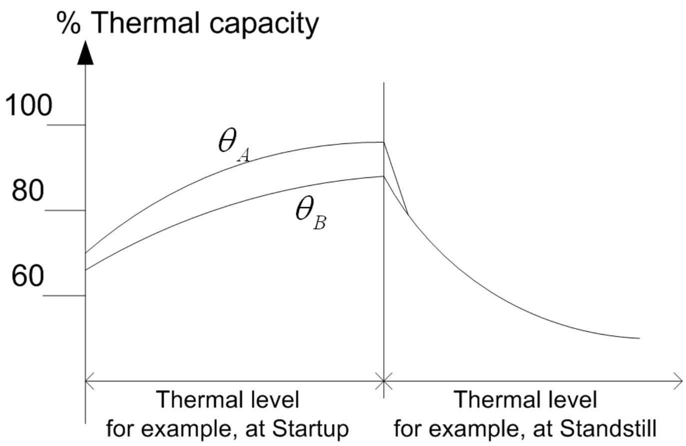


Figure 185: Thermal behavior

Setting the weighting factor

There are two thermal curves: one which characterizes the short-time loads and long-time overloads and which is also used for tripping and another which is used for monitoring the thermal condition of the motor. The value of the *Weighting factor p* setting determines the ratio of the thermal increase of the two curves.

When the *Weighting factor p* setting is 100 percent, a pure single time constant thermal unit is produced which is used for application with the cables. As presented in Figure 186, the hot curve with the value of *Weighting factor p* being 100 percent only allows an operate time which is about 10 percent of that with no prior load. For example, when the set time constant is 640 seconds, the operate time with the prior load 1 x FLC (full Load Current) and overload factor 1.05 is only 2 seconds, even if the motor could withstand at least 5 to 6 seconds. To allow the use of the full capacity of the motor, a lower value of *Weighting factor p* should be used.

Normally, an approximate value of half of the thermal capacity is used when the motor is running at full load. Thus by setting *Weighting factor p* to 50 percent, the IED notifies a 45 to 50 percent thermal capacity use at full load.

For direct-on-line started motors with hot spot tendencies, the value of *Weighting factor p* is typically set to 50 percent, which will properly distinguish between short-time thermal stress and long-time thermal history. After a short period of thermal stress, for example a motor startup, the thermal level starts to decrease quite sharply, simulating the leveling out of the hot spots. Consequently, the probability of successive allowed startups increases.

When protecting the objects without hot spot tendencies, for example motors started with soft starters, and cables, the value of *Weighting factor p* is set to 100 percent. With the value of *Weighting factor p* set to 100 percent, the thermal level decreases slowly after a heavy load condition. This makes the protection suitable for applications where no hot spots are expected. Only in special cases where the thermal overload protection is required to follow the characteristics of the object to be protected more closely and the thermal capacity of the object is very well known, a value between 50 and 100 percent is required.

For motor applications where, for example, two hot starts are allowed instead of three cold starts, the value of the setting *Weighting factor p* being 40 percent has proven to be useful. Setting the value of *Weighting factor p* significantly below 50 percent should be handled carefully as there is a possibility to overload the protected object as a thermal unit might allow too many hot starts or the thermal history of the motor has not been taken into account sufficiently.

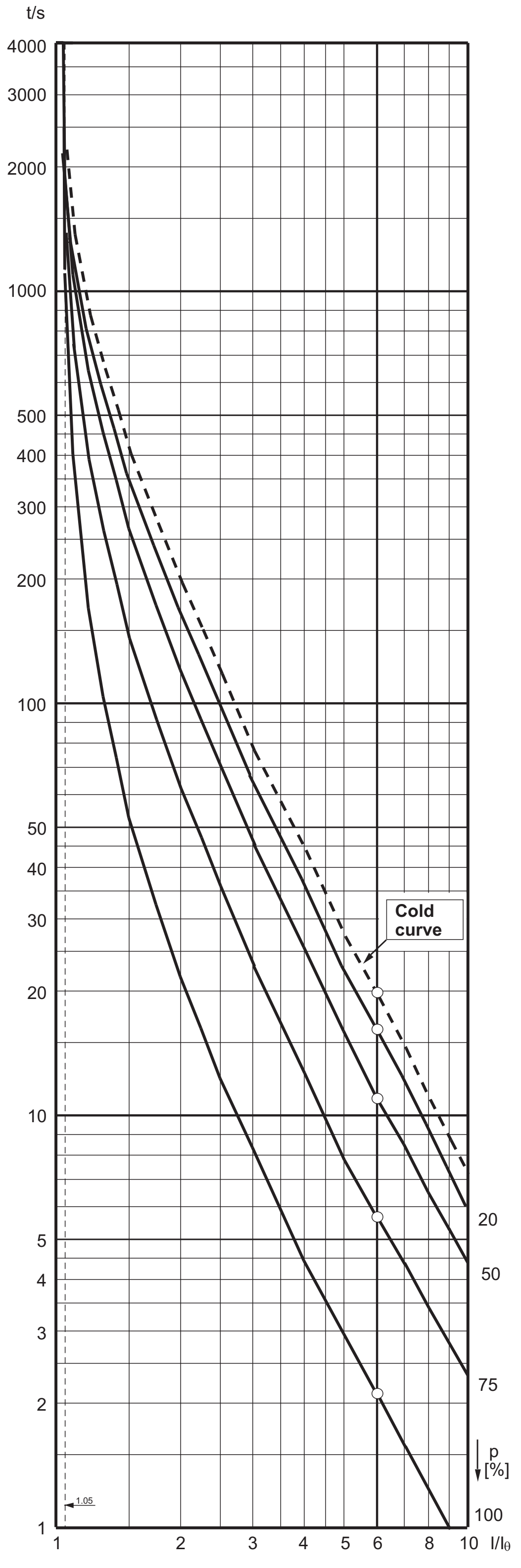


Figure 186: The influence of Weighting factor p at prior load 1xFLC, timeconstant = 640 sec, and Overload factor = 1.05

Setting the overload factor

The value of *Overload factor* defines the highest permissible continuous load. The recommended value is 1.05.

Setting the negative sequence factor

During the unbalance condition, the symmetry of the stator currents is disturbed and a counter-rotating negative sequence component current is set up. An increased stator current causes additional heating in the stator and the negative sequence component current excessive heating in the rotor. Also mechanical problems like rotor vibration can occur.

The most common cause of unbalance for three-phase motors is the loss of phase resulting in an open fuse, connector or conductor. Often mechanical problems can be more severe than the heating effects and therefore a separate unbalance protection is used.

Unbalances in other connected loads in the same busbar can also affect the motor. A voltage unbalance typically produces 5 to 7 times higher current unbalance. Because the thermal overload protection is based on the highest TRMS value of the phase current, the additional heating in stator winding is automatically taken into account. For more accurate thermal modeling, the *Negative Seq factor* setting is used for taking account of the rotor heating effect.

$$Negative\,Seq\ factor = \frac{R_{R2}}{R_{R1}}$$

(Equation 33)

R_{R2} rotor negative sequence resistance

R_{R1} rotor positive sequence resistance

A conservative estimate for the setting can be calculated:

$$Negative\,Seq\ factor = \frac{175}{I_{LR}^2}$$

I_{LR} locked rotor current (multiple of set *Rated current*). The same as the startup current at the beginning of the motor startup.

For example, if the rated current of a motor is 230 A, startup current is 5.7 x I_r,

$$Negative\,Seq\ factor = \frac{175}{5.7^2} = 5.4$$

Setting the thermal restart level

The restart disable level can be calculated as follows:

$$\theta_i = 100\% - \left(\frac{\textit{startup time of the motor}}{\textit{operate time when no prior load}} \times 100\% + \textit{margin} \right)$$

(Equation 34)

For example, the motor startup time is 11 seconds, start-up current 6 x rated and *Time constant start* is set for 800 seconds. Using the trip curve with no prior load, the operation time at 6 x rated current is 25 seconds, one motor startup uses 11/25 ≈ 45 percent of the thermal capacity of the motor. Therefore, the restart disable level must be set to below 100 percent - 45 percent = 55 percent, for example to 50 percent (100 percent - (45 percent + margin), where margin is 5 percent).

Setting the thermal alarm level

Tripping due to high overload is avoided by reducing the load of the motor on a prior alarm.

The value of the prior alarm level is set to a level which allows the use of the full thermal capacity of the motor without causing a trip due to a long overload time. Generally, the prior alarm level is set to a value of 80 to 90 percent of the trip level.

4.1.8.7 Signals

Table 410: MPTTR Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
AMB_TEMP	REAL	0.0	Ambient temperature from external temperature sensor
BLOCK	BOOLEAN	0	Block signal to block the function
START_EMERG	BOOLEAN	0	Signal for indicating the need for emergency start
SENSFLT	BOOLEAN	0	Validity status of ambient temperature sensor
RESET	BOOLEAN	0	Reset of thermal load

Table 411: MPTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal when thermal load exceeds operate setting
ALARM	BOOLEAN	Alarm signal when thermal load exceeds alarm setting
BLK_RESTART	BOOLEAN	Thermal overload indicator, to inhibit restart
THERM_LEVEL	REAL	Calculated thermal level of the device
TEMP_AMB	REAL	Ambient temperature used in calculations
THERMLEV_ST	REAL	Thermal level at beginning of motor startup
THERMLEV_END	REAL	Thermal level at the end of motor startup situation

4.1.8.8 Settings

Table 412: MPTTR Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Env temperature mode	FLC Only Use RTD Set Amb Temp	-	-	FLC Only	Mode of measuring ambient temperature
Env temperature Set	-20.0 - 70.0	Deg	0.1	40.0	Setting for ambient environment temperature
Alarm thermal value	50.0 - 100.0	%	0.1	95.0	Thermal level above which function gives an alarm
Restart thermal Val	20.0 - 80.0	%	0.1	40.0	Thermal level above which function inhibits motor restarting
Overload factor	1.00 - 1.20	-	0.01	1.05	Overload factor (k)
Weighting factor p	20.0 - 100.0	-	0.1	50.0	Weighting factor (p)
Time constant normal	80 - 4000	s	1	320	Motor time constant during the normal operation of motor
Time constant start	80 - 4000	s	1	320	Motor time constant during the start of motor
Time constant stop	80 - 60000	s	1	500	Motor time constant during the standstill condition of motor

Table 413: MPTTR Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Negative Seq factor	0.0 - 10.0	-	0.1	0.0	Heating effect factor for negative sequence current

Table 414: MPTTR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

Table 415: MPTTR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Initial thermal Val	0.0 - 100.0	%	0.1	74.0	Thermal level at power up

4.1.8.9 Measured values

Table 416: MPTTR Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0.0	True RMS motor current for phase A
I_RMS_B	REAL	0.0	True RMS motor current for phase B
I_RMS_C	REAL	0.0	True RMS motor current for phase C
I2_AMPL	REAL	0.0	Negative sequence current of the motor
AMB_TEMP	REAL	0.0	Ambient temperature from external temperature sensor
BLOCK	BOOLEAN	0	Block signal to block the function
START_EMERG	BOOLEAN	0	Signal for indicating the need for emergency start
SENSFLT	BOOLEAN	0	Validity status of ambient temperature sensor
RESET	BOOLEAN	0	Reset of thermal load

4.1.8.10 Monitored data

Table 417: MPTTR Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal when thermal load exceeds operate setting
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when thermal load exceeds alarm setting
BLK_RESTART	BOOLEAN	0=FALSE 1=TRUE	-	Thermal overload indicator, to inhibit restart
T_ENARESTART	INTEGER	-	s	Estimated time to reset of block restart
THERM_LEVEL	REAL	-	-	Calculated thermal level of the device
TEMP_AMB	REAL	-	-	Ambient temperature used in calculations
THERMLEV_ST	REAL	-	-	Thermal level at beginning of motor startup
THERMLEV_END	REAL	-	-	Thermal level at the end of motor startup situation

4.1.8.11 Technical data

Table 418: MPTTR Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	Current measurement: ±1.5% of the set value or $\pm 0.002 \times I_n$ (at currents in the range of $0.01...4.00 \times I_n$)
Operate time accuracy[1)]	±2.0% or ±0.050 s

1) Overload current > 1.2 × Operate level temperature

4.1.8.12 Technical revision history

Table 419: MPTTR technical revision history

Technical revision	Change
B	Minimum setting value changed from 8000 to 60000 for *Time constant stop* setting

4.1.9 Motor startup supervision STTPMSU

4.1.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor startup supervision	STTPMSU	Is2t n<	48,66,14,51LR

4.1.9.2 Function block

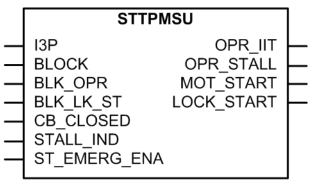


Figure 187: Function block

4.1.9.3 Functionality

The motor startup supervision function STTPMSU is designed for protection against excessive starting time and locked rotor conditions of the motor during starting. For a good and reliable operation of the motor, the thermal stress during the motor starting is maintained within the allowed limits.

The starting of the motor is supervised by monitoring the TRMS magnitude of all the phase currents or by monitoring the status of the circuit breaker connected to the motor.

During the startup period of the motor, STTPMSU calculates the integral of the I^2t value. If the calculated value exceeds the set value, the operate signal is activated.

STTPMSU has the provision to check the locked rotor condition of the motor using the speed switch, which means checking if the rotor is able to rotate or not. This feature operates after a predefined operating time.

STTPMSU also protects the motor from an excessive number of startups. Upon exceeding the specified number of startups within certain duration, STTPMSU blocks further starts. The restart of the motor is also inhibited after each start and continues to be inhibited for a set duration. When the lock of start of motor is enabled, STTPMSU gives the time remaining until the restart of the motor.

STTPMSU contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.1.9.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the motor startup supervision function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

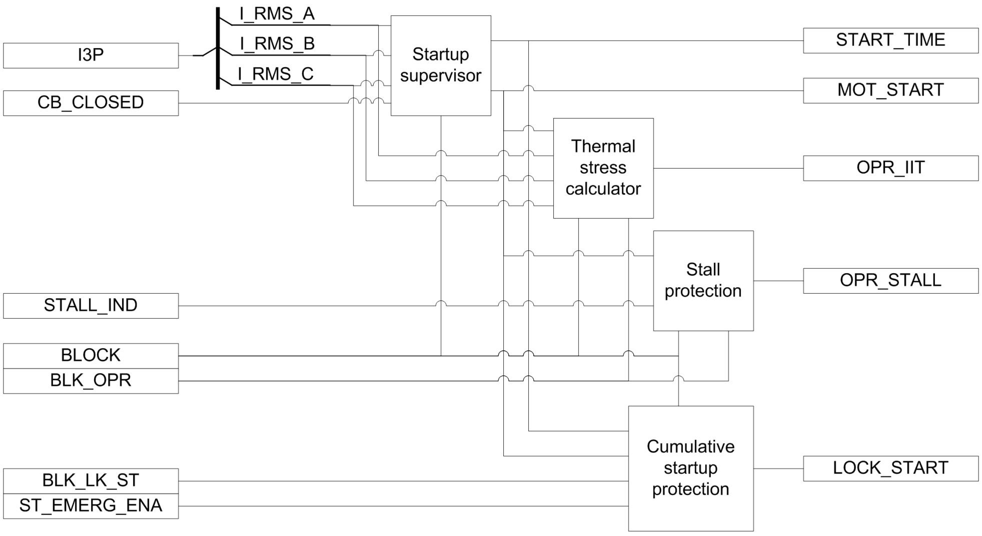


Figure 188: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Startup supervisor

This module detects the starting of the motor. The starting and stalling motor conditions are detected in four different modes of operation. This is done through the *Operation mode* setting.

When the *Operation mode* setting is operated in the "IIt" mode, the function calculates the value of the thermal stress of the motor during the startup condition. In this mode, the startup condition is detected by monitoring the TRMS currents.

The *Operation mode* setting in the "IIt, CB" mode enables the function to calculate the value of the thermal stress when a startup is monitored in addition to the CB_CLOSED input.

In the "IIt & stall" mode, the function calculates the thermal stress of the motor during the startup condition. In this mode, the startup condition is detected by monitoring the TRMS currents. In the "IIt & stall" mode, the function also checks for motor stalling by monitoring the speed switch.

In the "IIt & stall, CB" mode, the function calculates the thermal stresses of the motor during the startup condition. The startup condition is monitored in addition to the circuit breaker status. In the "IIt & stall, CB" mode, the function also checks for motor stalling by monitoring the speed switch.

When the trueRMS value of current is used for startup supervision in the "IIt" and "IIt & stall" modes, the module initially recognizes the de-energized condition of the motor when the values of all three phase currents are less than 0.1 pu for 100 ms. If the value of any of the phase currents rises after the de-energized condition from 0.1 pu to a value equal or greater than *Start detection A* within 50 ms after energization, the MOT_START output signal is activated indicating that the motor startup is in progress. The MOT_START output remains active until the values of all three phase currents drop below 0.9 × *Start detection A* and remain below that level for a time period of *Str over delay time*, that is, until the startup situation is over.

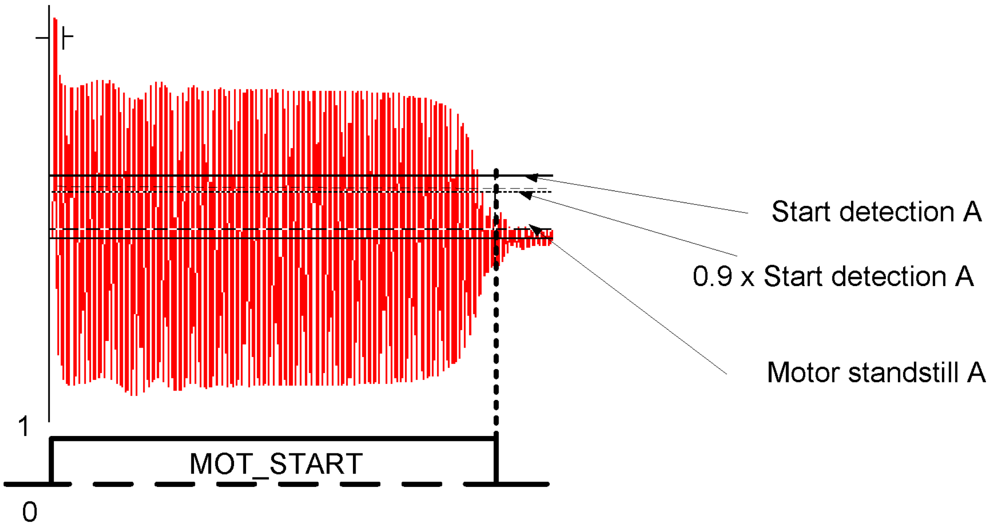


Figure 189: Functionality of the startup supervision in the "IIt and IIt&stall" mode

In case of the "IIt, CB" or "IIt & stall, CB" modes, the function initially recognizes the de-energized condition of the motor when the value of all three phase currents is below the value of the 0.1 pu setting for 100 ms. The beginning of the motor startup is recognized when CB is closed, that is, when the `CB_CLOSED` input is activated and at least one phase current value exceeds the 0.1 pu setting.

In normal practice, these two events do not take place at the same instant. The CB main contact is closed first, in which case the phase current value rises above 0.1 pu and after some delay the CB auxiliary contact gives the information of the `CB_CLOSED` input. In some cases, the `CB_CLOSED` input can be active but the value of current may not be greater than the value of the *Motor standstill A* setting. To allow both possibilities, a time slot of 200 milliseconds is provided for current and the `CB_CLOSED` input. If both events occur during this time, the motor startup is recognized.

The motor startup ends either within the value of the *Str over delay time* setting from the beginning of the startup or the opening of CB, that is, when the `CB_CLOSED` input is deactivated during the *Str over delay time*. The operation of the `MOT_START` output signal in this operation mode is as shown in Figure 190.

This CB mode can be used in soft-started or slip ring motors for protection against a large starting current, that is, a problem in starting and so on.

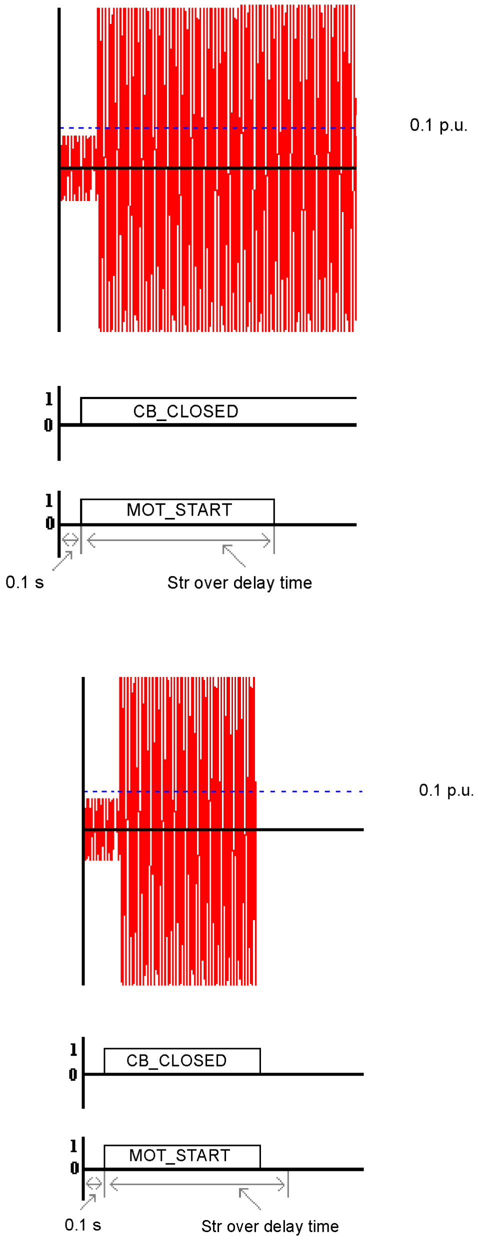


Figure 190: Functionality of the startup supervision in the "IIt, CB" and "IIt and stall, CB" modes

The *Str over delay time* setting has different purposes in different modes of operation.

- In the "IIt" or "IIt & stall" modes, the aim of this setting is to check for the completion of the motor startup period. The purpose of this time delay setting is to allow for short interruptions in the current without changing the state of the MOT_START output. In this mode of operation, the value of the setting is in the range of around 100 milliseconds.

- In the "IIt, CB" or "IIt & stall, CB" modes, the purpose of this setting is to check for the life of the protection scheme after the CB_CLOSED input has been activated. Based on the values of the phase currents, the completion of the startup period cannot be judged. In this mode of operation, the value of the time delay setting can even be as high as within the range of seconds, for example around 30 seconds.

The BLOCK input signal is used to block the operation of the MOT_START output. The activation of the BLOCK input signal deactivates the MOT_START output.

Thermal stress calculator

Because of the high current surges during the startup period, thermal stress is imposed on the rotor. With less air circulation in the ventilation of the rotor before it reaches its full speed, the situation becomes worse. Consequently, a long startup causes a rapid heating of the rotor.

This module calculates the thermal stress developed in the motor during startup. The heat developed during the starting can be calculated with the formula.

$$W = R_s \int_0^t i_s^2 \left(t\right) dt$$

(Equation 35)

R_s combined rotor and stator resistance

i_s starting current of the motor

t starting time of the motor

This equation is normally represented as the integral of I^2t. It is a commonly used method in protective relays to protect the motor from thermal stress during starting.

The advantage of this method over the traditional definite time overcurrent protection is that when the motor is started with a reduced voltage as in the star-delta starting method, the starting current is lower. This allows more starting time for the motor since the module is monitoring the integral of I^2t.

The module calculates the accumulated heat continuously and compares it to the limiting value obtained from the product of the square of the values of the *Motor start-up A* and *Motor start-up time* settings. When the calculated value of the thermal stress exceeds this limit, the OPR_IIT output is activated.

The module also measures the time START_TIME required by the motor to attain the rated speed and the relative thermal stress IIT_RL. The values are available in the monitored data view.

The BLOCK input is used to reset the operation of thermal stress calculator. The activation of the BLK_OPR input signal blocks the operation of the OPR_IIT output.

Stall protection

This module is activated only when the selected *Operation mode* setting value is "IIt & stall" or "IIt & stall, CB".

The startup current is specific to each motor and depends on the startup method used, like direct on-line, autotransformer and rotor resistance insertion.

The startup time is dependent of the load connected to the motor.

Based on the motor characteristics supplied by the manufacturer, this module is required if the stalling time is shorter than or too close to the starting time. In such cases, a speed switch must be used to indicate whether a motor is accelerating during startup or not.

At motor standstill, the STALL_IND input is active. It indicates that the rotor is not rotating. When the motor is started, at certain revolution the deactivation of the STALL_IND by the speed switch that indicates the rotor is rotating. If the input is not deactivated within *Lock rotor time*, the OPR_STALL output is activated.

The module calculates the duration of the motor in stalling condition, the STALL_RL output indicating the percent ratio of the start situation and the set value of *Lock rotor time*. The value is available in the monitored data view.

The BLK_OPR input signal is used to block the operation of the OPR_STALL output. The activation of the BLOCK input resets the operation timer.

Cumulative startup protection

This module protects the motor from an excessive number of startups.

Whenever the motor is started, the latest value of START_TIME is added to the existing value of T_ST_CNT and the updated cumulative startup time is available at T_ST_CNT. If the value of T_ST_CNT is greater than the value of *Cumulative time Lim*, the LOCK_START output is activated and lockout condition for the restart of motor is enabled during the time the output is active. The LOCK_START output remains high until the T_ST_CNT value reduces to a value less than the value of *Cumulative time Lim*. The start time counter reduces at the rate of the value of *Counter Red rate*.

The LOCK_START output becomes activated at the start of MOT_START. The output remains active for a period of *Restart inhibit time*.

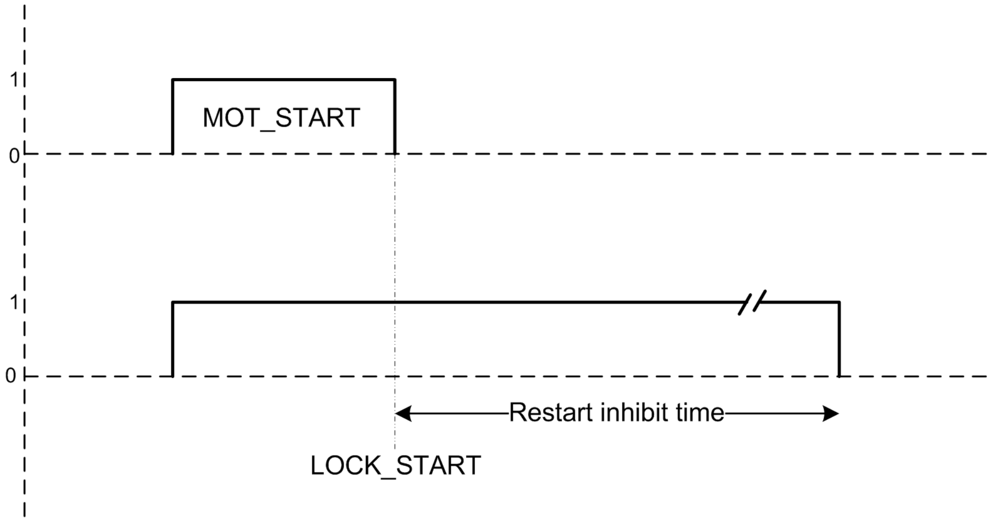


Figure 191: Time delay for cumulative start

This module also protects the motor from consecutive startups. When the LOCK_START output is active, T_RST_ENA shows the possible time for next restart. The value of T_RST_ENA is calculated by the difference of *Restart inhibit time* and the elapsed time from the instant LOCK_START is enabled.

When the ST_EMERG_ENA emergency start is set high, the value of the cumulative startup time counter is set less than the value of the *Cumulative time Lim* time limit. This disables LOCK_START and in turn makes the restart of the motor possible.

This module also calculates the total number of startups occurred, START_CNT.

The calculated values of T_RST_ENA, T_ST_CNT and START_CNT are available in the monitored data view.

The BLK_LK_ST input signal is used to block the operation of the LOCK_START output. The activation of the BLOCK input blocks the LOCK_START output for consecutive start condition.

4.1.9.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.1.9.6 Application

When a motor is started, it draws a current well in excess of the motor's full load rating throughout the period it takes for the motor to run up to the rated speed. The motor starting current decreases as the motor speed increases and the value of current remains close to the rotor locked value for most of the acceleration period.

The full voltage starting or the direct-on-line starting method is used out of the many methods used for starting the induction motor. If there is either an electrical or mechanical constraint, this starting method is not suitable. The full voltage starting produces the highest starting torque. A high starting torque is generally required to start a high-inertia load to limit the acceleration time. In this method, full voltage is applied to the motor when the switch is in the "On" position. This method of starting results in a large initial current surge, which is typically four to eight times that of the full-load current drawn by the motor. If a star-delta starter is used, the value of the line current will only be about one-third of the direct-on-line starting current.

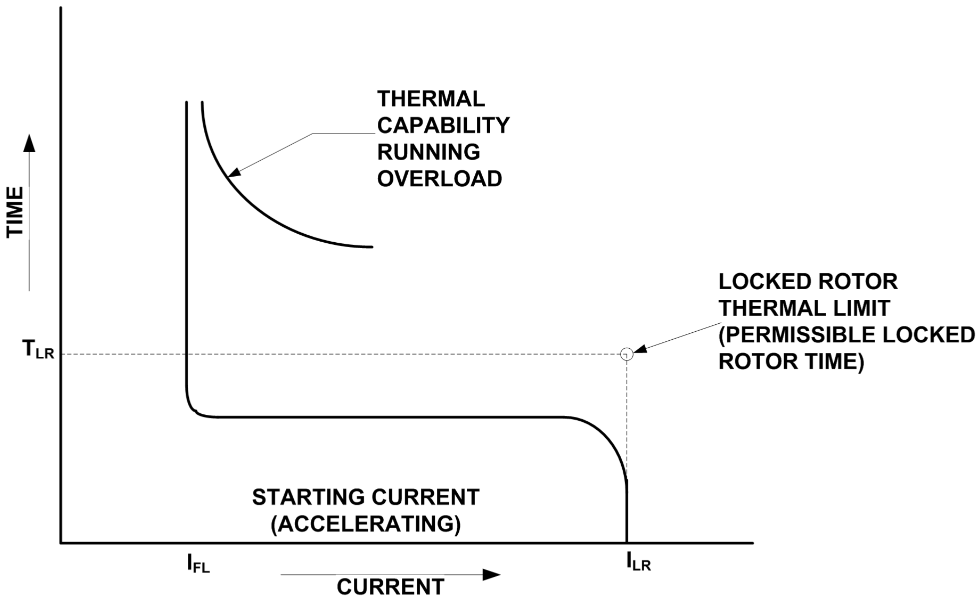


Figure 192: Typical motor starting and capability curves

The startup supervision of a motor is an important function because of the higher thermal stress developed during starting. During the startup, the current surge imposes a thermal strain on the rotor. This is exaggerated as the air flow for cooling is less because the fans do not rotate in their full speed. Moreover, the difference of speed between the rotating magnetic field and the rotor during the startup time induces a high magnitude of slip current in the rotor at frequencies higher than when the motor is at full speed. The skin effect is stronger at higher frequencies and all these factors increase the losses and the generated heat. This is worse when the rotor is locked.

The starting current for slip-ring motors is less than the full load current and therefore it is advisable to use the circuit breaker in the closed position to indicate the starting for such type of motors.

The starting times vary depending on motor design and load-torque characteristics. The time taken may vary from less than two seconds to more than 60 seconds. The starting time is determined for each application.

When the permissible stall time is less than the starting time of the motor, the stalling protection is used and the value of the time delay setting should be set slightly less than the permissible stall time. The speed switch on the motor shaft must be used for detecting whether the motor begins to accelerate or not. However, if the safe stall time is longer than the startup time of the motor, the speed switch is not required.

The failure of a motor to accelerate or to reach its full nominal speed in an acceptable time when the stator is energized is caused by several types of abnormal conditions, including a mechanical failure of the motor or load bearings, low supply voltage, open circuit in one phase of a three-phase voltage supply or too high starting voltage. All these abnormal conditions result in overheating.

Repeated starts increase the temperature to a high value in the stator or rotor windings, or both, unless enough time is allowed for the heat to dissipate. To ensure a safe operation it is necessary to provide a fixed-time interval between starts or limit the number of starts within a period of time. This is why the motor manufacturers have restrictions on how many starts are allowed in a defined time interval. This function does not allow starting of the motor if the number of starts exceeds the set level in the register that calculates them. This insures that the thermal effects on the motor for consecutive starts stay within permissible levels.

For example, the motor manufacturer may state that three starts at the maximum are allowed within 4 hours and the startup situation time is 60 seconds. By initiating three successive starts we reach the situation as illustrated. As a result, the value of the register adds up to a total of 180 seconds. Right after the third start has been initiated, the output lock of start of motor is activated and the fourth start will not be allowed, provided the time limit has been set to 121 seconds.

Furthermore, a maximum of three starts in 4 hours means that the value of the register should reach the set start time counter limit within 4 hours to allow a new start. Accordingly, the start time counter reduction should be 60 seconds in 4 hours and should thus be set to 60 s / 4 h = 15 s / h.

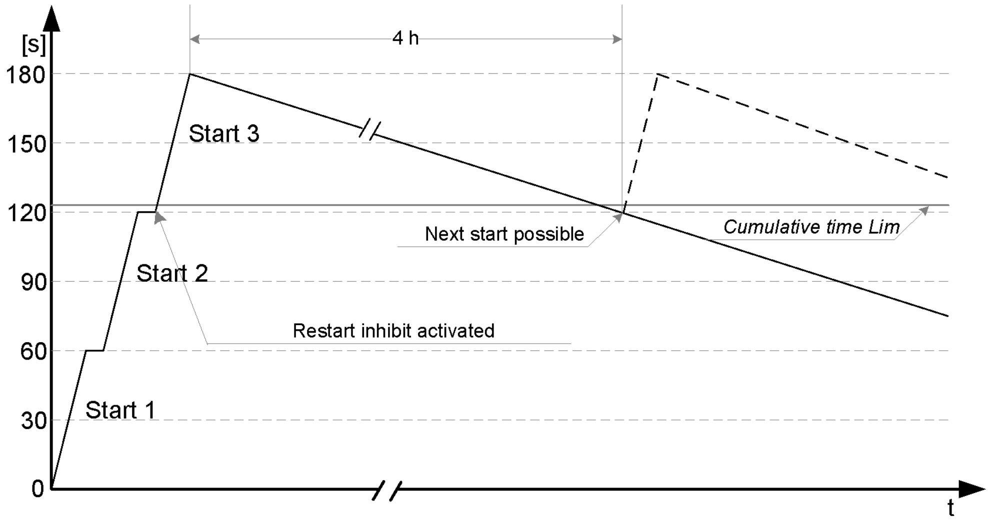


Figure 193: Typical motor-starting and capability curves

Setting of *Cumulative time Lim*

Cumulative time Lim is calculated by

$$\sum t_{si} = (n-1) \times t + margin$$

(Equation 36)

n	specified maximum allowed number of motor startups
t	startup time of the motor (in seconds)
margin	safety margin (~10...20 percent)

Setting of *Counter Red rate*

Counter Red rate is calculated by

$$\Delta \sum t_s = \frac{t}{t_{reset}}$$

(Equation 37)

t	specified start time of the motor in seconds
t_{reset}	duration during which the maximum number of motor startups stated by the manufacturer can be made; time in hours

4.1.9.7 Signals

Table 420: STTPMSU Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group connection for three phase current signals
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Blocks all operate signals
BLK_LK_ST	BOOLEAN	0	Blocks lock out condition for restart of motor
CB_CLOSED	BOOLEAN	0	Input signal showing the status of motor circuit breaker
STALL_IND	BOOLEAN	0	Input signal for showing the motor is not stalling
ST_EMERG_ENA	BOOLEAN	0	Enable emergency start to disable lock of start of motor

Table 421: STTPMSU Output signals

Name	Type	Description
OPR_IIT	BOOLEAN	Operate/trip signal for thermal stress.
OPR_STALL	BOOLEAN	Operate/trip signal for stalling protection.
MOT_START	BOOLEAN	Signal to show that motor startup is in progress
LOCK_START	BOOLEAN	Lock out condition for restart of motor.

4.1.9.8 Settings

Table 422: STTPMSU Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Motor start-up A	1.0 - 10.0	pu	0.1	2.0	Motor starting current
Motor start-up time	0.3 - 80.0	s	0.1	5.0	Motor starting time
Lock rotor time	2.0 - 120.0	s	1.0	10.0	Permitted stalling time

Table 423: STTPMSU Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Start detection A	0.1 - 10.0	pu	0.1	1.5	Current value for detecting starting of motor.

Table 424: STTPMSU Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On/Off
Operation mode	IIt IIt, CB IIt & stall IIt & stall, CB	-	-	IIt	Motor start-up operation mode
Emg start Red rate	0.00 - 100.00	%	0.01	20.00	Start time reduction factor when emergency start is On
Counter Red rate	2.0 - 250.0	s/h	0.1	60.0	Start time counter reduction rate
Cumulative time Lim	1.000 - 500.000	s	0.001	10.000	Cumulative time based restart inhibit limit
Restart inhibit time	0 - 250	Min	1	30	Time delay between consecutive startups
Str over delay time	0.000 - 60.000	s	0.001	0.100	Time delay to check for completion of motor startup period

Table 425: STTPMSU Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase

4.1.9.9 Measured values

Table 426: STTPMSU Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0.0	TrueRMS value of A-phase currrent
I_RMS_B	REAL	0.0	TrueRMS value of B-phase current
I_RMS_C	REAL	0.0	TrueRMS value of C-phase current
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Blocks all operate signals
BLK_LK_ST	BOOLEAN	0	Blocks lock out condition for restart of motor
CB_CLOSED	BOOLEAN	0	Input signal showing the status of motor circuit breaker
STALL_IND	BOOLEAN	0	Input signal for showing the motor is not stalling
ST_EMERG_ENA	BOOLEAN	0	Enable emergency start to disable lock of start of motor

4.1.9.10 Monitored data

Table 427: STTPMSU Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_IIT	BOOLEAN	0=FALSE 1=TRUE	-	Operate/trip signal for thermal stress.
OPR_STALL	BOOLEAN	0=FALSE 1=TRUE	-	Operate/trip signal for stalling protection.
MOT_START	BOOLEAN	0=FALSE 1=TRUE	-	Signal to show that motor startup is in progress
LOCK_START	BOOLEAN	0=FALSE 1=TRUE	-	Lock out condition for restart of motor.
START_CNT	INTEGER	-	-	Number of motor start-ups occurred
START_TIME	REAL	-	s	Measured motor latest startup time in sec
T_ST_CNT	REAL	-	s	Cumulated start-up time in sec
T_RST_ENA	INTEGER	-	-	Time left for restart when lockstart is enabled in minutes
IIT_RL	REAL	-	%	Thermal stress relative to set maximum thermal stress
STALL_RL	REAL	-	%	Start time relative to the operate time for stall condition

4.1.9.11 Technical data

Table 428: STTPMSU Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × I_n
Start time 1)2)	I_{Fault} = 1.1 × set *Start detection A*	Typically 25 ms (± 15ms)
Operate time accuracy		±1.0% of the set value or ±20 ms
Reset ratio		Typically 0.90

1) Current before = 0.0 × I_n, f_n = 50 Hz, overcurrent in one phase
2) Includes the delay of the signal output contact

4.1.9.12 Technical revision history

Table 429: STTPMSU technical revision history

Technical revision	Change
B	Change in ANSI symbol
C	Added feature to reset startup counter from clear menu

4.2 Earth-fault protection

4.2.1 Non-directional earth-fault protection EFxPTOC

4.2.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Non-directional earth-fault protection - Low stage	EFLPTOC	Io>	51N-1
Non-directional earth-fault protection - High stage	EFHPTOC	Io>>	51N-2
Non-directional earth-fault protection - Instantaneous stage	EFIPTOC	Io>>>	50N/51N

4.2.1.2 Function block

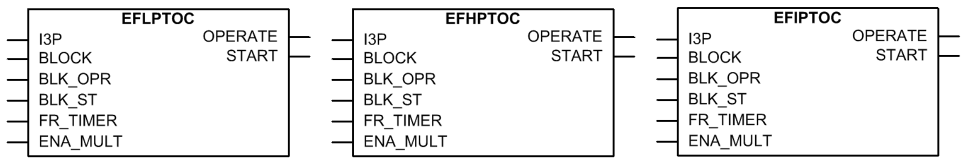


Figure 194: Function block

4.2.1.3 Functionality

The earth-fault function EFxPTOC is used as non-directional earth-fault protection for feeders.

The function starts and operates when the residual current exceeds the set limit. The operate time characteristic for low stage EFLPTOC and high stage EFHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage EFIPTOC always operates with the DT characteristic.

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.2.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of non-directional earth-fault protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

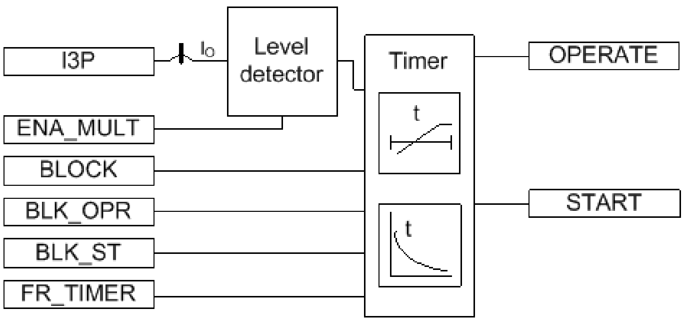


Figure 195: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Level detector

If the measured residual current is configured to be available for the protection function it will be used as operating quantity. Otherwise the internally calculated residual current is used, see more details from the SMAI function. The operating quantity is compared to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector sends an enable-signal to the timer module. If the ENA_MULT input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

Do not set the multiplier setting *Start value Mult* higher than necessary. If the value is too high, the function may not operate at all during an inrush followed by a fault, no matter how severe the fault is.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA_MULT input.

Timer

Once activated, the timer activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the `FR_TIMER` input.

4.2.1.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the residual current or voltage-related settings, for example, "*Residual Grp 1*", "*Residual Grp 2*" and "*Residual Grp 3*". One of the groups to be used with the "Base value Sel Res" setting must be selected.

4.2.1.6 Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

Table 430: Measurement modes supported by EFxPTOC stages

Measurement mode	Supported measurement modes		
	EFLPTOC	EFHPTOC	EFIPTOC
RMS	x	x	
DFT	x	x	
Peak-to-Peak	x	x	x

For a detailed description of the measurement modes, see the General function block features section in this manual.

4.2.1.7 Timer characteristics

EFxPTOC supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* and *Type of reset curve* settings. When the DT characteristic is selected, it is only affected by the *Operate delay time* and *Reset delay time* settings.

The IED provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The user can choose the DT characteristic by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The following characteristics, which comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages:

Table 431: Timer characteristics supported by different stages

Operating curve type	Supported by	
	EFLPTOC	EFHPTOC
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	x	
(5) ANSI Definite Time	x	x
(6) Long Time Extremely Inverse	x	
(7) Long Time Very Inverse	x	
(8) Long Time Inverse	x	
(9) IEC Normal Inverse	x	x
(10) IEC Very Inverse	x	x
(11) IEC Inverse	x	
(12) IEC Extremely Inverse	x	x
(13) IEC Short Time Inverse	x	
(14) IEC Long Time Inverse	x	
(15) IEC Definite Time	x	x
(17) User programmable curve	x	x
(18) RI type	x	
(19) RD type	x	

EFIPTOC supports only definite time characteristics.

For a detailed description of timers, see the General function block features section in this manual.

The *Type of reset curve* setting does not apply to EFIPTOC or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

4.2.1.8 Application

EFxPTOC is designed for protection and clearance of earth faults in distribution and sub-transmission networks where the neutral point is isolated or earthed via a resonance coil or through low resistance. It also applies to solidly earthed networks and earth-fault protection of different equipment connected to the power systems, such as shunt capacitor bank or shunt reactors and for backup earth-fault protection of power transformers.

Many applications require several steps using different current start levels and time delays. EFxPTOC consists of three different protection stages:

- Low (EFLPTOC)
- High (EFHPTOC)
- Instantaneous (EFIPTOC).

EFLPTOC contains several types of time-delay characteristics. EFHPTOC and EFIPTOC are used for fast clearance of serious earth faults.

Note the following when using the earth-fault function for the protection of transformers. When a power transformer is energized, an inrush current flows through the earthed star-point of all the transformers connected to the bus. This can cause the earth-fault function to operate. The operation can be avoided by using blocking from inrush detection or by setting longer operation time.

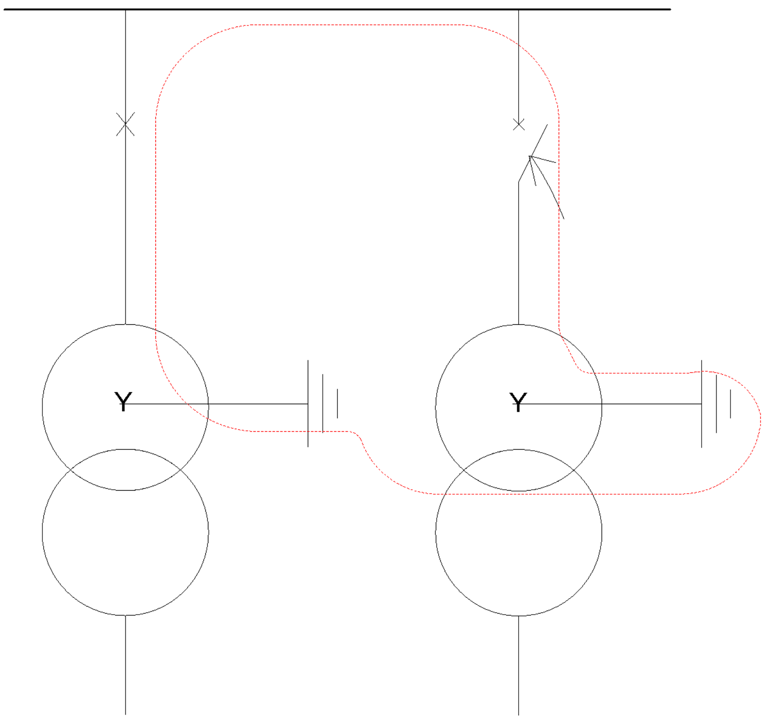


Figure 196: Path of inrush currents through earthed star-points of transformers

When the residual connection of the three phase CTs is used, an unwanted operation of the earth-fault protection IED sometimes occur during the motor startup. The reason for the unwanted IED operation typically happens due to the CT partial saturation during the motor startup. The CT saturation is caused by the DC component of the asymmetrical startup current. To avoid this problem a suitable stabilizing resistor can be connected in series with the earth-fault current input of the protection IED. The stabilizing resistor forces the current, fed by a non-saturated current transformer, to flow through the secondary circuit of a saturated current transformer.

Figure 197 shows the connection principle when the earth-fault current is measured through the residual connection of the three-phase CTs. The purpose of the voltage dependent resistor is to limit the voltage of the secondary circuit to a safe level.

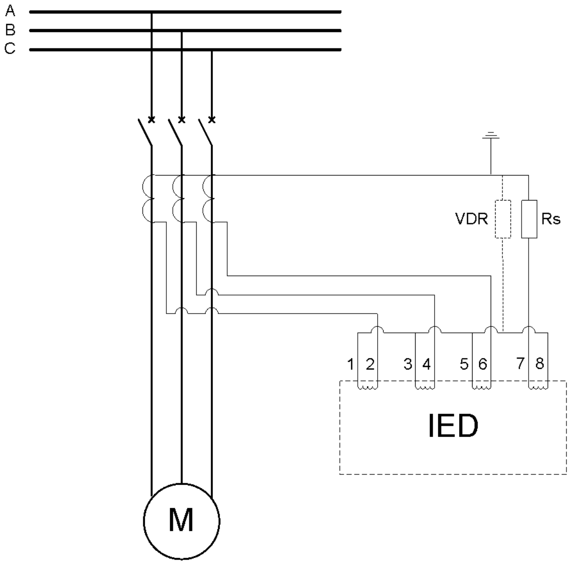


Figure 197: Connection principle of the earth-fault current when measured through the residual connection of the three-phase CTs

4.2.1.9 Signals

Table 432: EFLPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 433: *EFHPTOC Input signals*

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 434: *EFIPTOC Input signals*

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 435: *EFLPTOC Output signals*

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started

Table 436: *EFHPTOC Output signals*

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started

Table 437: *EFIPTOC Output signals*

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started

4.2.1.10 Settings

Table 438: EFLPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.010 - 5.000	pu	0.005	0.010	Start value
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	ANSI Ext. inv. ANSI Very inv. ANSI Norm. inv. ANSI Mod. inv. ANSI Def. Time L.T.E. inv. L.T.V. inv. L.T. inv. IEC Norm. inv. IEC Very inv. IEC inv. IEC Ext. inv. IEC S.T. inv. IEC L.T. inv. IEC Def. Time Programmable RI type RD type	-	-	ANSI Def. Time	Selection of time delay curve type
Operate delay time	0.04 - 200.00	s	0.01	0.04	Operate delay time

Table 439: EFLPTOC Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type

Table 440: EFLPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 441: EFLPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Selects used measurement mode
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time
Minimum operate time	0.040 - 60.000	s	0.001	0.040	Minimum operate time for IDMT curves

Table 442: EFHPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.10 - 40.00	pu	0.01	0.10	Start value
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	ANSI Ext. inv. ANSI Norm. inv. ANSI Def. Time IEC Norm. inv. IEC Very inv. IEC Ext. inv. IEC Def. Time Programmable	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.02 - 200.00	s	0.01	0.02	Operate delay time

Table 443: EFHPTOC Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type

Table 444: EFHPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 445: EFHPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Selects used measurement mode
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time
Minimum operate time	0.020 - 60.000	s	0.001	0.020	Minimum operate time for IDMT curves

Table 446: EFIPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.10 - 40.00	pu	0.01	0.10	Start value
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Operate delay time	0.02 - 200.00	s	0.01	0.02	Operate delay time

Table 447: EFIPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 448: EFIPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.2.1.11 Measured values

Table 449: EFLPTOC Measured values

Name	Type	Default	Description
I_AMPL_RES	REAL	0	Residual current amplitude (DFT)
I_RMS_RES	REAL	0	Residual current amplitude (RMS)
I_PTOP_RES	REAL	0	Residual current amplitude (PTOP)
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 450: EFHPTOC Measured values

Name	Type	Default	Description
I_AMPL_RES	REAL	0	Residual current amplitude (DFT)
I_RMS_RES	REAL	0	Residual current amplitude (RMS)
I_PTOP_RES	REAL	0	Residual current amplitude (PTOP)
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

Table 451: EFIPTOC Measured values

Name	Type	Default	Description
I0_PTOP	REAL	0	Residual current amplitude (PTOP)
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier

4.2.1.12 Monitored data

Table 452: EFLPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
START_DUR	REAL	-	%	Ratio of start time / operate time
INVAL_CRV	BOOLEAN	0=FALSE 1=TRUE	-	Invalid curve parameters

Table 453: EFHPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
START_DUR	REAL	-	%	Ratio of start time / operate time
INVAL_CRV	BOOLEAN	0=FALSE 1=TRUE	-	Invalid curve parameters

Table 454: EFIPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
START_DUR	REAL	-	%	Ratio of start time / operate time

4.2.1.13 Technical data

Table 455: EFxPTOC Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
	EFLPTOC	±1.5% of the set value or $\pm 0.001 \times I_n$
	EFHPTOC and EFIPTOC	±1.5% of set value or $\pm 0.002 \times I_n$ (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n)
Table continues on next page		

Characteristic		Value
Start time [1][2]	EFIPTOC: I_{Fault} = 2 × set *Start value*	Typically 12 ms (±5 ms)
	EFHPTOC: I_{Fault} = 2 × set *Start value*	Typically 19 ms (±5 ms)
	EFLPTOC: I_{Fault} = 2 × set *Start value*	Typically 23 ms (±15 ms)
Reset time		<45 ms
Reset ratio		Typically 0.96
Retardation time		<30 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms [3]
Suppression of harmonics		RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression

1) *Operate curve type* = IEC definite time, *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 50 Hz, earth-fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20

4.2.1.14 Technical revision history

Table 456: EFLPTOC technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

Table 457: EFHPTOC technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

4.2.2 Directional earth-fault protection DEFxPDEF

4.2.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional earth-fault protection - Low stage	DEFLPDEF	Io>->	67N-1
Directional earth-fault protection - High stage	DEFHPDEF	Io>>->	67N-2

4.2.2.2 Function block

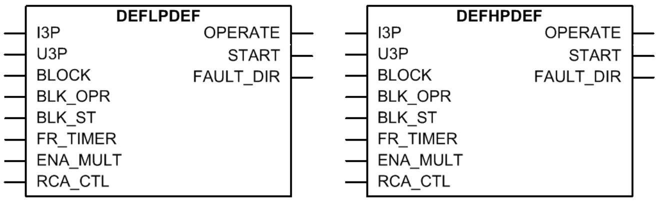


Figure 198: Function block

4.2.2.3 Functionality

The earth-fault function DEFxPDEF is used as directional earth-fault protection for feeders.

The function starts and operates when the operating quantity (current) and polarizing quantity (voltage) exceed the set limits and the angle between them is inside the set operating sector. The operate time characteristic for low stage (DEFLPDEF) and high stage (DEFHPDEF) can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.2.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of directional earth-fault protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

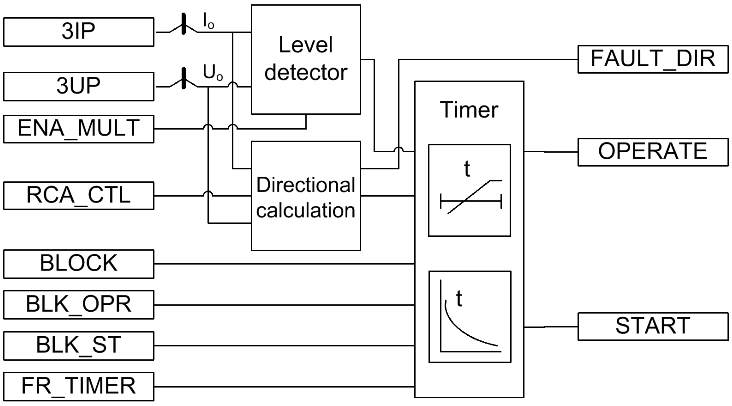


Figure 199: Functional module diagram. Group signals I3P and U3P are used for feeding the necessary analog signals to the function.

Level detector

The polarizing quantity can be selected with the setting *Pol quantity*. The selectable options are ""Zero seq. volt."" and ""Neg. seq. volt."". The option ""Zero seq. volt."" refers to the measured residual voltage if the measured residual voltage is configured to be available for the protection function. Otherwise it refers to the internally calculated residual voltage, see the SMAI function for more details. The magnitude of the operating quantity is compared to the set *Start value* and the magnitude of the polarizing quantity is compared to the set *Voltage start value*. If both limits are exceeded, the level detector sends an enabling signal to the timer module. When the *Enable voltage limit* setting is set to "No", *Voltage start value* has no effect and the level detection is purely based on the operating quantity. If the `ENA_MULT` input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

Typically, the `ENA_MULT` input is connected to the inrush detection function INRHPAR. In case of inrush, INRPHAR activates the `ENA_MULT` input, which multiplies *Start value* by the *Start value Mult* setting.

Directional calculation

The directional calculation module monitors the angle between the polarizing quantity and operating quantity. Depending on the *Pol quantity* setting, the polarizing quantity can be the residual voltage or the negative sequence voltage. When the angle is in the operation sector, the module sends the enabling signal to the timer module.

The minimum signal level which allows the directional operation can be set with the *Min operate current* and *Min operate voltage* settings.

If *Pol quantity* is set to "Zero seq. volt", the residual current and residual voltage are used for directional calculation.

If *Pol quantity* is set to "Neg. seq. volt", the negative sequence current and negative sequence voltage are used for directional calculation.

A convention is used in the phasor diagrams representing the operation of DEFxPDEF; the polarity of the polarizing quantity (Uo or U2) is reversed, that is, the polarizing quantity in the phasor diagrams is either -Uo or -U2. Reversing is done by switching the polarity of the residual current measuring channel. Similarly the polarity of the calculated Io and I_2 is also switched.

For defining the operation sector, five modes are available through the *Operation mode* setting.

Table 458: Operation modes

Operation mode	Description
Phase angle	The operating sectors for forward and reverse are defined with the settings *Min forward angle*, *Max forward angle*, *Min reverse angle* and *Max reverse angle*.
IoSin	The operating sectors are defined as "forward" when |Io| × sin (ANGLE) has a positive value and "reverse" when the value is negative. ANGLE is the angle difference between -Uo and Io.
IoCos	As "IoSin" mode. Only cosine is used for calculating the operation current.
Phase angle 80	The sector maximum values are frozen to 80 degrees respectively. Only *Min forward angle* and *Min reverse angle* are settable.
Phase angle 88	The sector maximum values are frozen to 88 degrees. Otherwise as "Phase angle 80" mode.

Polarizing quantity selection "Neg. seq. volt." is available only in the "Phase angle" operation mode.

The directionality of the operation can be selected with the *Directional mode* setting. The user can select either "Non-directional", "Forward" or "Reverse" operation. The operation criterion is selected with the *Operation mode* setting. By setting *Allow Non Dir* to "True", non-directional operation is allowed when the directionality information is invalid, that is, when the magnitude of the polarizing quantity is less than the value of the *Min operate voltage* setting.

If the *Enable voltage limit* setting is set to "True", the magnitude of the polarizing quantity is checked even if *Directional mode* is set to "Non-directional" or *Allow Non Dir* to "True".

The *Characteristic angle* setting is used in the "Phase angle" mode to adjust the operation according to the method of neutral point earthing so that in an isolated network the *Characteristic angle* (φ_{RCA}) = -90° and in a compensated network

φ_{RCA} = 0°. In addition, the characteristic angle can be changed via the control signal RCA_CTL. RCA_CTL affects the *Characteristic angle* setting.

The *Correction angle* setting can be used to improve selectivity when there are inaccuracies due to measurement transformers. The setting decreases the operation sector. The correction can only be used with the "IoCos" or "IoSin" modes.

The polarity of the polarizing quantity can be reversed by setting the *Pol reversal* to "True", which turns the polarizing quantity by 180 degrees.

For definitions of different directional earth-fault characteristics, see the Directional earth-fault characteristics section in this manual.

The directional calculation module calculates several values which are presented in the monitored data.

Table 459: Monitored data values

Monitored data values	Description
FAULT_DIR	The detected direction of fault during fault situations, that is, when START output is active.
DIRECTION	The momentary operating direction indication output.
ANGLE	Also called operating angle, shows the angle difference between the polarizing quantity (Uo, U_2) and operating quantity (Io, I_2).
ANGLE_RCA	The angle difference between the operating angle and *Characteristic angle*, that is, ANGLE_RCA = ANGLE – *Characteristic angle*.
I_OPER	The current that is used for fault detection. If the *Operation mode* setting is "Phase angle", "Phase angle 80" or "Phase angle 88", I_OPER is the measured or calculated residual current. If the *Operation mode* setting is "IoSin", I_OPER is calculated as follows I_OPER = Io × sin(ANGLE). If the *Operation mode* setting is "IoCos", I_OPER is calculated as follows I_OPER = Io × cos(ANGLE).

Monitored data values are accessible on the LHMI or through tools via communications.

Timer

Once activated, the timer activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The `START` output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets internal timers. The binary input `BLK_ST` can be used to block the start signals. The binary input `BLK_OPR` can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the `FR_TIMER` input.

The angle values available at the input monitor data view are in radians.

4.2.2.5 Directional earth-fault principles

In many cases it is difficult to achieve selective earth-fault protection based on the magnitude of residual current only. To obtain a selective earth-fault protection scheme, it is necessary to take the phase angle of Io into account. This is done by comparing the phase angle of the operating and polarizing quantity.

Relay characteristic angle

The *Characteristic angle*, also known as Relay Characteristic Angle (RCA), Relay Base Angle or Maximum Torque Angle (MTA), is used in the "Phase angle" mode to turn the directional characteristic, if the expected fault current angle does not coincide with the polarizing quantity to produce the maximum torque. That is, RCA is the angle between the maximum torque line and polarizing quantity. If the polarizing quantity is in phase with the maximum torque line, RCA is 0 degrees. The angle is positive if operating current lags the polarizing quantity and negative if it leads the polarizing quantity.

Example 1.

The "Phase angle" mode is selected, compensated network (φRCA = 0 deg)

=> *Characteristic angle* = 0 deg

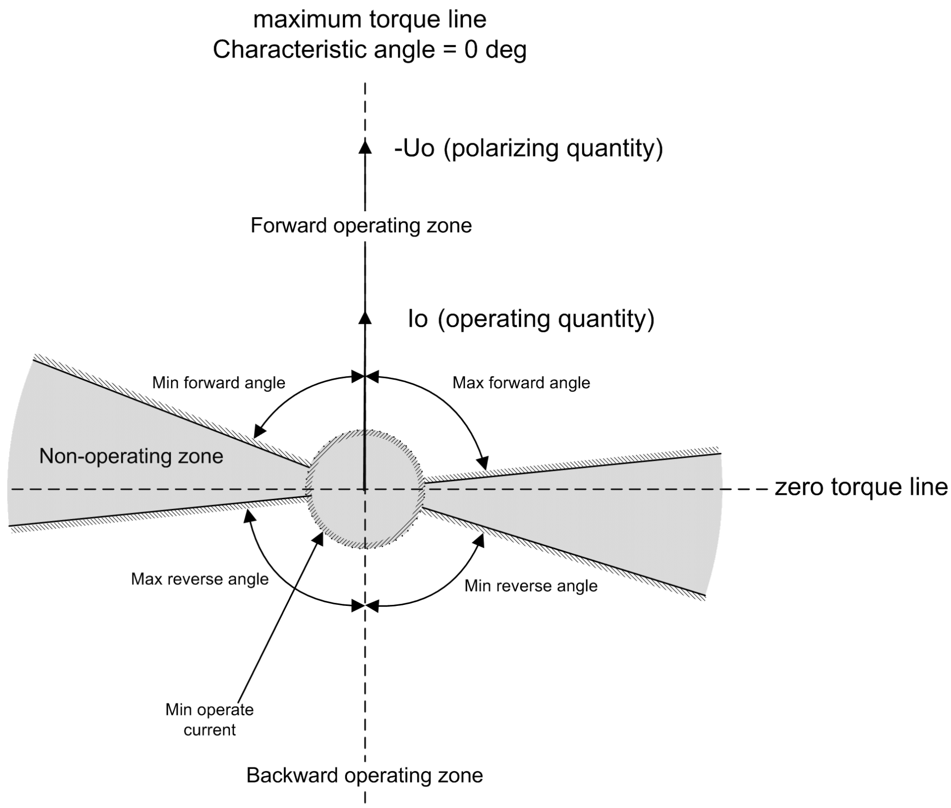


Figure 200: Definition of the relay characteristic angle, RCA=0 degrees in a compensated network

Example 2.

The "Phase angle" mode is selected, solidly earthed network (φRCA = +60 deg)

=> *Characteristic angle* = +60 deg

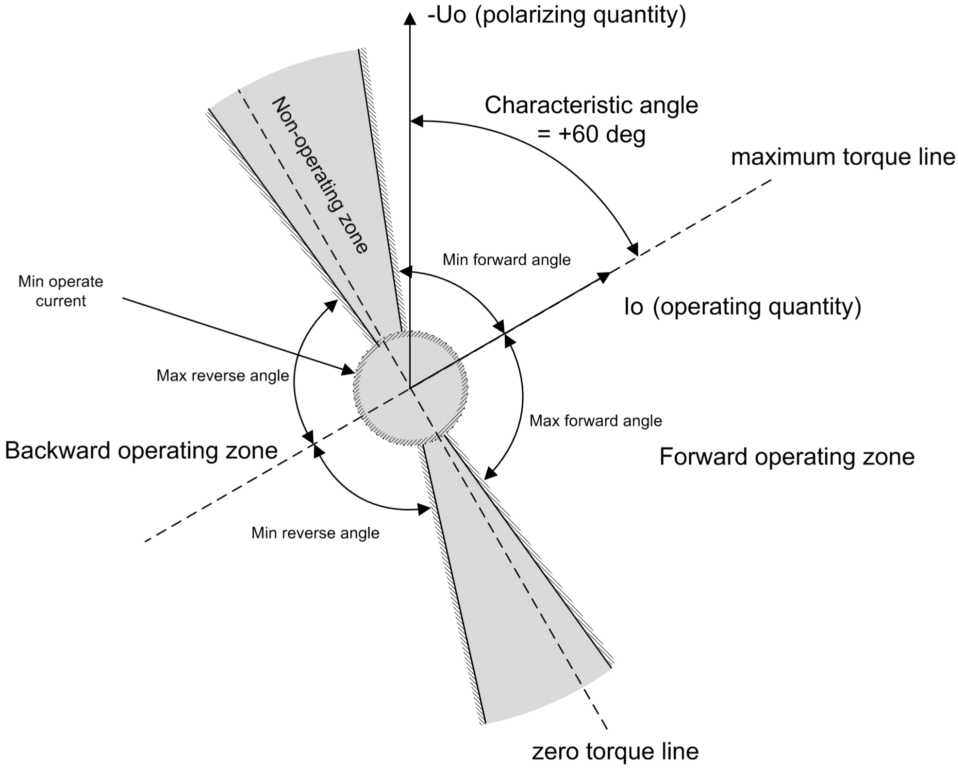


Figure 201: Definition of the relay characteristic angle, RCA=+60 degrees in a solidly earthed network

Example 3.

The "Phase angle" mode is selected, isolated network (φRCA = -90 deg)

=> *Characteristic angle* = -90 deg

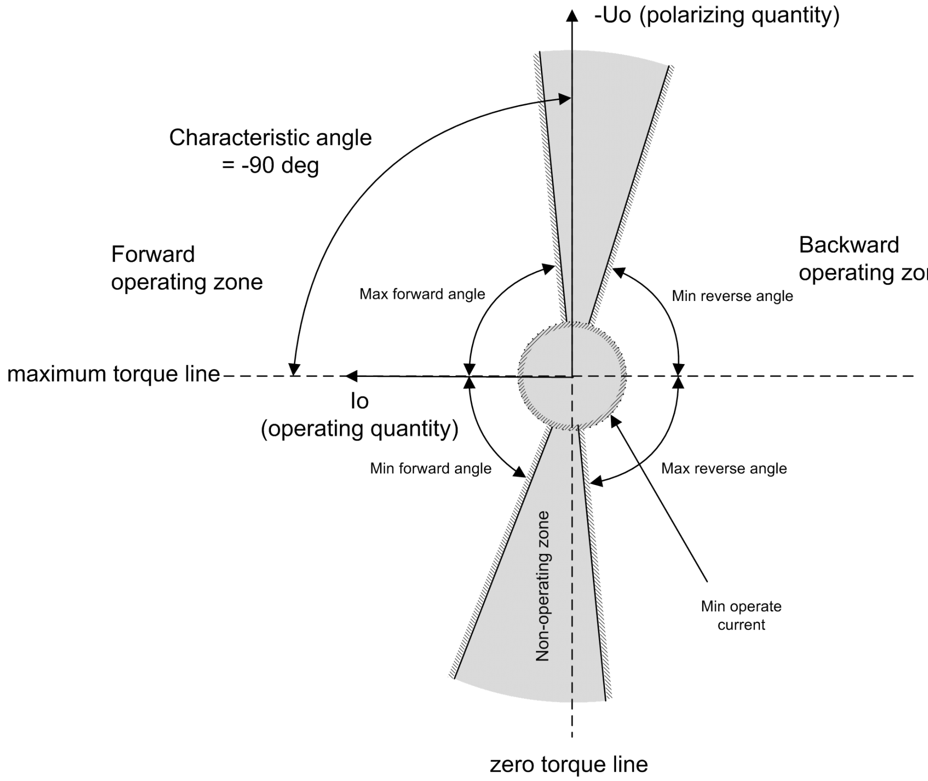


Figure 202: Definition of the relay characteristic angle, RCA=–90 degrees in an isolated network

Directional earth-fault protection in an isolated neutral network

In isolated networks, there is no intentional connection between the system neutral point and earth. The only connection is through the phase-to-earth capacitances (C_0) of phases and leakage resistances (R_0). This means that the residual current is mainly capacitive and has a phase shift of –90 degrees compared to the polarizing voltage. Consequently, the relay characteristic angle (RCA) should be set to -90 degrees and the operation criteria to "IoSin" or "Phase angle". The width of the operating sector in the phase angle criteria can be selected with the settings *Min forward angle*, *Max forward angle*, *Min reverse angle* or *Max reverse angle*. Figure 203 illustrates a simplified equivalent circuit for an unearthed network with an earth fault in phase C.

For definitions of different directional earth-fault characteristics, see Directional earth-fault principles.

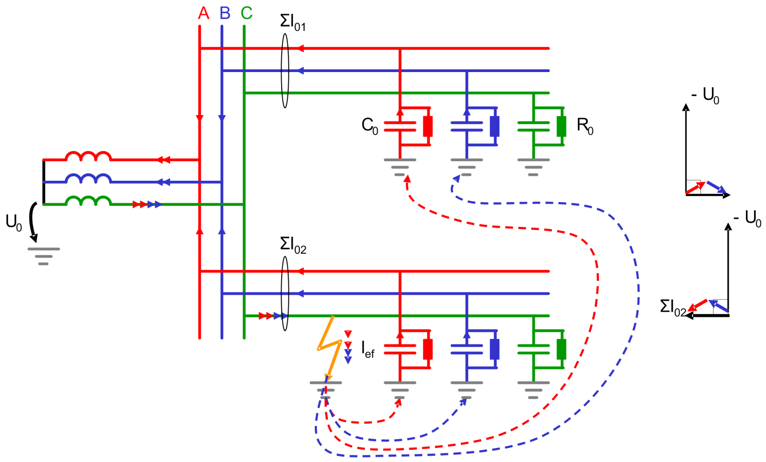


Figure 203: Earth-fault situation in an isolated network

Directional earth-fault protection in a compensated network

In compensated networks, the capacitive fault current and the inductive resonance coil current compensate each other. The protection cannot be based on the reactive current measurement, since the current of the compensation coil would disturb the operation of the relays. In this case, the selectivity is based on the measurement of the active current component. The magnitude of this component is often small and must be increased by means of a parallel resistor in the compensation equipment. When measuring the resistive part of the residual current, the relay characteristic angle (RCA) should be set to 0 degrees and the operation criteria to "IoSin" or "Phase angle". Figure 204 illustrates a simplified equivalent circuit for a compensated network with an earth fault in phase C.

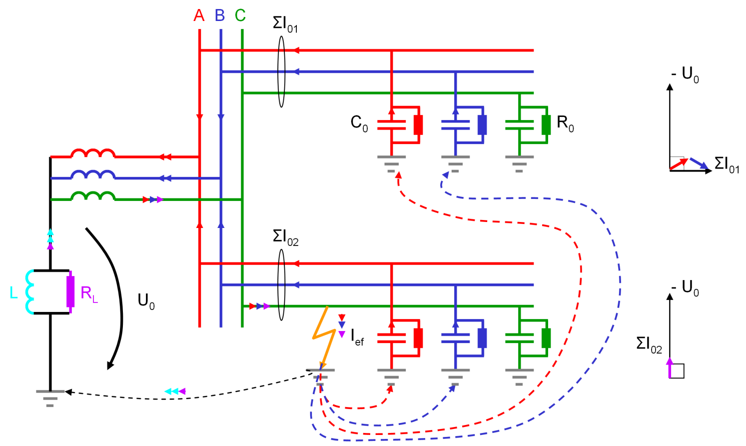


Figure 204: Earth-fault situation in a compensated network

The Petersen coil or the earthing resistor may be temporarily out of operation. To keep the protection scheme selective, it is necessary to update the characteristic angle setting accordingly. This can be done with an auxiliary input in the relay which receives a signal from an auxiliary switch of the disconnector of the Petersen coil in compensated networks. As a result the characteristic angle is set automatically to suit the earthing method used. The RCA_CTL input can be used to change the operation criteria as described in Table 460 and Table 461:

Table 460: Relay characteristic angle control in Iosin(φ) and Iocos(φ) operation criteria

Operation mode setting:	`RCA_CTL` = FALSE	`RCA_CTL` = TRUE
Iosin	Actual operation mode: Iosin	Actual operation mode: Iocos
Iocos	Actual operation mode: Iocos	Actual operation mode: Iosin

Table 461: Characteristic angle control in phase angle operation mode

Characteristic angle setting	`RCA_CTL` = FALSE	`RCA_CTL` = TRUE
-90°	φ_{RCA} = -90°	φ_{RCA} = 0°
0°	φ_{RCA} = 0°	φ_{RCA} = -90°

Use of the extended phase angle characteristic

The traditional method of adapting the directional earth-fault protection function to the prevailing neutral earthing conditions is done with the *Characteristic angle* setting. In an unearthed network, *Characteristic angle* is set to -90 degrees and in a compensated network *Characteristic angle* is set to 0 degrees. In case the earthing method of the network is temporarily changed from compensated to unearthed due to the disconnection of the arc suppression coil, the *Characteristic angle* setting should be modified correspondingly. This can be done using the setting groups or the `RCA_CTL` input. Alternatively, the operating sector of the directional earth-fault protection function can be extended to cover the operating sectors of both neutral earthing principles. Such characteristic is valid for both unearthed and compensated network and does not require any modification in case the neutral earthing changes temporarily from the unearthed to compensated network or vice versa.

The extended phase angle characteristic is created by entering a value of over 90 degrees for the *Min forward angle* setting; a typical value is 170 degrees (*Min reverse angle* in case *Directional mode* is set to "Reverse"). The *Max forward angle* setting should be set to cover the possible measurement inaccuracies of current and voltage transformers; a typical value is 80 degrees (*Max reverse angle* in case *Directional mode* is set to "Reverse").

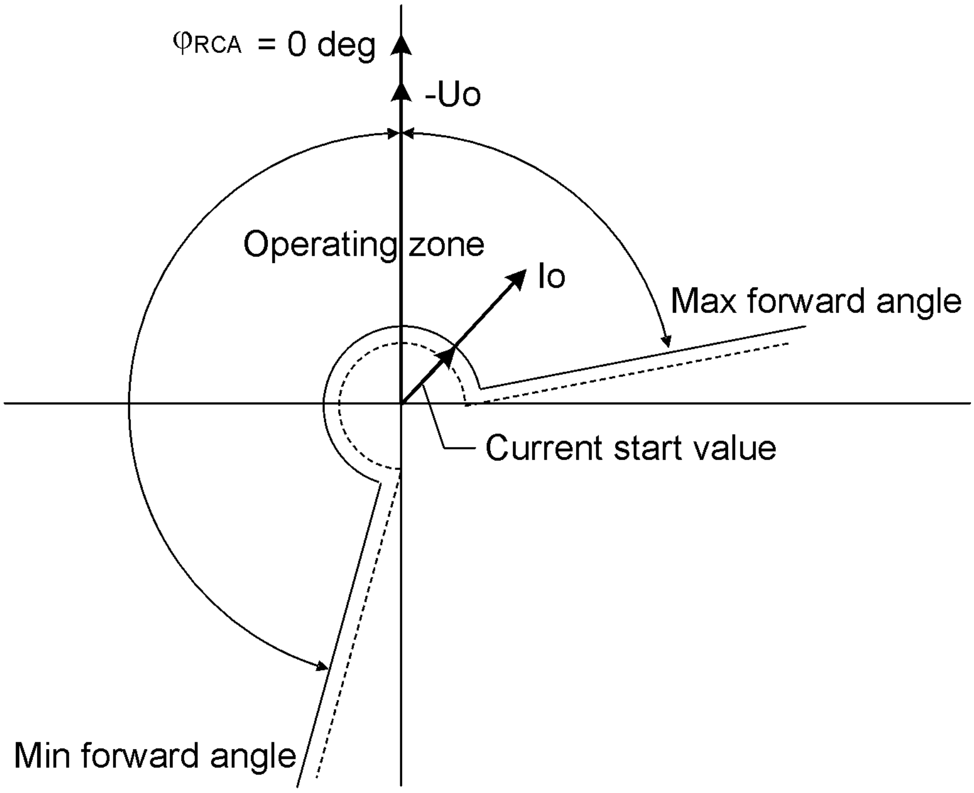


Figure 205: Extended operation area in directional earth-fault protection

4.2.2.6 Base values

In this function block, some of the settings are set in per unit (p.u). These p.u. values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "Phase Grp 1", "Phase Grp 2" and "Phase Grp 3". Similarly, "Residual Grp 1", "Residual Grp 2" and "Residual Grp 3" are supported for the residual current or voltage-related settings. One of the groups to be used with the *Base value Sel phase* or *Base value Sel Res* settings must be selected.

4.2.2.7 Timer characteristics

DEFxPDEF supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* setting.

The IED provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The user can choose the DT characteristic by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The following characteristics, which comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages:

Table 462: Timer characteristics supported by different stages

Operating curve type	Supported by	
	DEFLPDEF	DEFHPDEF
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	x	
(5) ANSI Definite Time	x	x
(6) Long Time Extremely Inverse	x	
(7) Long Time Very Inverse	x	
(8) Long Time Inverse	x	
(9) IEC Normal Inverse	x	
(10) IEC Very Inverse	x	
(11) IEC Inverse	x	
(12) IEC Extremely Inverse	x	
(13) IEC Short Time Inverse	x	
(14) IEC Long Time Inverse	x	
(15) IEC Definite Time	x	x
(17) User programmable curve	x	x
(18) RI type	x	
(19) RD type	x	

For a detailed description of the timers, see the General function block features section in this manual.

Table 463: Reset time characteristics supported by different stages

Reset curve type	Supported by		
	DEFLPDEF	DEFHPDEF	Note
(1) Immediate	x	x	Available for all operate time curves
(2) Def time reset	x	x	Available for all operate time curves
(3) Inverse reset	x	x	Available only for ANSI and user programmable curves

4.2.2.8 Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

Table 464: Measurement modes supported by DEFxPDEF stages

Measurement mode	Supported measurement modes	
	DEFLPDEF	DEFHPDEF
RMS	x	x
DFT	x	x
Peak-to-Peak	x	x

For a detailed description of the measurement modes, see the General function block features section in this manual.

4.2.2.9 Directional earth-fault characteristics

Phase angle characteristic

The operation criterion phase angle is selected with the *Operation mode* setting using the value "Phase angle".

When the phase angle criterion is used, the function indicates with the `DIRECTION` output whether the operating quantity is within the forward or reverse operation sector or within the non-directional sector.

The forward and reverse sectors are defined separately. The forward operation area is limited with the *Min forward angle* and *Max forward angle* settings. The reverse operation area is limited with the *Min reverse angle* and *Max reverse angle* settings.

The sector limits are always given as positive degree values.

In the forward operation area, the *Max forward angle* setting gives the clockwise sector and the *Min forward angle* setting correspondingly the counterclockwise sector, measured from the *Characteristic angle* setting.

In the reverse operation area, the *Max reverse angle* setting gives the clockwise sector and the *Min reverse angle* setting correspondingly the counterclockwise sector, measured from the complement of the *Characteristic angle* setting (180 degrees phase shift) .

The relay characteristic angle (RCA) is set to positive if the operating current lags the polarizing quantity. It is set to negative if it leads the polarizing quantity.

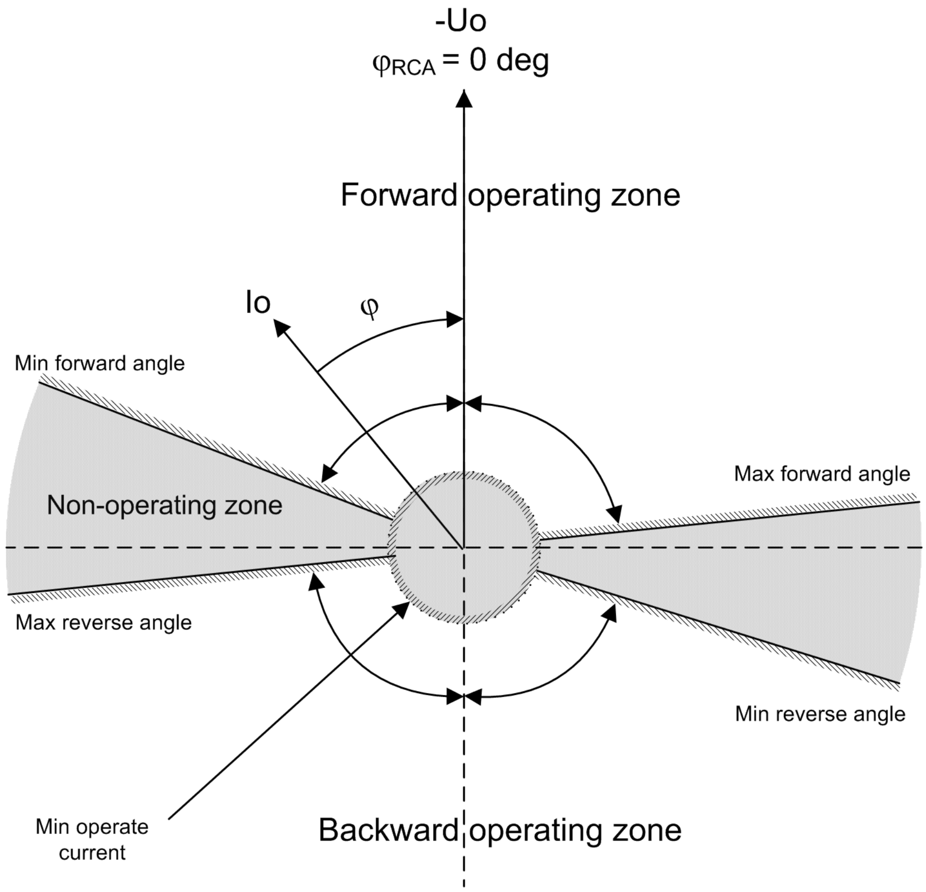


Figure 206: Configurable operating sectors in phase angle characteristic

Table 465: Momentary operating direction

Fault direction	The value for DIRECTION
Angle between the polarizing and operating quantity is not in any of the defined sectors.	0 = unknown
Angle between the polarizing and operating quantity is in the forward sector.	1= forward
Angle between the polarizing and operating quantity is in the reverse sector.	2 = backward
Angle between the polarizing and operating quantity is in both the forward and the reverse sectors, that is, the sectors are overlapping.	3 = both

If the *Allow Non Dir* setting is "False", the directional operation (forward, reverse) is not allowed when the measured polarizing or operating quantities are invalid, that is, their magnitude is below the set minimum values. The minimum values can be defined with the settings *Min operate current* and *Min operate voltage*. In case of low magnitudes, the FAULT_DIR and DIRECTION outputs are set to 0 = unknown, except when the *Allow non dir* setting is "True". In that case, the function is allowed to operate in the directional mode as non-directional, since the directional information is invalid.

Iosin(φ) and Iocos(φ) criteria

A more modern approach to directional protection is the active or reactive current measurement. The operating characteristic of the directional operation depends on the earthing principle of the network. The Iosin(φ) characteristics is used in an isolated network, measuring the reactive component of the fault current caused by the earth capacitance. The Iocos(φ) characteristics is used in a compensated network, measuring the active component of the fault current.

The operation criteria Iosin(φ) and Iocos(φ) are selected with the *Operation mode* setting using the values "IoSin" or "IoCos" respectively.

The angle correction setting can be used to improve selectivity. The setting decreases the operation sector. The correction can only be used with the Iosin(φ) or Iocos(φ) criterion. The RCA_CTL input is used to change the Io characteristic:

Table 466: Relay characteristic angle control in the IoSin and IoCos operation criteria

Operation mode:	RCA_CTL = "False"	RCA_CTL = "True"
IoSin	Actual operation criterion: Iosin(φ)	Actual operation criterion: Iocos(φ)
IoCos	Actual operation criterion: Iocos(φ)	Actual operation criterion: Iosin(φ)

When the Iosin(φ) or Iocos(φ) criterion is used, the component indicates a forward- or reverse-type fault through the FAULT_DIR and DIRECTION outputs, in which 1 equals a forward fault and 2 equals a reverse fault. Directional operation is not allowed (the *Allow non dir* setting is "False") when the measured polarizing or operating quantities are not valid, that is, when their magnitude is below the set minimum values. The minimum values can be defined with the *Min operate current* and *Min operate voltage* settings. In case of low magnitude, the FAULT_DIR and DIRECTION outputs are set to 0 = unknown, except when the *Allow non dir* setting is "True". In that case, the function is allowed to operate in the directional mode as non-directional, since the directional information is invalid.

The calculated Iosin(φ) or Iocos(φ) current used in direction determination can be read through the I_OPER monitored data. The value can be passed directly to a decisive element, which provides the final start and operate signals.

The I_OPER monitored data gives an absolute value of the calculated current.

The following examples show the characteristics of the different operation criteria:

Example 1.

Iosin(φ) criterion selected, forward-type fault

```
=> FAULT_DIR = 1
```

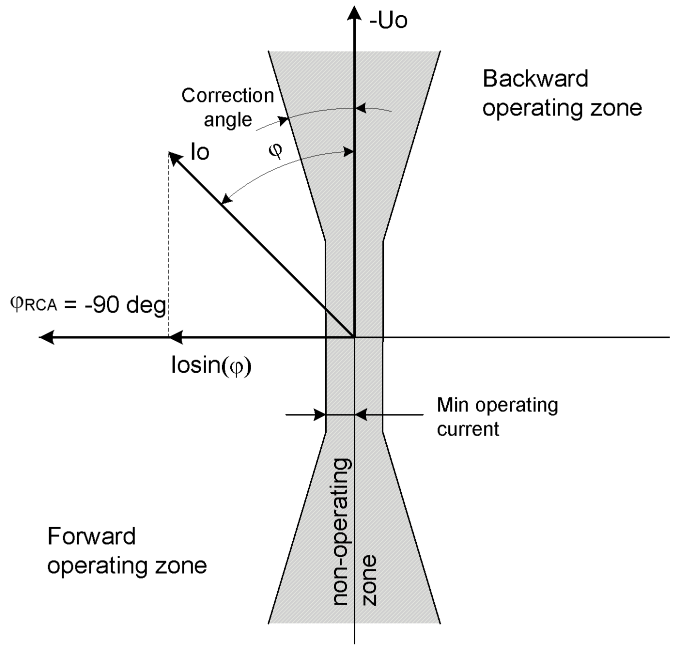


Figure 207: Operating characteristic Iosin(φ) in forward fault

The operating sector is limited by Angle correction, that is, the operating sector is 180 degrees - 2*(Angle correction).

Example 2.

Iosin(φ) criterion selected, reverse-type fault

```
=> FAULT_DIR = 2
```

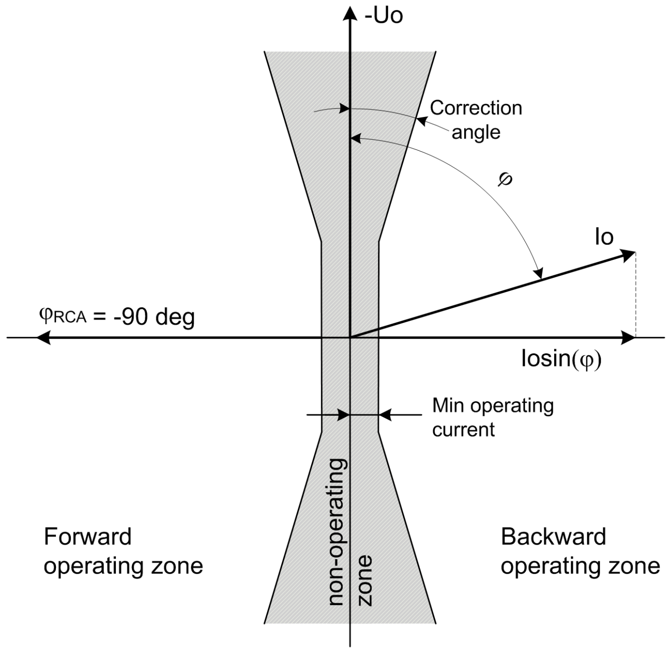


Figure 208: Operating characteristic Iosin(φ) in reverse fault

Example 3.

Iocos(φ) criterion selected, forward-type fault

`=> FAULT_DIR = 1`

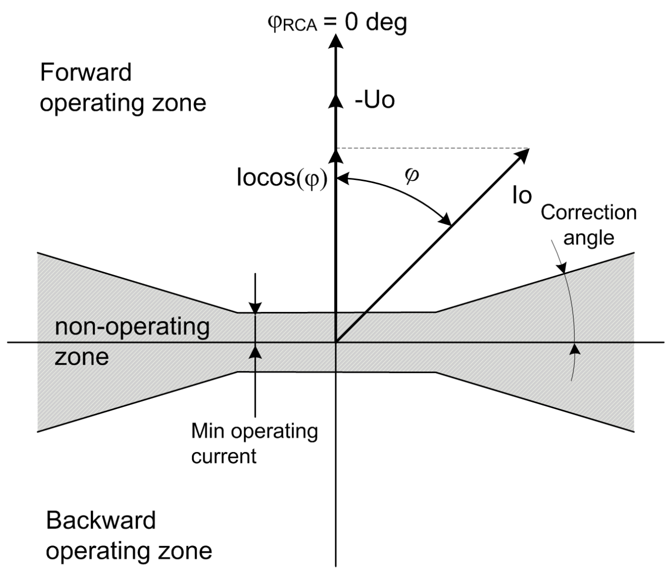


Figure 209: Operating characteristic Iocos(φ) in forward fault

Example 4.

Iocos(φ) criterion selected, reverse-type fault

```
=> FAULT_DIR = 2
```

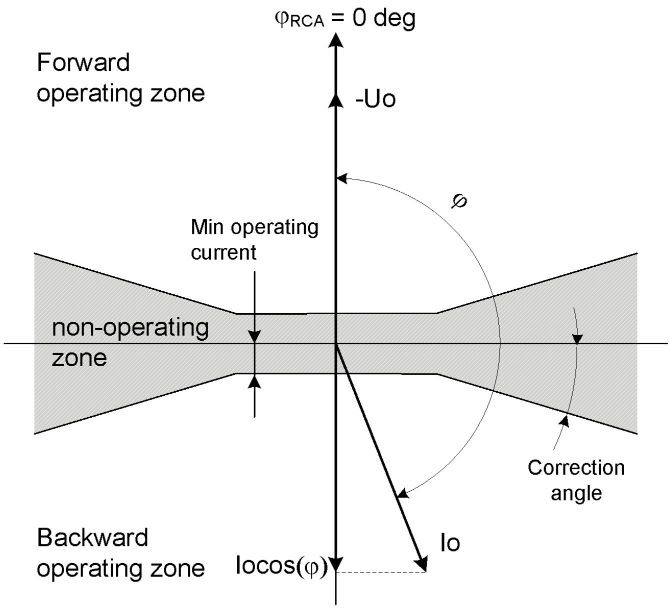


Figure 210: Operating characteristic Iocos(φ) in reverse fault

Phase angle 80

The operation criterion phase angle 80 is selected with the *Operation mode* setting by using the value "Phase angle 80".

Phase angle 80 implements the same functionality as the phase angle but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings cannot be set but they have a fixed value of 80 degrees
- The sector limits of the fixed sectors are rounded.

The sector rounding is used for cancelling the CT measurement errors at low current amplitudes. When the current amplitude falls below three percent of the nominal current, the sector is reduced to 70 degrees at the fixed sector side. This makes the protection more selective, which means that the phase angle measurement errors do not cause faulty operation.

There is no sector rounding on the other side of the sector.

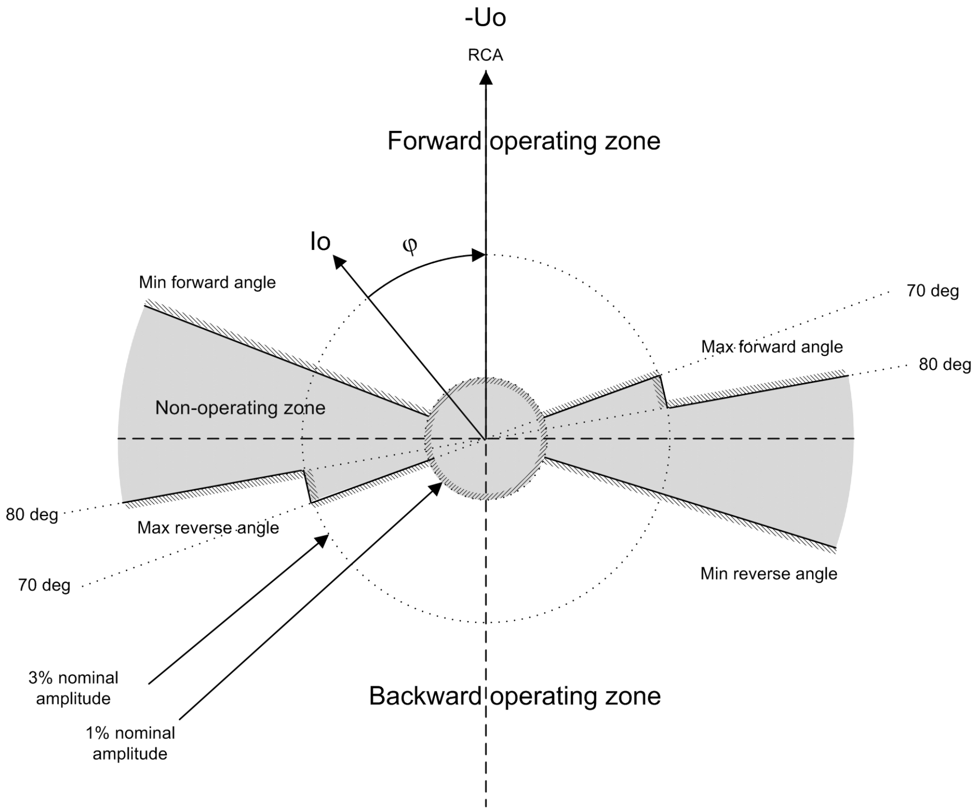


Figure 211: Operating characteristic for phase angle 80

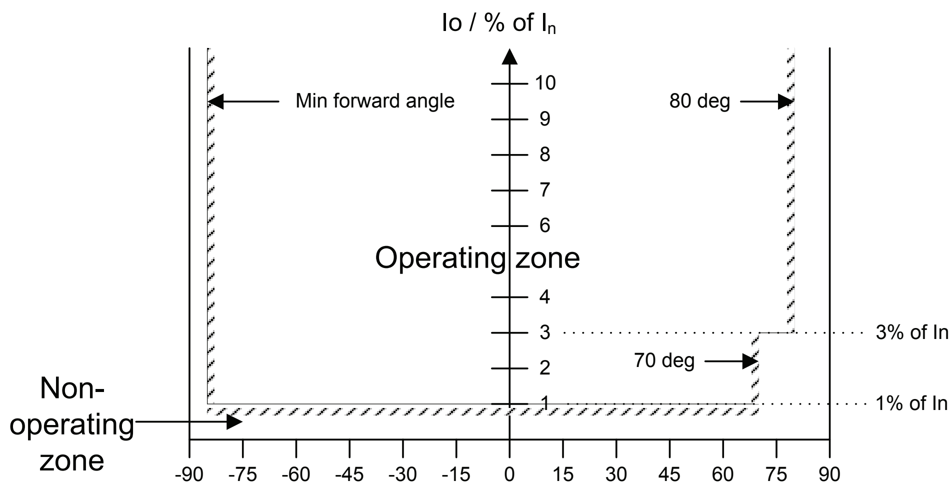


Figure 212: Phase angle 80 amplitude

Phase angle 88

The operation criterion phase angle 88 is selected with the *Operation mode* setting using the value "Phase angle 88".

Phase angle 88 implements the same functionality as the phase angle but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings cannot be set but they have a fixed value of 88 degrees
- The sector limits of the fixed sectors are rounded.

Sector rounding in the phase angle 88 consists of three parts:

- If the current amplitude is between 1...20 percent of the nominal current, the sector limit increases linearly from 73 degrees to 85 degrees
- If the current amplitude is between 20...100 percent of the nominal current, the sector limit increases linearly from 85 degrees to 88 degrees
- If the current amplitude is more than 100 percent of the nominal current, the sector limit is 88 degrees.

There is no sector rounding on the other side of the sector.

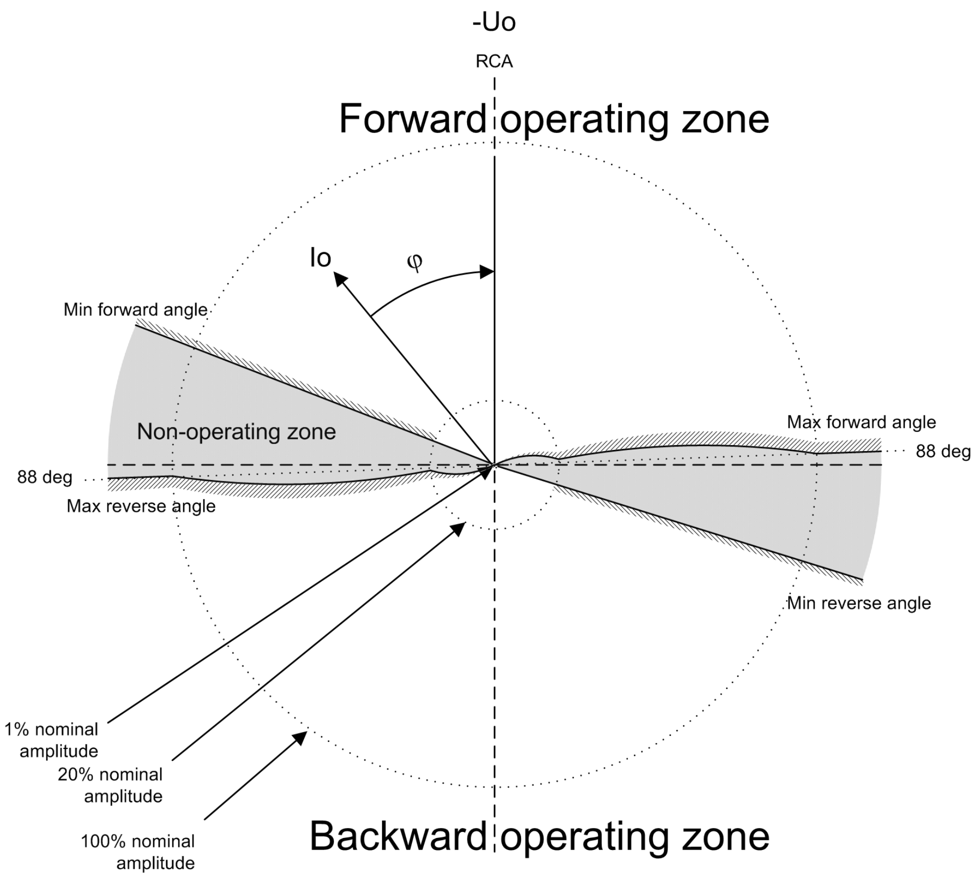


Figure 213: Operating characteristic for phase angle 88

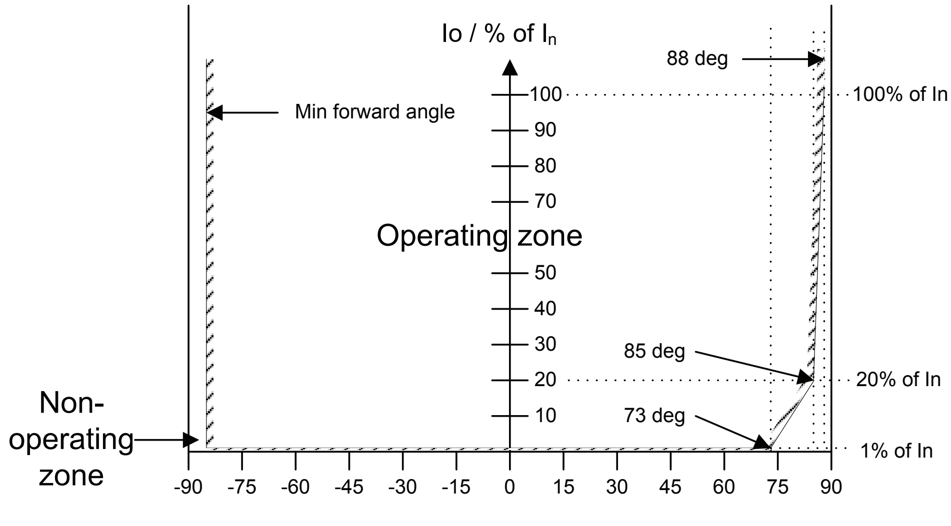


Figure 214: Phase angle 88 amplitude

4.2.2.10 Application

The directional earth-fault protection (DEFxPDEF) is designed for protection and clearance of earth faults and for earth-fault protection of different equipment connected to the power systems, such as shunt capacitor banks or shunt reactors, and for backup earth-fault protection of power transformers.

Many applications require several steps using different current start levels and time delays. DEFxPDEF consists of two different stages:

- low (DEFLPDEF)
- high (DEFHPDEF)

DEFLPDEF contains several types of time delay characteristics. DEFHPDEF is used for fast clearance of serious earth faults.

The protection can be based on the phase angle criterion with extended operating sector. It can also be based on measuring either the reactive part Iosin(φ) or the active part Iocos(φ) of the residual current. In isolated networks or in networks with high impedance earthing, the phase-to-earth fault current is significantly smaller than the short-circuit currents. In addition, the magnitude of the fault current is almost independent of the fault location in the network.

The function uses the residual current components Iocos(φ) or Iosin(φ) according to the earthing method, where φ is the angle between the residual current and the reference residual voltage (-Uo). In compensated networks, the phase angle criterion with extended operating sector can also be used. When the relay characteristic angle RCA is 0 degrees, the negative quadrant of the operation sector can be extended with the *Min forward angle* setting. The operation sector can be set between 0 and -180 degrees, so that the total operation sector is from +90 to

-180 degrees. In other words, the sector can be up to 270 degrees wide. This allows the protection settings to stay the same when the resonance coil is disconnected from between the neutral point and earth.

System neutral earthing is meant to protect personnel and equipment and to reduce interference for example in telecommunication systems. The neutral earthing sets challenges for protection systems, especially for earth-fault protection.

In isolated networks, there is no intentional connection between the system neutral point and earth. The only connection is through the line-to-earth capacitances (C_0) of phases and leakage resistances (R_0). This means that the residual current is mainly capacitive and has –90 degrees phase shift compared to the residual voltage (-Uo). The characteristic angle is -90 degrees.

In resonance-earthed networks, the capacitive fault current and the inductive resonance coil current compensate each other. The protection cannot be based on the reactive current measurement, since the current of the compensation coil would disturb the operation of the relays. In this case, the selectivity is based on the measurement of the active current component. This means that the residual current is mainly resistive and has zero phase shift compared to the residual voltage (-Uo) and the characteristic angle is 0 degrees. Often the magnitude of this component is small, and must be increased by means of a parallel resistor in the compensation equipment.

In networks where the neutral point is earthed through low resistance, the characteristic angle is also 0 degrees (for phase angle). Alternatively, Iocos(φ) operation can be used.

In solidly earthed networks, the *Characteristic angle* is typically set to +60 degrees for the phase angle. Alternatively, Iosin(φ) operation can be used with a reversal polarizing quantity. The polarizing quantity can be rotated 180 degrees by setting the *Pol reversal* parameter to "True" or by switching the polarity of the residual voltage measurement wires. Although the Iosin(φ) operation can be used in solidly earthed networks, the phase angle is recommended.

Connection of measuring transformers in directional earth fault applications

The residual current Io can be measured with a core balance current transformer or the residual connection of the phase current signals. If the neutral of the network is either isolated or earthed with high impedance, a core balance current transformer is recommended to be used in earth-fault protection. To ensure sufficient accuracy of residual current measurements and consequently the selectivity of the scheme, the core balance current transformers should have a transformation ratio of at least 70:1. Lower transformation ratios such as 50:1 or 50:5 are not recommended.

Attention should be paid to make sure the measuring transformers are connected correctly so that DEFxPDEF is able to detect the fault current direction without failure. As directional earth fault uses residual current and residual voltage (-Uo), the poles of the measuring transformers must match each other and also the fault current direction. Also the earthing of the cable sheath must be taken into notice when using core balance current transformers. The following figure describes how measuring transformers can be connected to the IED.

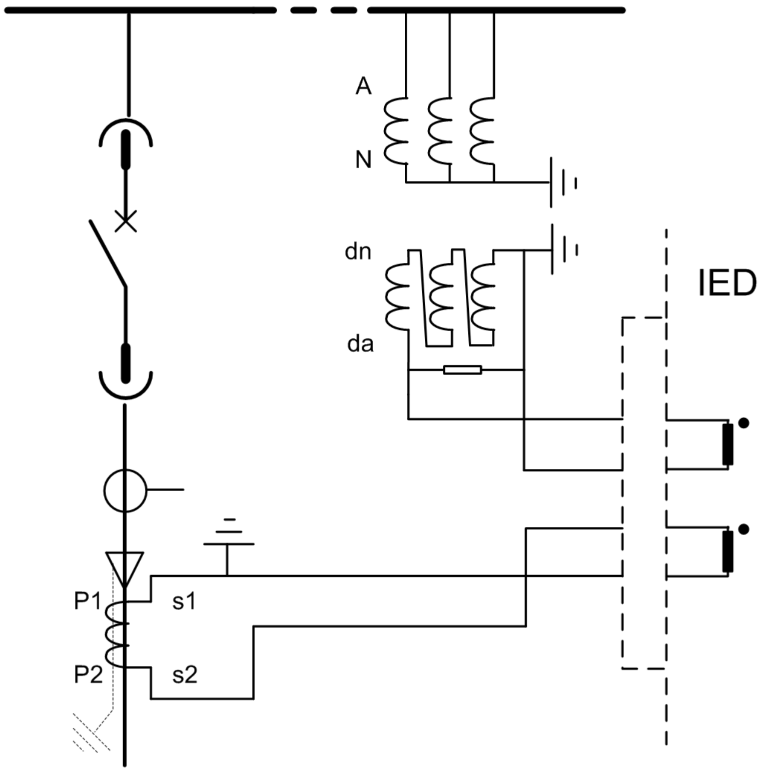


Figure 215: Connection of measuring transformers

4.2.2.11 Signals

Table 467: DEFLPDEF Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
U3P	GROUP SIGNAL	-	Group signal for voltage inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0	Relay characteristic angle control

Table 468: DEFHPDEF Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
U3P	GROUP SIGNAL	-	Group signal for voltage inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0	Relay characteristic angle control

Table 469: DEFLPDEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started
FAULT_DIR	INTEGER	Detected fault direction

Table 470: DEFHPDEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started
FAULT_DIR	INTEGER	Detected fault direction

4.2.2.12 Settings

Table 471: DEFLPDEF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Directional mode	Non-directional Forward Reverse	-	-	Forward	Directional mode
Start value	0.010 - 5.000	pu	0.005	0.010	Start value
Voltage start value	0.010 - 1.000	pu	0.001	0.010	Voltage start value
Characteristic angle	-179 - 180	Deg	1	-90	Characteristic angle
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	ANSI Ext. inv. ANSI Very inv. ANSI Norm. inv. ANSI Mod. inv. ANSI Def. Time L.T.E. inv. L.T.V. inv. L.T. inv. IEC Norm. inv. IEC Very inv. IEC inv. IEC Ext. inv. IEC S.T. inv. IEC L.T. inv. IEC Def. Time Programmable RI type RD type	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.06 - 200.00	s	0.01	0.06	Operate delay time

Table 472: DEFLPDEF Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Operation mode	Phase angle IoSin IoCos Phase angle 80 Phase angle 88	-	-	Phase angle	Operating quantity used to determine fault direction
Pol quantity	Zero seq. volt. Neg. seq. volt.	-	-	Zero seq. volt.	Polarizing quantity
Max forward angle	0 - 180	Deg	1	88	Maximum phase angle in forward direction
Min forward angle	0 - 180	Deg	1	88	Minimum phase angle in forward direction
Max reverse angle	0 - 180	Deg	1	88	Maximum phase angle in reverse direction
Min reverse angle	0 - 180	Deg	1	88	Minimum phase angle in reverse direction
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type
Enable voltage limit	No Yes	-	-	Yes	Enable voltage limit

Table 473: DEFLPDEF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 474: DEFLPDEF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Selects used measurement mode
Correction angle	0.0 - 10.0	Deg	0.1	0.0	Angle correction
Min operate current	0.005 - 1.000	pu	0.001	0.005	Minimum operating current
Min operate voltage	0.01 - 1.00	pu	0.01	0.01	Minimum operating voltage
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time
Minimum operate time	0.060 - 60.000	s	0.001	0.060	Minimum operate time for IDMT curves
Allow Non Dir	Not allowed Allowed	-	-	Not allowed	Allows prot activation as non-dir when dir info is invalid
Pol reversal	No Yes	-	-	No	Rotate polarizing quantity

Table 475: DEFHPDEF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Directional mode	Non-directional Forward Reverse	-	-	Forward	Directional mode
Start value	0.10 - 40.00	pu	0.01	0.10	Start value
Voltage start value	0.010 - 1.000	pu	0.001	0.010	Voltage start value
Characteristic angle	-179 - 180	Deg	1	-90	Characteristic angle
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	ANSI Ext. inv. ANSI Norm. inv. ANSI Def. Time IEC Def. Time Programmable	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.06 - 200.00	s	0.01	0.06	Operate delay time

Table 476: DEFHPDEF Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Operation mode	Phase angle IoSin IoCos Phase angle 80 Phase angle 88	-	-	Phase angle	Operating quantity used to determine fault direction
Pol quantity	Zero seq. volt. Neg. seq. volt.	-	-	Zero seq. volt.	Polarizing quantity
Max forward angle	0 - 180	Deg	1	88	Maximum phase angle in forward direction
Min forward angle	0 - 180	Deg	1	88	Minimum phase angle in forward direction
Max reverse angle	0 - 180	Deg	1	88	Maximum phase angle in reverse direction
Min reverse angle	0 - 180	Deg	1	88	Minimum phase angle in reverse direction
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type
Enable voltage limit	No Yes	-	-	Yes	Enable voltage limit

Table 477: DEFHPDEF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 478: DEFHPDEF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Selects used measurement mode
Correction angle	0.0 - 10.0	Deg	0.1	0.0	Angle correction
Min operate current	0.005 - 1.000	pu	0.001	0.005	Minimum operating current
Min operate voltage	0.01 - 1.00	pu	0.01	0.01	Minimum operating voltage
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time
Minimum operate time	0.060 - 60.000	s	0.001	0.060	Minimum operate time for IDMT curves
Allow Non Dir	Not allowed Allowed	-	-	Not allowed	Allows prot activation as non-dir when dir info is invalid
Pol reversal	No Yes	-	-	No	Rotate polarizing quantity

4.2.2.13 Measured values

Table 479: DEFLPDEF Measured values

Name	Type	Default	Description
I_AMPL_RES	REAL	0	Residual current amplitude (DFT)
I_ANGL_RES	REAL	0	Residual current phase angle
I_RMS_RES	REAL	0	Residual current amplitude (RMS)
I_PTOP_RES	REAL	0	Residual current amplitude (PTOP)
I2_AMPL	REAL	0	Negative sequence current amplitude (DFT)
I2_ANGL	REAL	0	Negative sequence current phase angle
U_AMPL_RES	REAL	0	Residual voltage amplitude (DFT)
U_ANGL_RES	REAL	0	Residual voltage phase angle
U2_AMPL	REAL	0	Negative sequence voltage amplitude (DFT)
U2_ANGL	REAL	0	Negative sequence voltage phase angle
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0	Relay characteristic angle control

Table 480: DEFHPDEF Measured values

Name	Type	Default	Description
I_AMPL_RES	REAL	0	Residual current amplitude (DFT)
I_ANGL_RES	REAL	0	Residual current phase angle
I_RMS_RES	REAL	0	Residual current amplitude (RMS)
I_PTOP_RES	REAL	0	Residual current amplitude (PTOP)
I2_AMPL	REAL	0	Negative sequence current amplitude (DFT)
I2_ANGL	REAL	0	Negative sequence current phase angle

Table continues on next page

Name	Type	Default	Description
U_AMPL_RES	REAL	0	Residual voltage amplitude (DFT)
U_ANGL_RES	REAL	0	Residual voltage phase angle
U2_AMPL	REAL	0	Negative sequence voltage amplitude (DFT)
U2_ANGL	REAL	0	Negative sequence voltage phase angle
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
ENA_MULT	BOOLEAN	0	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0	Relay characteristic angle control

4.2.2.14 Monitored data

Table 481: DEFLPDEF Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
FAULT_DIR	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Detected fault direction
DIRECTION	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information
ANGLE_RCA	REAL	-	deg	Angle between operating angle and characteristic angle
ANGLE	REAL	-	deg	Angle between polarizing and operating quantity
I_OPER	REAL	-	A	Calculated operating current
START_DUR	REAL	-	%	Ratio of start time / operate time
INVAL_CRV	BOOLEAN	0=FALSE 1=TRUE	-	Invalid curve parameters

Table 482: DEFHPDEF Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
FAULT_DIR	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Detected fault direction
DIRECTION	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Direction information
ANGLE_RCA	REAL	-	deg	Angle between operating angle and characteristic angle
ANGLE	REAL	-	deg	Angle between polarizing and operating quantity
I_OPER	REAL	-	A	Calculated operating current
START_DUR	REAL	-	%	Ratio of start time / operate time
INVAL_CRV	BOOLEAN	0=FALSE 1=TRUE	-	Invalid curve parameters

4.2.2.15 Technical data

Table 483: DEFxPDEF Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
	DEFLPDEF	Current: ±1.5% of the set value or ±0.002 × I_n Voltage ±1.5% of the set value or ±0.002 × U_n Phase angle: ±2°
	DEFHPDEF	Current: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n) Voltage: ±1.5% of the set value or ±0.002 × U_n Phase angle: ±2°
Start time [1)2)]	DEFHPDEF and DEFLPTDEF: I_{Fault} = 2 × set *Start value*	Typically 54 ms (±15 ms)
Reset time		Typically 40 ms
Reset ratio		Typically 0.96
Table continues on next page		

Characteristic	Value
Retardation time	<30 ms
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode	±5.0% of the theoretical value or ±20 ms 3)
Suppression of harmonics	RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression

1) *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 50 Hz, earth-fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5 to 20

4.2.2.16 Technical revision history

Table 484: DEFLPDEF technical revision history

Technical revision	Change
B	The setting *Voltage start value* is set in reference to *Voltage base Val PP*, if *Pol* quantity is set to “Neg. seq. volt" (previously it was *Voltage base Val Res*).
C	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

Table 485: DEFHPDEF technical revision history

Technical revision	Change
B	The setting *Voltage start value* is set in reference to *Voltage base Val PP*, if *Pol quantity* is set to “Neg. seq. volt" (previously it was *Voltage base Val Res*).
C	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

4.2.3 Transient/intermittent earth-fault protection INTRPTEF

4.2.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Transient/intermittent earth-fault protection	INTRPTEF	Io> ->IEF	67NIEF

4.2.3.2 Function block

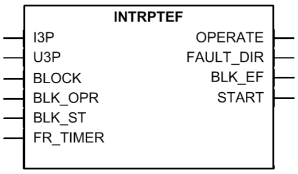


Figure 216: Function block

The INTRPTEF function block should always be connected to SMAI with 80 samples per cycle.

4.2.3.3 Functionality

The transient/intermittent measuring earth-fault protection INTRPTEF is a function designed for the protection and clearance of permanent and intermittent earth faults in distribution and sub-transmission networks. Fault detection is done from the residual current and residual voltage signals by monitoring the transients.

4.2.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of transient/intermittent earth-fault protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

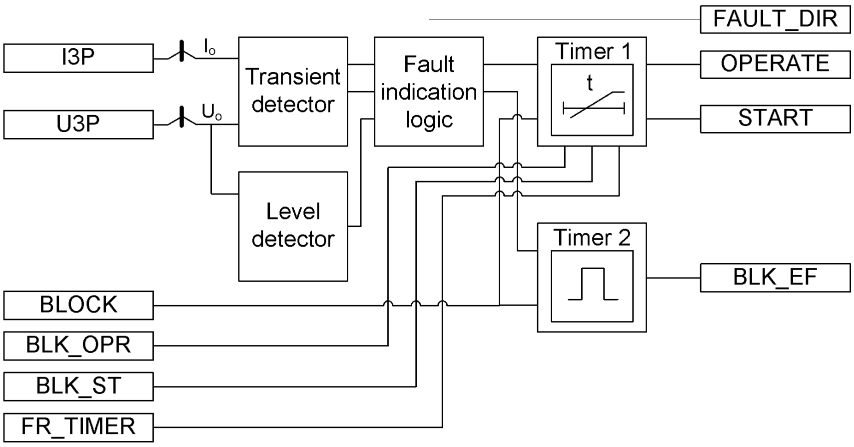


Figure 217: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Level detector

The Level detector module is used only when selected *Operation mode* is "Transient EF". The module compares the measured residual voltage to the set *Voltage start value*. If the measured value exceeds the set *Voltage start value*, the module reports the exceeding of the value to the Fault indication logic.

Transient detector

The transient detection is supervised with a settable current threshold. With a special filtering technique, the setting *Min operate current* is based on the fundamental frequency current. This setting should be set based on the value of the parallel resistor of the coil, with security margin. For example, if the resistive current of the parallel resistor is 10 A, a value of 0.7 × 10 A = 7 A could be used. The same setting is applicable in case the coil is disconnected and the network becomes unearthed. Generally, a smaller value should be used and it must never exceed the value of the parallel resistor to allow operation of the faulted feeder.

Fault indication logic

Depending on the set *Operation mode*, INTRPTEF has two independent modes for detecting earth faults. The "Transient EF" mode is intended to detect all kinds of earth faults. The "Intermittent EF" mode is dedicated for detecting intermittent earth faults in cable networks.

To satisfy the sensitivity requirements, the basic earth-fault protection (based on fundamental frequency phasors) should always be used in parallel with INTRPTEF function.

The Fault indication logic module determines the direction of the fault. The fault direction determination is secured by multi-frequency neutral admittance measurement and special filtering techniques. This enables fault direction determination which is not sensitive to disturbances in measured Io and Uo signals, for example, switching transients.

When the setting value "Forward" is used, the protection operates when the fault is in the protected feeder. When the setting value "Reverse" is used, the protection operates when the fault is outside the protected feeder (in the background network). If the direction has no importance, the value "Non-directional" can be selected. The detected fault direction FAULT_DIR is available as output or in the monitored data view.

In the "Transient EF" mode, when the start transient of the fault is detected and the Uo level exceeds the set *Voltage start value*, Timer 1 is activated. Timer 1 is kept activated until the Uo level exceeds the set value or in case of a drop-off, the drop-off duration is shorter than the set *Reset delay time*.

In the "Intermittent EF" mode, when the start transient of the fault is detected and the Uo level exceeds the set *Voltage start value*, Timer 1 is activated. When a required amount of intermittent earth-fault transients set with the *Peak counter* *limit* setting are detected without the function being reset (depends on the drop-off time set with the *Reset delay time* setting), Timer 1 is activated. The `START` output is kept activated as long as transients are occurring during the drop-off time *Reset delay time*.

Timer 1

The time characteristic is according to DT. In the "Transient EF" mode, the `OPERATE` output is activated after *Operate delay time* if the residual voltage exceeds the set *Voltage start value*. The *Reset delay time* starts to elapse when residual voltage falls below *Voltage start value*. If there is no OPERATE activation, for example, the fault disappears momentarily, START stays activated until the *Reset delay time* elapses. After OPERATE activation, START and OPERATE signals are reset as soon as Uo falls below *Voltage start Value*.

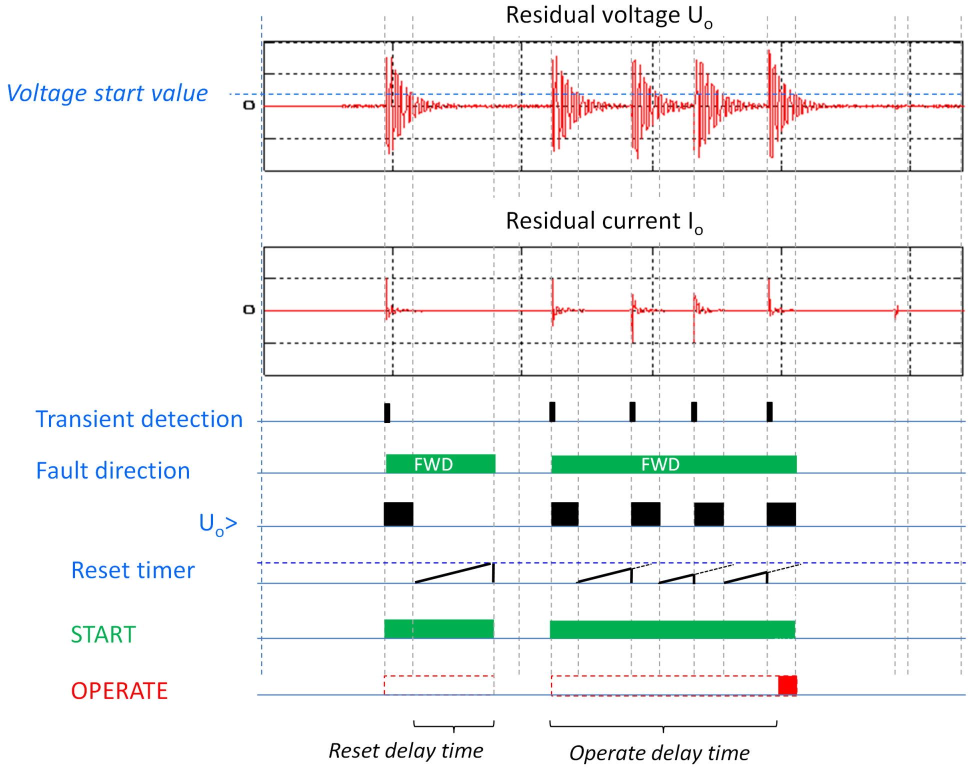


Figure 218: Example of INTRPTEF operation in "Transient EF" mode in the faulty feeder

In the "Intermittent EF" mode, the `OPERATE` output is activated when the following conditions are fulfilled.

- The number of transients that have been detected exceeds the *Peak counter limit* setting
- The timer has reached the time set in the *Operate delay time* setting
- One additional transient is detected during the drop-off cycle

The *Reset delay time* starts to elapse from each detected transient (peak). In case there is no OPERATE activation, for example, the fault disappears momentarily. START stays activated until the *Reset delay time* elapses, that is, reset takes place if time between transients is more than *Reset delay time*. After OPERATE activation, a fixed pulse length of 100 ms for OPERATE is given, whereas START is reset after *Reset delay time* elapses.

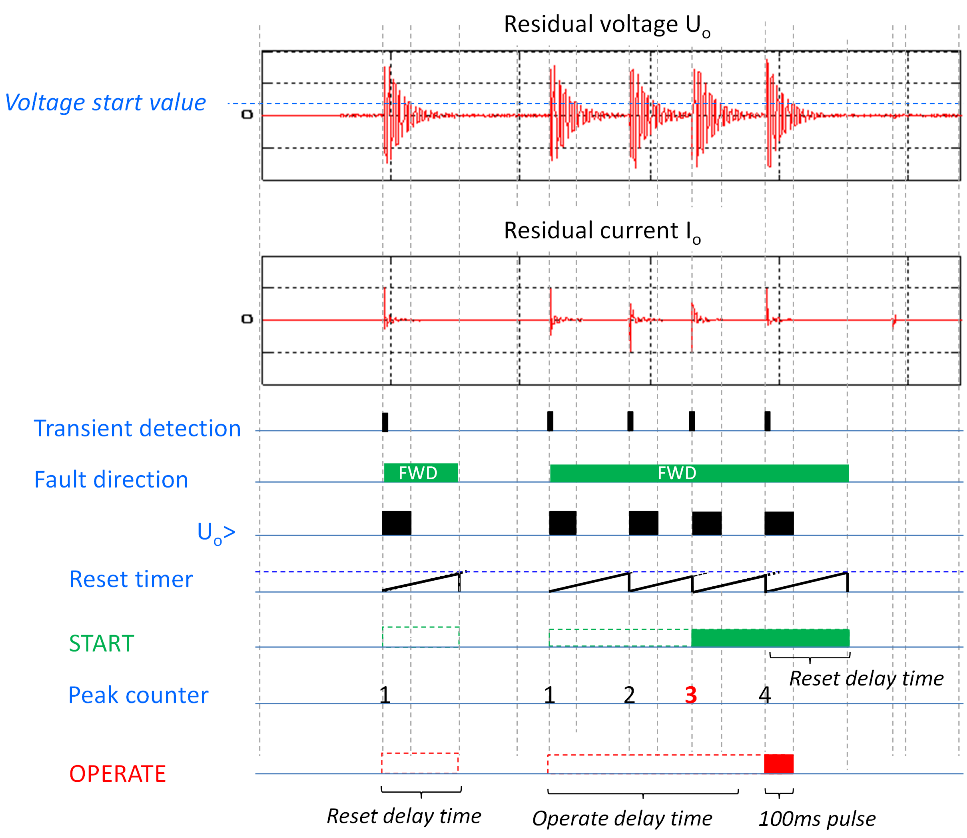


Figure 219: Example of INTRPTEF operation in "Intermittent EF" mode in the faulty feeder, Peak counter limit = 3

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets Timer 1. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Timer 2

If the function is used in the directional mode and an opposite direction transient is detected, the `BLK_EF` output is activated for the fixed delay time of 25 ms. If the `START` output is activated when the `BLK_EF` output is active, the `BLK_EF` output is deactivated. Activation of `BLOCK` input deactivates the output `BLK_EF` and resets Timer 2.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets internal timers. The binary input `BLK_ST` can be used to block the start signals. The binary input `BLK_OPR` can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the `FR_TIMER` input.

4.2.3.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the residual current or voltage-related settings, for example, "*Residual Grp 1*", "*Residual Grp 2*" and "*Residual Grp 3*". One of the groups to be used with the "Base value Sel Res" setting must be selected.

4.2.3.6 Application

INTRPTEF is an earth-fault function dedicated to operate in intermittent and permanent earth faults occurring in distribution and sub-transmission networks. Fault detection is done from the residual current and residual voltage signals by monitoring the transients with predefined criteria. As the function has a dedicated purpose for the fault types, fast detection and clearance of the faults can be achieved.

Intermittent earth fault

Intermittent earth fault is a special type of fault that is encountered especially in compensated networks with underground cables. A typical reason for this type of fault is the deterioration of cable insulation either due to mechanical stress or due to insulation material aging process where water or moisture gradually penetrates the cable insulation. This eventually reduces the voltage withstand of the insulation, leading to a series of cable insulation breakdowns. The fault is initiated as the phase-to-earth voltage exceeds the reduced insulation level of the fault point and mostly extinguishes itself as the fault current drops to zero for the first time, as shown in Figure 220. As a result, very short transients, that is, rapid changes in the form of spikes in residual current (Io) and in residual voltage (Uo), can be repeatedly measured. Typically, the fault resistance in case of an intermittent earth fault is only a few ohms.

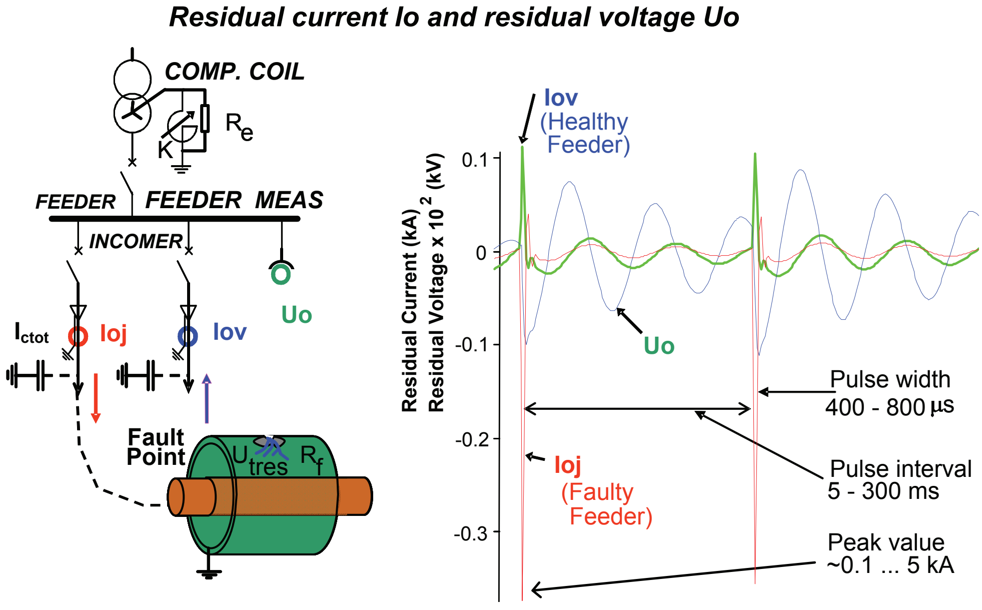


Figure 220: Typical intermittent earth-fault characteristics

Earth-fault transients

In general, earth faults generate transients in currents and voltages. There are several factors that affect the magnitude and frequency of these transients, such as the fault moment on the voltage wave, fault location, fault resistance and the parameters of the feeders and the supplying transformers. In the fault initiation, the voltage of the faulty phase decreases and the corresponding capacitance is discharged to earth (→ discharge transients). At the same time, the voltages of the healthy phases increase and the related capacitances are charged (→ charge transient).

If the fault is permanent (non-transient) in nature, only the initial fault transient in current and voltage can be measured, whereas the intermittent fault creates repetitive transients.

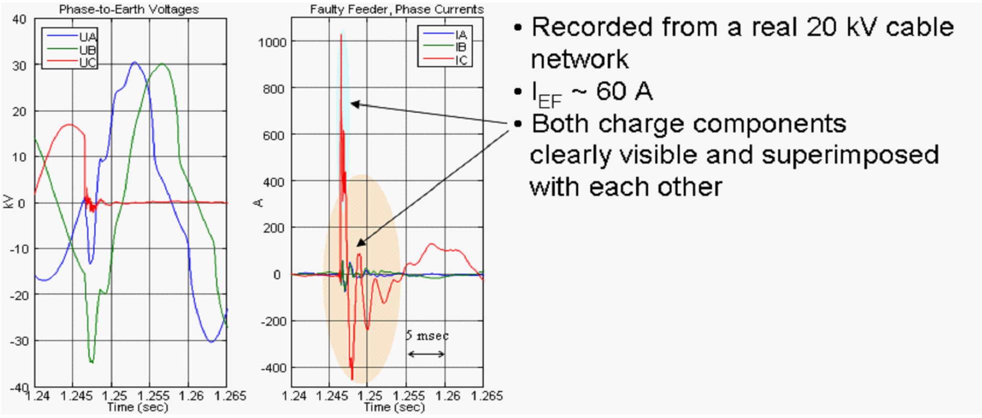


Figure 221: Example of earth-fault transients, including discharge and charge transient components, when a permanent fault occurs in a 20 kV network in phase C

4.2.3.7 Signals

Table 486: INTRPTEF Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
U3P	GROUP SIGNAL	-	Group signal for voltage inputs
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Block of trip signal
BLK_ST	BOOLEAN	0	Block of start signal
FR_TIMER	BOOLEAN	0	Freeze operation timer

Table 487: INTRPTEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal
START	BOOLEAN	Start signal
FAULT_DIR	INTEGER	Detected fault direction
BLK_EF	BOOLEAN	Block signal for EF to indicate opposite direction peaks

4.2.3.8 Settings

Table 488: INTRPTEF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Directional mode	Non-directional Forward Reverse	-	-	Forward	Directional mode (Non-directional,Forward,Reverse)
Voltage start value	0.05 - 0.50	pu	0.01	0.20	Voltage start value for transient EF
Operate delay time	0.04 - 1200.00	s	0.01	0.50	Operate delay time

Table 489: INTRPTEF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Operation mode	Intermittent EF Transient EF	-	-	Intermittent EF	Operation criteria
Min operate current	0.01 - 1.00	pu	0.01	0.01	Minimum operating current for transient detector

Table 490: INTRPTEF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Peak counter limit	2 - 20	-	1	2	Min requirement for peak counter before start in IEF mode
Pol reversal	0 - 1	-	1	0	Rotate polarizing quantity
Reset delay time	0.000 - 60.000	s	0.001	0.500	Reset delay time
Block EF reset time	0.025 - 1.000	s	0.001	0.025	Reset time of the BLK_EF output

4.2.3.9 Measured values

Table 491: INTRPTEF Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Block of trip signal
BLK_ST	BOOLEAN	0	Block of start signal
FR_TIMER	BOOLEAN	0	Freeze operation timer

4.2.3.10 Monitored data

Table 492: INTRPTEF Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal
FAULT_DIR	INTEGER	0=Unknown 1=Forward 2=Backward	-	Detected fault direction
BLK_EF	BOOLEAN	0=FALSE 1=TRUE	-	Block signal for EF to indicate opposite direction peaks
START_DUR	REAL	-	%	Ratio of start time / operate time

4.2.3.11 Technical data

Table 493: INTRPTEF Technical data

Characteristic	Value
Operation accuracy (Uo criteria with transient protection)	At the frequency $f = f_n$
	±1.5% of the set value or ±0.002 × Uo
Operate time accuracy	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5

4.2.3.12 Technical revision history

Table 494: INTRPTEF technical revision history

Technical revision	Change
B	Setting name changed from *Ground start value* to *Voltage start value*
C	*Min operate current* and *Pol reversal* settings are added. The minimum setting value changed from 0.005 to 0.05 and default setting value changed from 0.005 to 0.20 for *Voltage start value* setting.

4.2.4 Admittance-based earth-fault protection EFPADM

4.2.4.1 Identification

Functional description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Admittance-based earth-fault protection	EFPADM	Yo>->	21YN

4.2.4.2 Function block

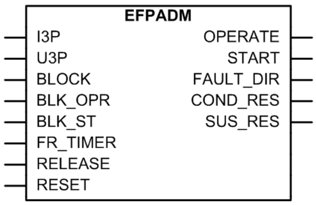


Figure 222: Function block

4.2.4.3 Functionality

The admittance-based earth-fault protection function EFPADM provides a selective earth-fault protection function for high-resistance earthed, unearthed and compensated networks. It can be applied for the protection of overhead lines as well as with underground cables. It can be used as an alternative solution to traditional residual current-based earth-fault protection functions, such as the IoCos mode in DEFxPDEF. Main advantages of EFPADM include a versatile applicability, good sensitivity and easy setting principles.

EFPADM is based on evaluating the neutral admittance of the network, that is, the quotient:

$$\underline{Y}o = \underline{I}o / -\underline{U}o$$

(Equation 38)

The measured admittance is compared to the admittance characteristic boundaries in the admittance plane. The supported characteristics include overadmittance, oversusceptance, overconductance or any combination of the three. The directionality of the oversusceptance and overconductance criteria can be defined as forward, reverse or non-directional, and the boundary lines can be tilted if required by the application. This allows the optimization of the shape of the admittance characteristics for any given application.

EFPADM supports two calculation algorithms for admittance. The admittance calculation can be set to include or exclude the prefault zero-sequence values of the network. Furthermore, the calculated admittance is recorded at the time of the trip and it can be monitored for post-fault analysis purposes.

To ensure the security of the protection, the admittance calculation is supervised by a residual overvoltage condition which releases the admittance protection during a fault condition. Alternatively, the release signal can be provided by an external binary signal.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.2.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the admittance-based earth-fault protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

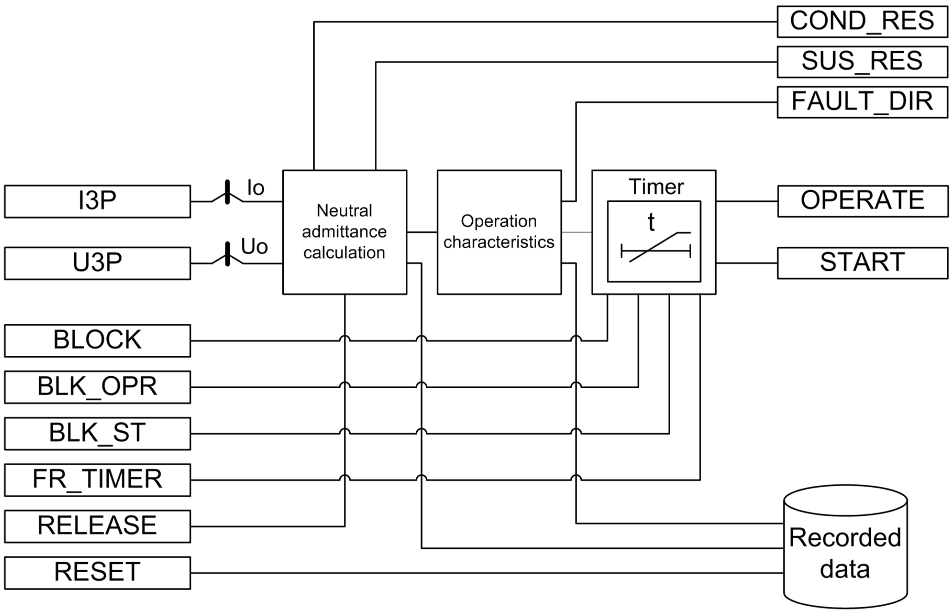


Figure 223: Functional module diagram

Neutral admittance calculation

The function can operate on the measured or calculated residual quantities. The residual current is automatically calculated from the phase quantities if the measured residual quantities are not available.

When the residual voltage exceeds the set threshold *Voltage start value*, an earth fault is detected and the neutral admittance calculation is released.

To ensure a sufficient accuracy for the Io and Uo measurements, it is required that the residual voltage exceeds the value set by *Min operate voltage*. If the admittance calculation mode is "Delta", the minimum change in the residual voltage due to a fault must be 0.01 pu to enable the operation. Similarly, the residual current must exceed the value set by *Min operate current*.

The polarity of the polarizing quantity Uo can be changed, that is, rotated by 180 degrees, by setting the *Pol reversal* parameter to "True" or by switching the polarity of the residual voltage measurement wires.

As an alternative for the internal residual overvoltage-based start condition, the neutral admittance protection can also be externally released by utilizing the `RELEASE` input.

When *Admittance Clc mode* is set to "Delta", the external logic used must be able to give RELEASE in less than 0.1 s. Otherwise the collected pre-fault values are overwritten with fault time values. If it is slower, *Admittance Clc mode* must be set to “Normal”.

Neutral admittance is calculated as the quotient between the residual current and residual voltage (polarity reversed) fundamental frequency phasors. The *Admittance Clc mode* setting defines the calculation mode:

Admittance Clc mode = "Normal"

$$\underline{Yo} = \frac{\underline{Io}_{fault}}{-\underline{Uo}_{fault}}$$

(Equation 39)

Admittance Clc mode = "Delta"

$$\underline{Yo} = \frac{\underline{Io}_{fault} - \underline{Io}_{prefault}}{-(\underline{Uo}_{fault} - \underline{Uo}_{prefault})} = \frac{\Delta \underline{Io}}{-\Delta \underline{Uo}}$$

(Equation 40)

$\underline{Yo}$	Calculated neutral admittance [Siemens]
$\underline{Io}_{fault}$	Residual current during the fault [Amperes]
$\underline{Uo}_{fault}$	Residual voltage during the fault [Volts]
$\underline{Io}_{prefault}$	Prefault residual current [Amperes]
$\underline{Uo}_{prefault}$	Prefault residual voltage [Volts]
$\Delta\underline{Io}$	Change in the residual current due to fault [Amperes]
$\Delta\underline{Uo}$	Change in the residual voltage due to fault [Volts]

Traditionally, admittance calculation is done with the calculation mode "Normal", that is, with the current and voltage values directly measured during the fault. As an alternative, by selecting the calculation mode "Delta", the prefault zero-sequence asymmetry of the network can be removed from the admittance calculation. Theoretically, this makes the admittance calculation totally immune to fault resistance, that is, the estimated admittance value is not affected by fault resistance. Utilization of the change in Uo and Io due to a fault in the admittance calculation also mitigates the effects of the VT and CT measurement errors, thus improving the measuring accuracy, the sensitivity and the selectivity of the protection.

Calculation mode "Delta" is recommended in case a high sensitivity of the protection is required, if the network has a high degree of asymmetry during the healthy state or if the residual current measurement is based on sum connection, that is, the Holmgren connection.

Neutral admittance calculation produces the following values during forward and reverse faults:

Fault in reverse direction, that is, outside the protected feeder:

$$\underline{Y}o = -\underline{Y}_{Fdtot}$$

(Equation 41)

$$\approx -j \cdot \frac{I_{eFd}}{U_{ph}}$$

(Equation 42)

$\underline{Y}_{Fdtot}$	Sum of the phase-to-earth admittances ($\underline{Y}_{FdA}$, $\underline{Y}_{FdB}$, $\underline{Y}_{FdC}$) of the protected feeder
I_{eFd}	Magnitude of the earth-fault current of the protected feeder when the fault resistance is zero ohm
U_{ph}	Magnitude of the nominal phase-to-earth voltage of the system

Equation 41 shows that in case of outside faults, the measured admittance equals the admittance of the protected feeder with a negative sign. The measured admittance is dominantly reactive; the small resistive part of the measured admittance is due to the leakage losses of the feeder. Theoretically, the measured admittance is located in the third quadrant in the admittance plane close to the im($\underline{Y}$o) axis, see Figure 224.

The result of Equation 41 is valid regardless of the neutral earthing method. In compensated networks the compensation degree does not affect the result. This enables a straightforward setting principle for the neutral admittance protection: admittance characteristic is set to cover the value $\underline{Y}o = -\underline{Y}_{Fdtot}$ with a suitable margin.

Due to inaccuracies in voltage and current measurement, the small real part of the calculated neutral admittance may appear as positive, which brings the measured admittance in the fourth quadrant in the admittance plane. This should be considered when setting the admittance characteristic.

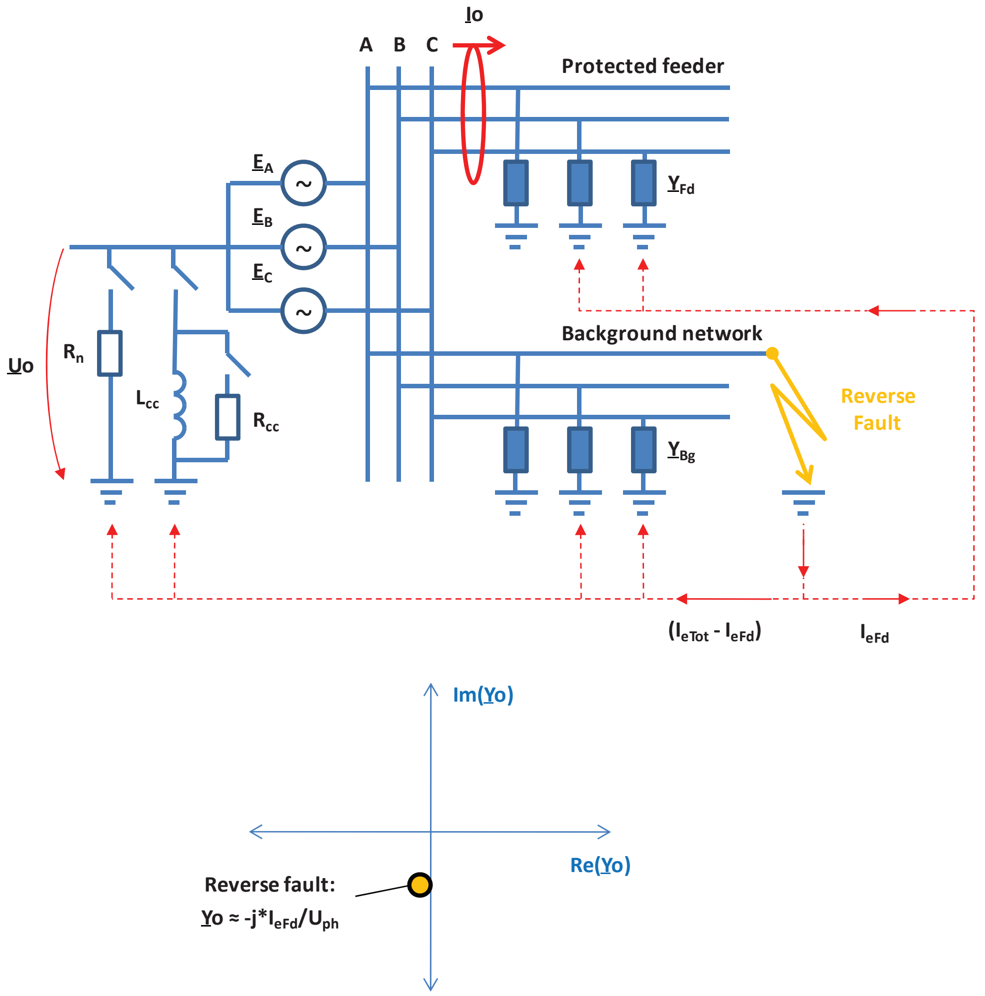


Figure 224: Admittance calculation during a reverse fault

R_{CC}	Resistance of the parallel resistor
L_{CC}	Inductance of the compensation coil
R_n	Resistance of the neutral earthing resistor
$\underline{Y}_{Fd}$	Phase-to-earth admittance of the protected feeder
$\underline{Y}_{Bg}$	Phase-to-earth admittance of the background network

For example, in a 15 kV compensated network with the magnitude of the earth-fault current in the protected feeder being 10 A (Rf = 0 ohm), the theoretical value for the measured admittance during an earth fault in the reverse direction, that is, outside the protected feeder, can be calculated:

$$\underline{Y}o \approx -j \cdot \frac{I_{eFd}}{U_{ph}} = -j \cdot \frac{10A}{15/\sqrt{3}kV} = -j \cdot 1.15 \text{ milliSiemens}$$

(Equation 43)

The result is valid regardless of the neutral earthing method.

In this case, the resistive part of the measured admittance is due to leakage losses of the protected feeder. As they are typically very small, the resistive part is close to zero. Due to inaccuracies in the voltage and current measurement, the small real part of the apparent neutral admittance may appear positive. This should be considered in the setting of the admittance characteristic.

Fault in the forward direction, that is, inside the protected feeder:

Unearthed network:

$$\underline{Y}o = \underline{Y}_{Bgtot}$$

(Equation 44)

$$\approx j \cdot \left(\frac{I_{eTot} - I_{eFd}}{U_{ph}} \right)$$

(Equation 45)

Compensated network:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{CC}$$

(Equation 46)

$$\approx \frac{I_{Rcc} + j \cdot \left(I_{eTot} \cdot (1 - K) - I_{eFd} \right)}{U_{ph}}$$

(Equation 47)

High-resistance earthed network:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{Rn}$$

(Equation 48)

$$\approx \frac{I_{Rn} + j \cdot \left(I_{eTot} - I_{eFd} \right)}{U_{ph}}$$

(Equation 49)

$\underline{Y}_{Bgtot}$	Sum of the phase-to-earth admittances ($\underline{Y}_{BgA}$, $\underline{Y}_{BgB}$, $\underline{Y}_{BgC}$) of the background network
$\underline{Y}_{CC}$	Admittance of the earthing arrangement (compensation coil and parallel resistor)
I_{Rcc}	Rated current of the parallel resistor
I_{eFd}	Magnitude of the earth-fault current of the protected feeder when the fault resistance is zero ohm
I_{eTot}	Magnitude of the uncompensated earth-fault current of the network when Rf is zero ohm
K	Compensation degree, K = 1 full resonance, K<1 undercompensated, K>1 overcompensated
I_{Rn}	Rated current of the neutral earthing resistor

Equation 44 shows that in case of a fault inside the protected feeder in unearthed networks, the measured admittance equals the admittance of the background network. The admittance is dominantly reactive; the small resistive part of the measured admittance is due to the leakage losses of the background network. Theoretically, the measured admittance is located in the first quadrant in the admittance plane, close to the im(Yo) axis, see Figure 225.

Equation 46 shows that in case of a fault inside the protected feeder in compensated networks, the measured admittance equals the admittance of the background network and the coil including the parallel resistor. Basically, the compensation degree determines the imaginary part of the measured admittance and the resistive part is due to the parallel resistor of the coil and the leakage losses of the background network and the losses of the coil. Theoretically, the measured admittance is located in the first or fourth quadrant in the admittance plane, depending on the compensation degree, see Figure 225.

Before the parallel resistor is connected, the resistive part of the measured admittance is due to the leakage losses of the background network and the losses of the coil. As they are typically small, the resistive part may not be sufficiently large to secure the discrimination of the fault and its direction based on the measured conductance. This and the rating and the operation logic of the parallel resistor should be considered when setting the admittance characteristic in compensated networks.

Equation 48 shows that in case of a fault inside the protected feeder in high-resistance earthed systems, the measured admittance equals the admittance of the background network and the neutral earthing resistor. Basically, the imaginary part of the measured admittance is due to the phase-to-earth capacitances of the background network, and the resistive part is due to the neutral earthing resistor and the leakage losses of the background network. Theoretically, the measured admittance is located in the first quadrant in the admittance plane, see Figure 225.

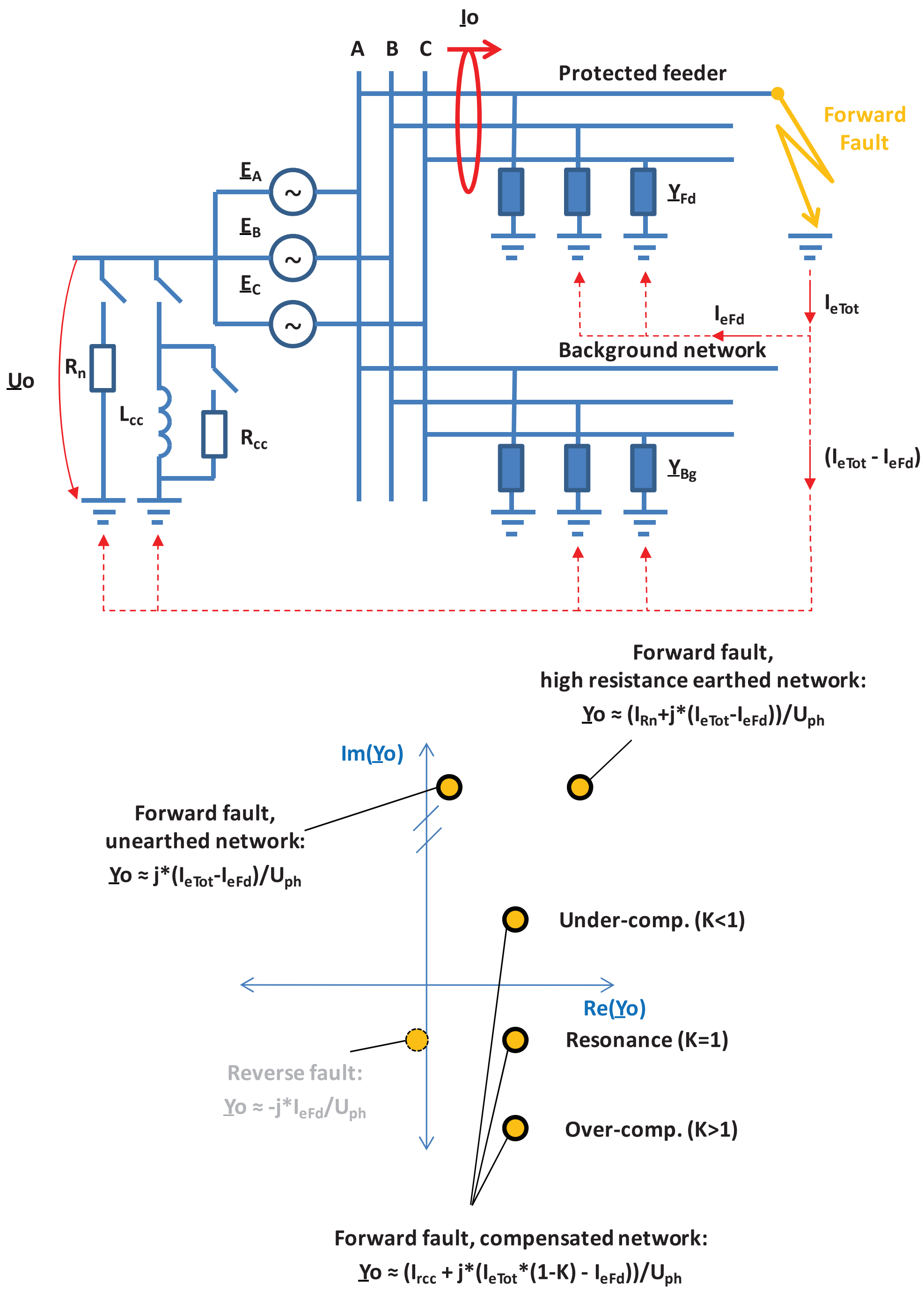


Figure 225: Admittance calculation during a forward fault

When the network is fully compensated in compensated networks, theoretically during a forward fault the imaginary part of the measured admittance equals the susceptance of the protected feeder with a negative sign. The discrimination between a forward and reverse fault must therefore be based on the real part of the measured admittance, that is, conductance. Thus, the best selectivity is achieved when the compensated network is operated either in the undercompensated or overcompensated mode.

For example, in a 15 kV compensated network, the magnitude of the earth fault current of the protected feeder is 10 A (Rf = 0 ohm) and the magnitude of the network is 100 A (Rf = 0 ohm). During an earth fault, a 15 A resistor is connected in parallel to the coil after a 1.0 second delay. Compensation degree is overcompensated, K = 1.1.

During an earth fault in the forward direction, that is, inside the protected feeder, the theoretical value for the measured admittance after the connection of the parallel resistor can be calculated:

$$\underline{Y}o \approx \frac{I_{Rcc} + j \cdot \left(I_{eTot} \cdot (1-K) - I_{eFd}\right)}{U_{ph}}$$
$$= \frac{15A + j \cdot \left(100A \cdot (1-1.1) - 10A\right)}{15kV/\sqrt{3}} \approx \left(1.73 - j \cdot 2.31\right) \text{ milliSiemens}$$

(Equation 50)

Before the parallel resistor is connected, the resistive part of the measured admittance is due to the leakage losses of the background network and the losses of the coil. As they are typically small, the resistive part may not be sufficiently large to secure the discrimination of the fault and its direction based on the measured conductance. This and the rating and the operation logic of the parallel resistor should be considered when setting the admittance characteristic.

The calculated admittance values are available for post-fault analysis purposes as the outputs COND_RES (real part of the calculated neutral admittance) and SUS_RES (imaginary part of the calculated neutral admittance). The unit of admittance is milliSiemens (mS).

When a high sensitivity of the protection is required, the residual current should be measured with a cable/ring core CT, that is, the Ferranti CT. Also the use of the sensitive Io input should be considered. The residual voltage measurement should be done with an open delta connection of the three single pole-insulated voltage transformers.

Operation characteristic

After the admittance calculation is released, the calculated neutral admittance is compared to the admittance characteristic boundaries in the admittance plane. If the calculated neutral admittance $\underline{Y}o$ moves outside the characteristic, the enabling signal is sent to the timer.

EFPADM supports a wide range of different characteristics to achieve the maximum flexibility and sensitivity in different applications. The basic characteristic shape is selected with the *Operation mode* and *Directional mode* settings. *Operation mode* defines which operation criterion or criteria are enabled and *Directional mode* defines if the forward, reverse or non-directional boundary lines for that particular operation mode are activated. The detected fault direction information is provided by the `FAULT_DIR` output during the start situation.

Table 495: Operation criteria

Operation mode	Description
Yo	Admittance criterion
Bo	Susceptance criterion
Go	Conductance criterion
Yo, Go	Admittance criterion combined with the conductance criterion
Yo, Bo	Admittance criterion combined with the susceptance criterion
Go, Bo	Conductance criterion combined with the susceptance criterion
Yo, Go, Bo	Admittance criterion combined with the conductance and susceptance criterion

The options for the *Directional mode* setting are "Non-directional", "Forward" and "Reverse".

Figure 226, Figure 227 and Figure 228 illustrate the admittance characteristics supported by EFPADM and the settings relevant to that particular characteristic. The most typical characteristics are highlighted and explained in details in the chapter Neutral admittance characteristics. Operation is achieved when the calculated neutral admittance $\underline{Y}o$ moves outside the characteristic (the operation area is marked with gray).

The settings defining the admittance characteristics are given in milliSiemens (mS). The conversion equation for the admittance from secondary to primary is:

$$Y_{pri} = Y_{sec} \cdot \frac{ni_{CT}}{nu_{VT}}$$

(Equation 51)

ni_{CT} CT ratio for the residual current Io

nu_{VT} VT ratio for the residual voltage Uo

Example: Admittance setting in the secondary is 5.00 milliSiemens. The CT ratio is 100/1 A and the VT ratio is 11547/100 V. The admittance setting in the primary can be calculated.

$$Y_{pri} = 5.00\ milliSiemens \cdot \frac{100/1A}{11547/100V} = 4.33\ milliSiemens$$

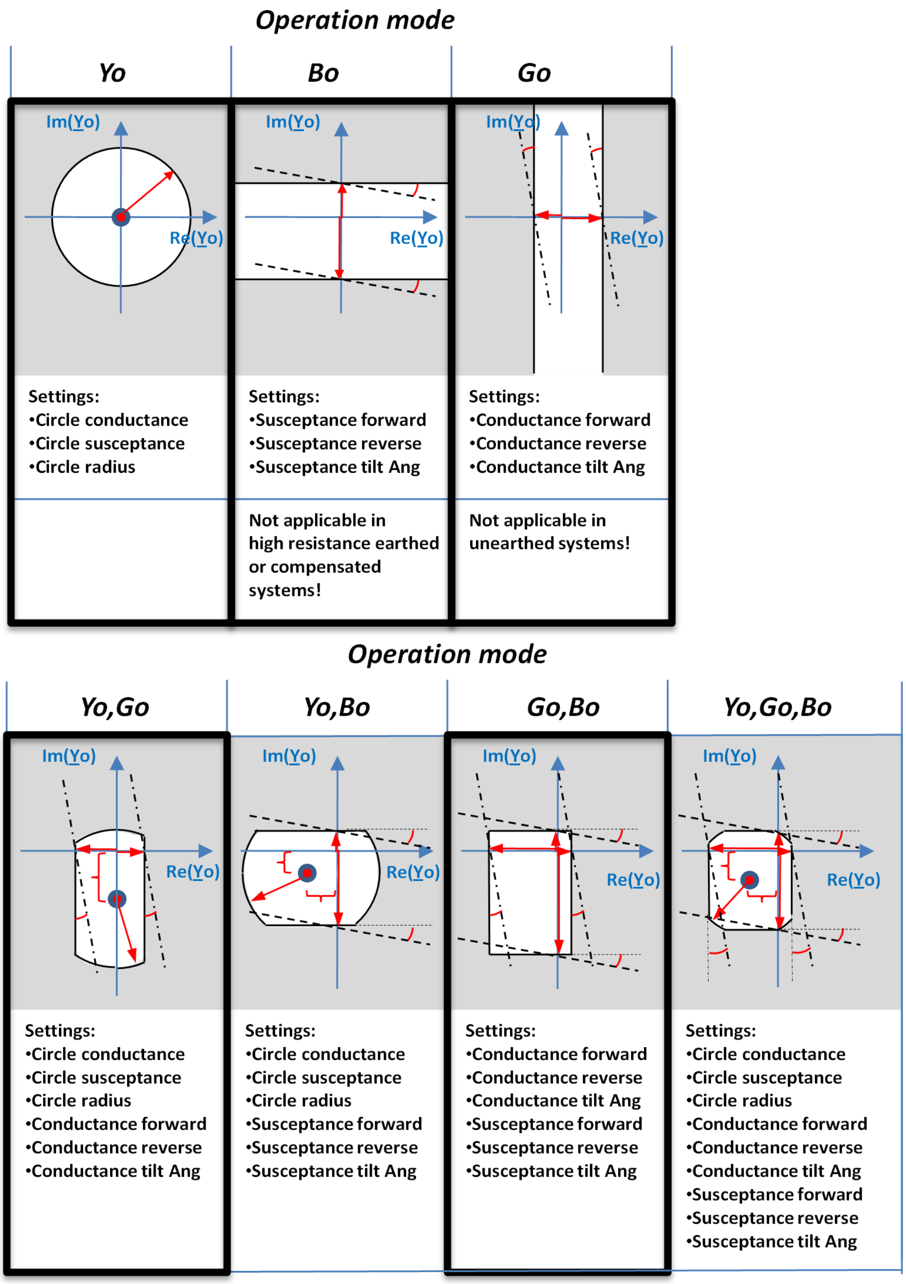


Figure 226: Admittance characteristic with different operation modes when Directional mode = "Non-directional"

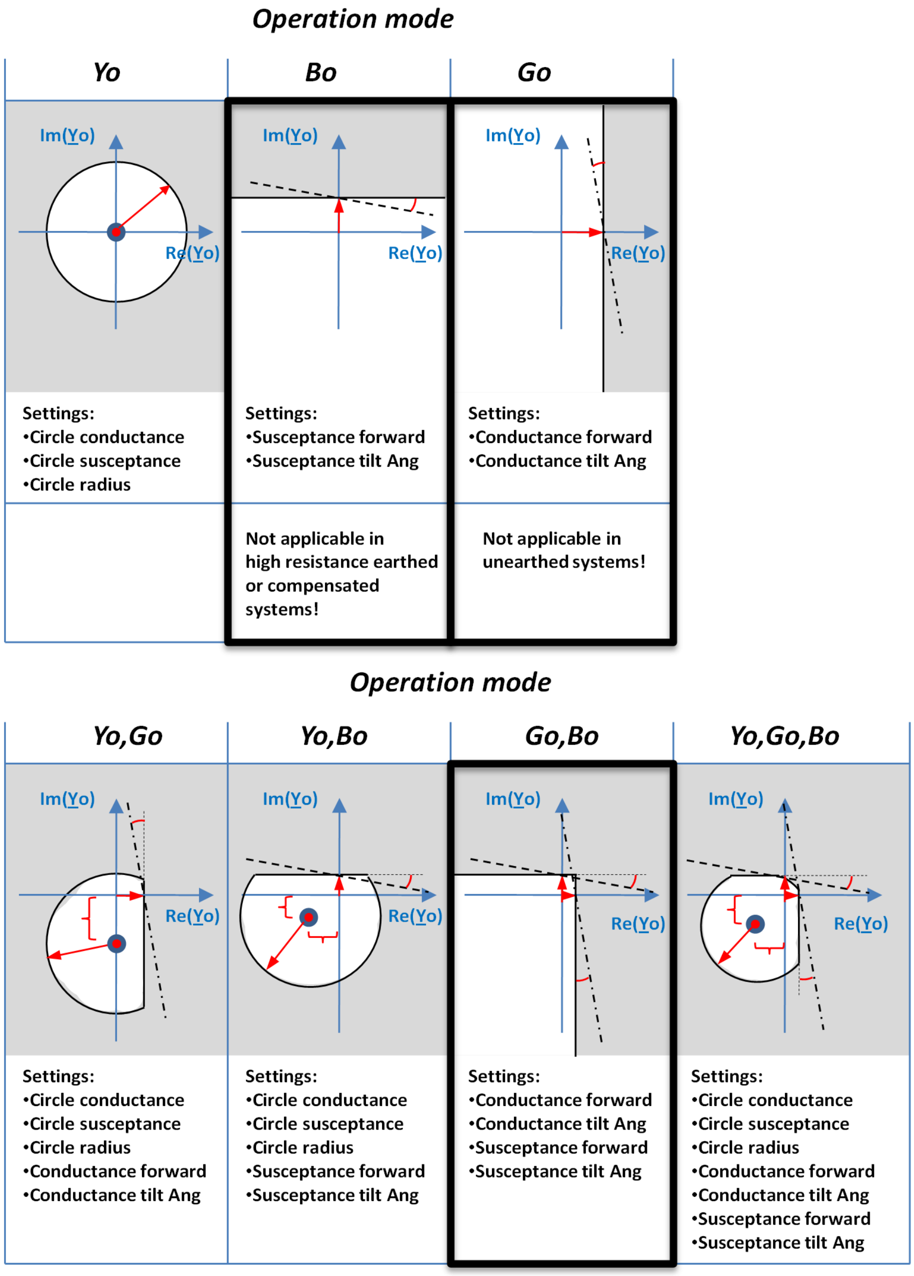


Figure 227: Admittance characteristic with different operation modes when Directional mode = "Forward"

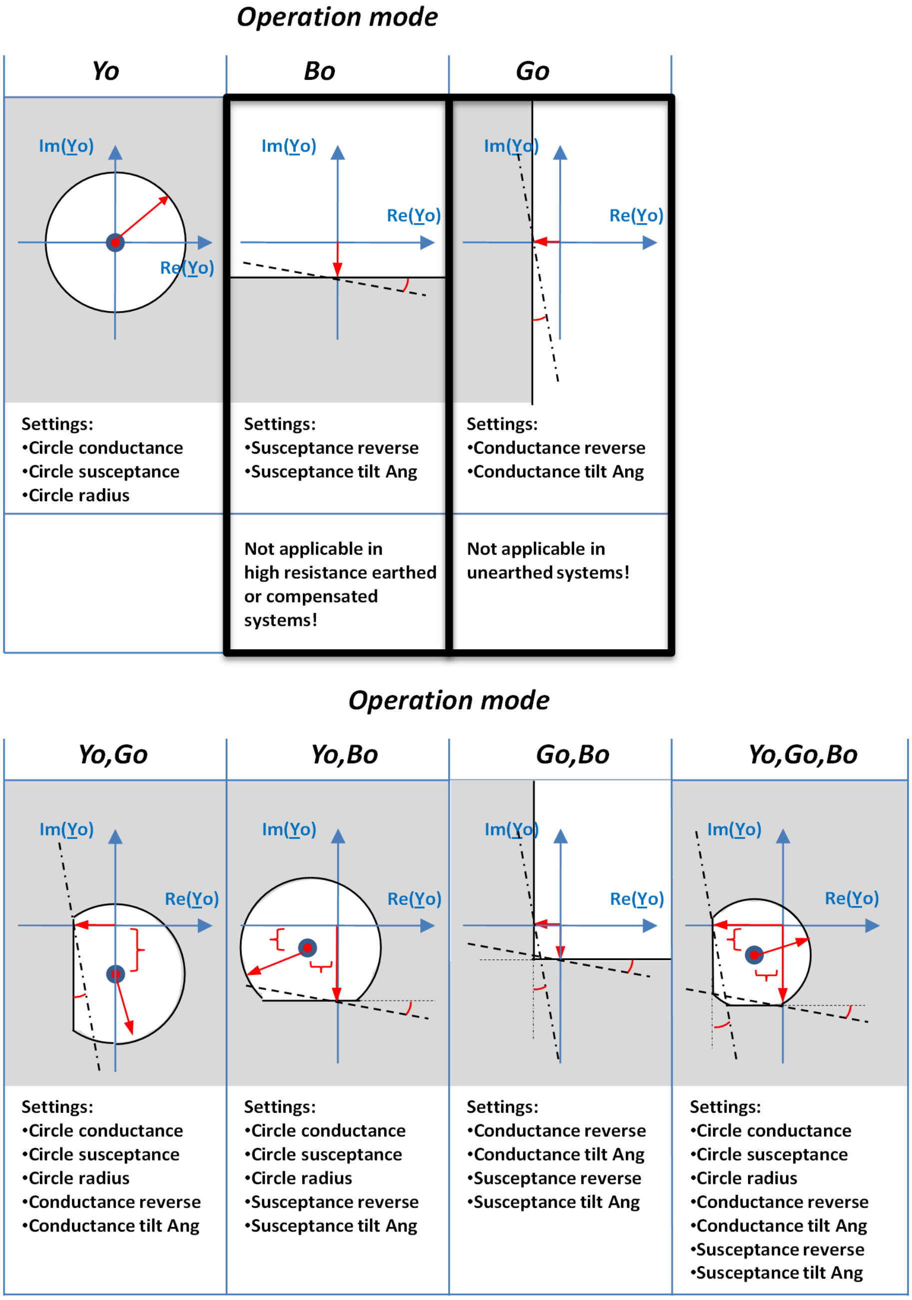


Figure 228: Admittance characteristic with different operation modes when Directional mode = "Reverse"

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set with the *Operate delay time* setting, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set with the *Reset delay time* setting, the operation timer resets and the START output is deactivated. The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input BLOCK is used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST is used to block the start signals. The binary input BLK_OPR is used to block the operating signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

4.2.4.5 Neutral admittance characteristics

The applied characteristic should always be set to cover the total admittance of the protected feeder with a suitable margin. However, more detailed setting value selection principles depend on the characteristic in question.

The settings defining the admittance characteristics are given in millisiemens.

The sign of the admittance characteristic settings should be considered based on the location of characteristic boundary in the admittance plane. All forward-settings are given with positive sign and reverse-settings with negative sign.

All characteristics have a relative hysteresis for the boundary line(s). The hysteresis decreases characteristics and increases the operating area when neutral admittance enters the operating area. In case of overadmittance characteristic, the hysteresis affects the circle radius and not the midpoint.

The monitored data CONFLICT is set to indicate setting conflicts in operation modes when a non-directional susceptance or conductance criterion is used. The forward and reverse boundary settings should be set so that the forward setting is always larger than the reverse setting and that there is space between them.

Overadmittance characteristic

The overadmittance criterion is enabled with the setting *Operation mode* set to "Yo". The characteristic is a circle with the radius defined with the *Circle radius* setting. For the sake of application flexibility, the midpoint of the circle can be moved away from the origin with the *Circle conductance* and *Circle susceptance* settings. Default values for *Circle conductance* and *Circle susceptance* are 0.0 mS, that is, the characteristic is an origin-centered circle.

Operation is achieved when the measured admittance moves outside the circle.

The overadmittance criterion is typically applied in unearthed networks, but it can also be used in compensated networks, especially if the circle is set off from the origin.

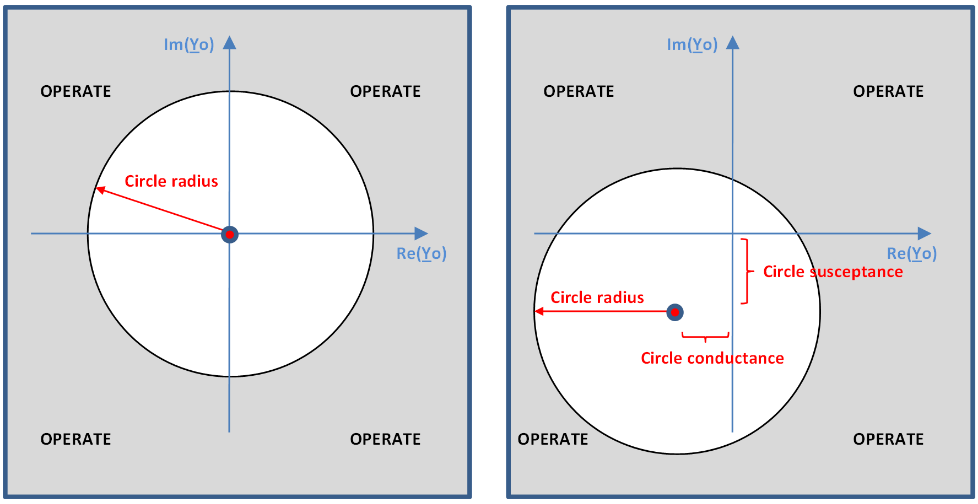


Figure 229: Overadmittance characteristic. Left figure: classical origin-centered admittance circle. Right figure: admittance circle is set off from the origin.

Non-directional overconductance characteristic

The non-directional overconductance criterion is enabled with the *Operation mode* setting set to "Go" and *Directional mode* to "Non-directional". The characteristic is defined with two overconductance boundary lines with the *Conductance forward* and *Conductance reverse* settings. For the sake of application flexibility, the boundary lines can be tilted by the angle defined with the *Conductance tilt Ang* setting. By default, the tilt angle is zero degrees, that is, the boundary line is a vertical line in the admittance plane. A positive tilt value rotates the boundary line counterclockwise from the vertical axis.

In case of non-directional conductance criterion, the *Conductance reverse* setting must be set to a smaller value than *Conductance forward*. If this rule is not followed, a conflict situation is declared in the monitored data CONFLICT.

Operation is achieved when the measured admittance moves over either of the boundary lines.

The non-directional overconductance criterion is applicable in high-resistance earthed and compensated networks. It must not be applied in unearthed networks.

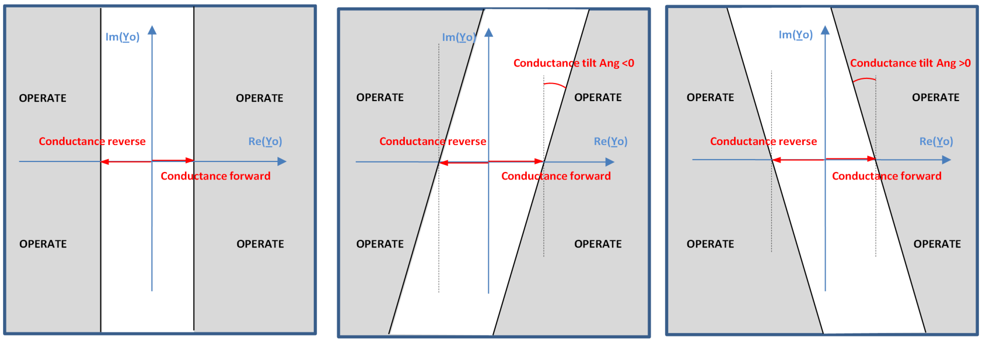


Figure 230: Non-directional overconductance characteristic. Left figure: classical non-directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

Forward directional overconductance characteristic

The forward directional overconductance criterion is enabled with the *Operation mode* setting set to "Go" and *Directional mode* set to "Forward". The characteristic is defined by one overconductance boundary line with the *Conductance forward* setting. For the sake of application flexibility, the boundary line can be tilted with the angle defined with the *Conductance tilt Ang* setting. By default, the tilt angle is zero degrees, that is, the boundary line is a vertical line in the admittance plane. A positive tilt value rotates the boundary line counterclockwise from the vertical axis.

Operation is achieved when the measured admittance moves over the boundary line.

The forward directional overconductance criterion is applicable in high-resistance earthed and compensated networks. It must not be applied in unearthed networks.

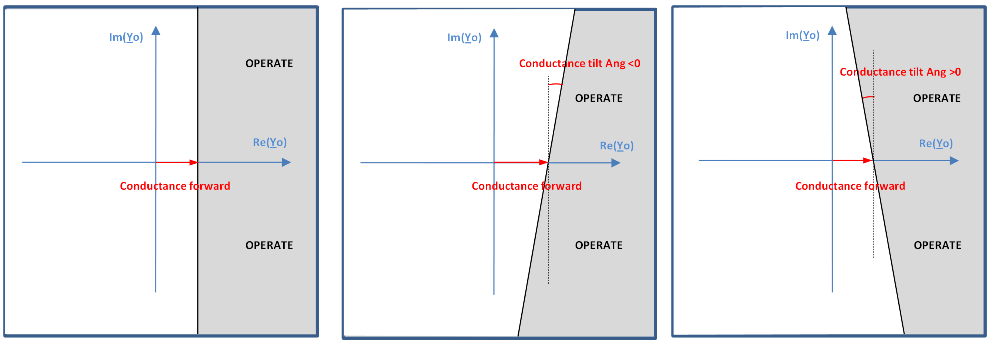


Figure 231: Forward directional overconductance characteristic. Left figure: classical forward directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

Forward directional oversusceptance characteristic

The forward directional oversusceptance criterion is enabled with the *Operation mode* setting set to "Bo" and *Directional mode* to "Forward". The characteristic is defined by one oversusceptance boundary line with the *Susceptance forward* setting. For the sake of application flexibility, the boundary line can be tilted by the angle defined with the *Susceptance tilt Ang* setting. By default, the tilt angle is zero degrees, that is, the boundary line is a horizontal line in the admittance plane. A positive tilt value rotates the boundary line counterclockwise from the horizontal axis

Operation is achieved when the measured admittance moves over the boundary line.

The forward directional oversusceptance criterion is applicable in unearthed networks. It must not be applied in compensated networks.

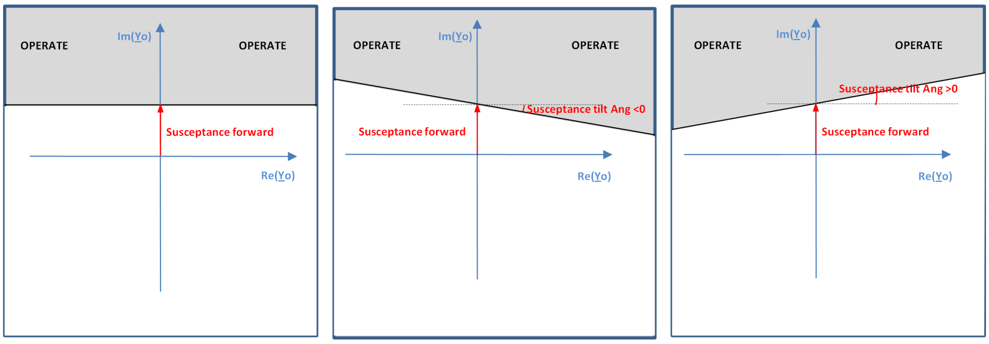


Figure 232: Forward directional oversusceptance characteristic. Left figure: classical forward directional oversusceptance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

Combined overadmittance and overconductance characteristic

The combined overadmittance and overconductance criterion is enabled with the *Operation mode* setting set to "Yo, Go" and *Directional mode* to "Non-directional". The characteristic is a combination of a circle with the radius defined with the *Circle radius* setting and two overconductance boundary lines with the settings *Conductance forward* and *Conductance reverse*. For the sake of application flexibility, the midpoint of the circle can be moved from the origin with the *Circle conductance* and *Circle susceptance* settings. Also the boundary lines can be tilted by the angle defined with the *Conductance tilt Ang* setting. By default, the *Circle conductance* and *Circle susceptance* are 0.0 mS and *Conductance tilt Ang* equals zero degrees, that is, the characteristic is a combination of an origin-centered circle with two vertical overconductance boundary lines. A positive tilt value for the *Conductance tilt Ang* setting rotates boundary lines counterclockwise from the vertical axis.

In case of the non-directional conductance criterion, the *Conductance reverse* setting must be set to a smaller value than *Conductance forward*. If this rule is not followed, a conflict situation is declared in the monitored data CONFLICT. If this rule is not followed, a conflict situation is declared in the monitored data CONFLICT.

Operation is achieved when the measured admittance moves outside the characteristic.

The combined overadmittance and overconductance criterion is applicable in unearthed, high-resistance earthed and compensated networks or in systems where the system earthing may temporarily change during normal operation from compensated network to unearthed system.

Compared to the overadmittance criterion, the combined characteristic improves sensitivity in high-resistance earthed and compensated networks. Compared to the non-directional overconductance criterion, the combined characteristic enables the protection to be applied also in unearthed systems.

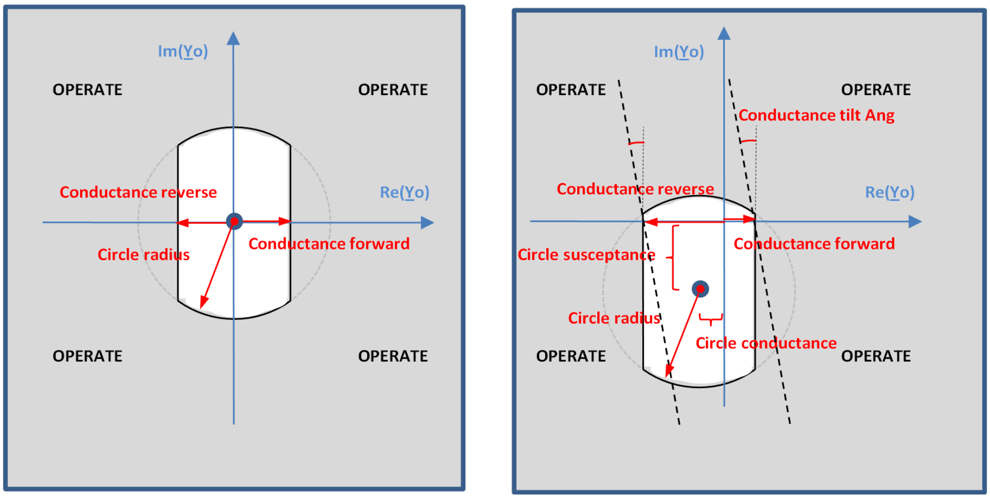


Figure 233: Combined overadmittance and overconductance characteristic. Left figure: classical origin-centered admittance circle combined with two overconductance boundary lines. Right figure: admittance circle is set off from the origin.

Combined overconductance and oversusceptance characteristic

The combined overconductance and oversusceptance criterion is enabled with the *Operation mode* setting set to "Go, Bo".

By setting *Directional mode* to "Forward", the characteristic is a combination of two boundary lines with the settings *Conductance forward* and *Susceptance forward*. See Figure 234.

By setting *Directional mode* to "Non-directional", the characteristic is a combination of four boundary lines with the settings *Conductance forward*, *Conductance reverse*, *Susceptance forward* and *Susceptance reverse*. See Figure 235.

For the sake of application flexibility, the boundary lines can be tilted by the angle defined with the *Conductance tilt Ang* and *Susceptance tilt Ang* settings. By default, the tilt angles are zero degrees, that is, the boundary lines are straight lines in the admittance plane. A positive *Conductance tilt Ang* value rotates the overconductance boundary line counterclockwise from the vertical axis. A positive *Susceptance tilt Ang* value rotates the oversusceptance boundary line counterclockwise from the horizontal axis.

In case of the non-directional conductance and susceptance criteria, the *Conductance reverse* setting must be set to a smaller value than *Conductance forward* and the *Susceptance reverse* setting must be set to a smaller value than *Susceptance forward*. If this rule is not followed, a conflict situation is declared in the monitored data CONFLICT.

Operation is achieved when the measured admittance moves outside the characteristic.

The combined overconductance and oversusceptance criterion is applicable in high-resistance earthed, unearthed and compensated networks or in the systems where the system earthing may temporarily change during normal operation from compensated to unearthed system.

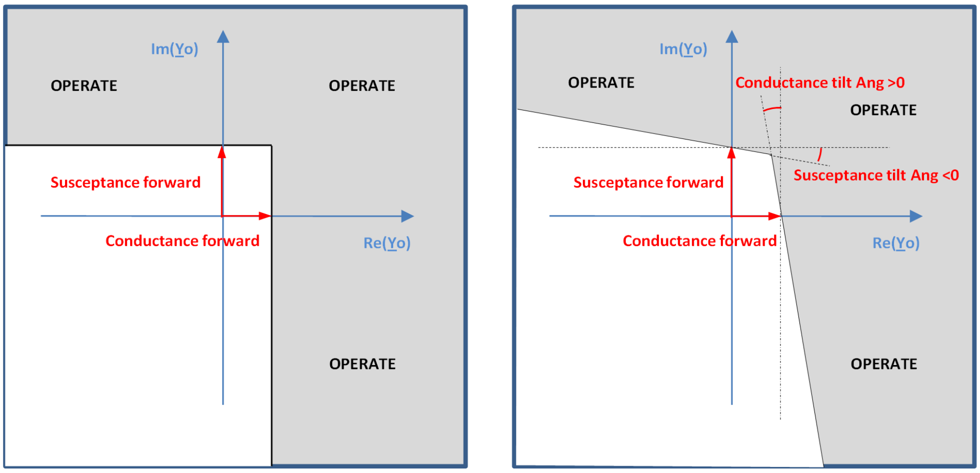


Figure 234: Combined forward directional overconductance and forward directional oversusceptance characteristic. Left figure: the Conductance tilt Ang and Susceptance tilt Ang settings equal zero degrees. Right figure: the setting Conductance tilt Ang > 0 degrees and the setting Susceptance tilt Ang < 0 degrees.

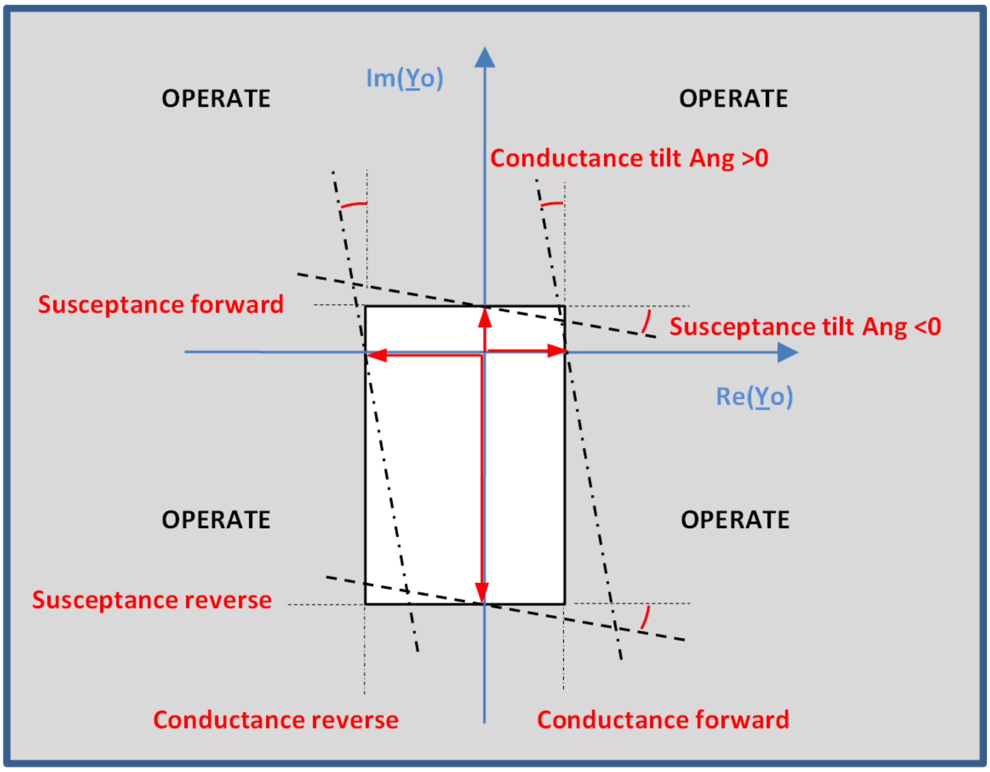


Figure 235: Combined non-directional overconductance and non-directional oversusceptance characteristic

The non-directional overconductance and non-directional oversusceptance characteristic provides a good sensitivity and selectivity when the characteristic is set to cover the total admittance of the protected feeder with a proper margin.

4.2.4.6 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the residual current or voltage-related settings, for example, "*Residual Grp 1*", "*Residual Grp 2*" and "*Residual Grp 3*". One of the groups to be used with the "Base value Sel Res" setting must be selected.

4.2.4.7 Recorded data

The required information for a later fault analysis is recorded when the recording function of EFPADM is triggered. The triggering occurs at the moment of a trip or a falling edge of the start signal.

Table 496: EFPADM recorded data

Parameter name	Description
n Recording time	Recording date and time
n FAULT_DIR	Detected fault direction
n COND_RES (Go)	Real part of neutral admittance
n SUS_RES (Bo)	Imaginary part of neutral admittance
n I_AMPL_RES Pre Flt	Magnitude of prefault residual current
n I_ANGL_RES Pre Flt	Angle of prefault residual current
n U_AMPL_RES Pre Flt	Magnitude of prefault residual voltage
n U_ANGL_RES Pre Flt	Angle of prefault residual voltage
n I_AMPL_RES fault	Magnitude of fault state residual current
n I_ANGL_RES fault	Angle of fault state residual current
n U_AMPL_RES fault	Magnitude of fault state residual voltage
n U_ANGL_RES fault	Angle of fault state residual voltage
n START_DUR	Ratio of started time / operation time

The triggering moment of the recorded data is stored in the *n Recording time* parameter. The *n COND_RES (Go)* and *n SUS_RES (Bo)* parameters are the real and imaginary components of the neutral admittance calculation used in the operation characteristics functionality. The direction of the fault determined by the operation characteristics is indicated with the *n FAULT_DIR* parameter ("Unknown", "Forward", "Backward" or "Both").

The prefault residual current and voltage values can be read from the *n I_AMPL_RES Pre Flt*, *n I_ANGL_RES Pre Flt*, *n U_AMPL_RES Pre Flt* and *n U_ANGL_RES Pre Flt* parameters. The corresponding fault state current and voltage values can be found in the parameters *n I_AMPL_RES fault*, *n I_ANGL_RES fault*, *n U_AMPL_RES fault* and *n U_ANGL_RES fault*. The start duration value is stored in the *n START_DUR* parameter.

When *Admittance Clc mode* is set to "Normal", the prefault values are not collected.

There are a total of three sets of recorded data which are saved in the data banks 1, 2 and 3. The data bank 1 holds the most recent recorded data and the older data are moved to the following banks (1->2 and 2->3) when triggering occurs. When all three banks have data and a new triggering occurs, the latest data are placed into bank 1 and the data in bank 3 become overwritten by the data from bank 2.

The activation of the `RESET` binary input resets all recorded data banks.

4.2.4.8 Application

Neutral admittance protection provides a selective earth-fault protection function for high-resistance earthed, unearthed and compensated networks. It can be applied for the protection of overhead lines as well as with underground cables. It can be used as an alternative solution to traditional residual current-based earth-fault protection functions, for example the IoCos mode in DEFxPDEF. Main advantages of EFPADM include versatile applicability, good sensitivity and easy setting principles.

As a start condition for the neutral admittance protection, the residual overvoltage condition is used. When the residual voltage exceeds the set threshold *Voltage start value*, an earth fault is detected and the neutral admittance calculation is released. In order to guarantee a high security of protection, that is, avoid false starts, the *Voltage start value* setting must be set above the highest possible value of Uo during normal operation with a proper margin. It should consider all possible operation conditions and configuration changes in the network. In unearthed systems, the healthy-state Uo is typically less than 1% × Uph (Uph = nominal phase-to-earth voltage). In compensated networks, the healthy-state Uo may reach values even up to 30% × Uph if the network includes large parts of overheadlines without a phase transposition. Generally, the highest Uo is achieved when the compensation coil is tuned to the full resonance and when the parallel resistor of the coil is not connected.

The residual overvoltage-based start condition for the admittance protection enables a multistage protection principle. For example, one instance of EFPADM could be used for alarming to detect faults with a high fault resistance using a relatively low value for the *Voltage start value* setting. Another instance of EFPADM could then be set to trip with a lower sensitivity by selecting a higher value of the *Voltage start value* setting than in the alarming instance (stage).

To apply the neutral admittance protection, at least the following network data are required:

- System earthing method
- Maximum value for Uo during the healthy state
- Maximum earth-fault current of the protected feeder when the fault resistance Rf is zero ohm
- Maximum uncompensated earth-fault current of the system (Rf = 0 Ω)
- Rated current of the parallel resistor of the coil (active current forcing scheme) in the case of a compensated neutral network
- Rated current of the neutral earthing resistor in the case of a high-resistance earthed system
- Knowledge of the magnitude of Uo as a function of the fault resistance to verify the sensitivity of the protection in terms of fault resistance

Figure 236 shows the influence of fault resistance on the residual voltage magnitude in unearthed and compensated networks. Such information should be available to verify the correct *Voltage start value* setting, which helps to fulfil the requirements for the sensitivity of the protection in terms of fault resistance.

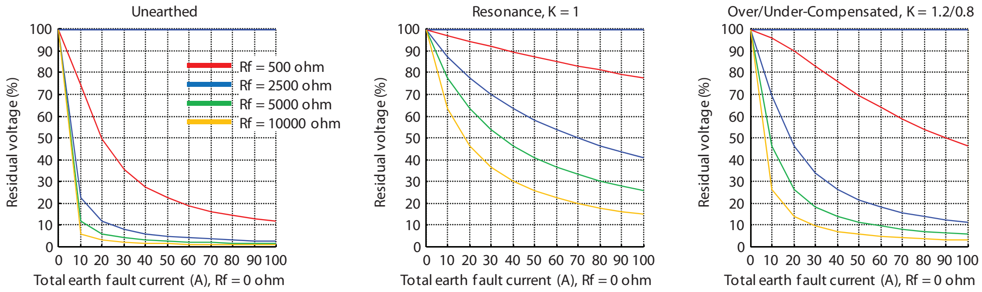


Figure 236: Influence of fault resistance on the residual voltage magnitude in 10 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

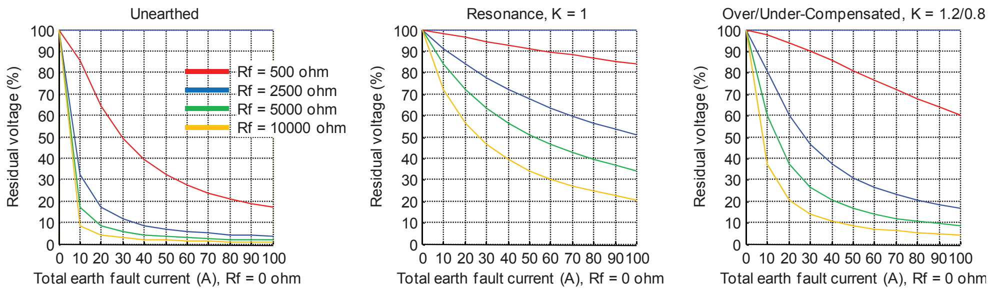


Figure 237: Influence of fault resistance on the residual voltage magnitude in 15 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

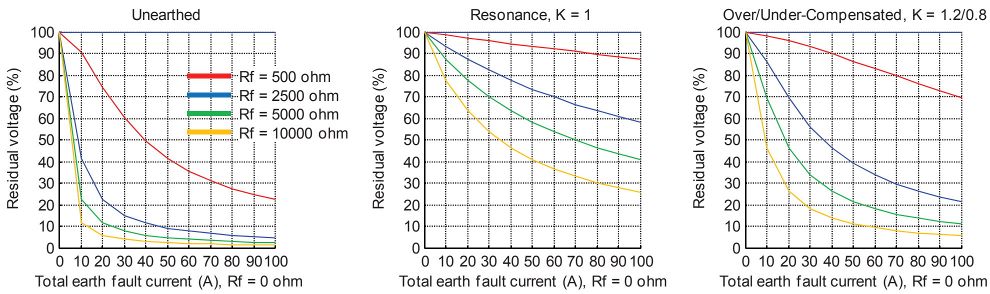


Figure 238: Influence of fault resistance on the residual voltage magnitude in 20 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

Example

In a 15 kV, 50 Hz compensated network, the maximum value for Uo during the healthy state is 10% × Uph. Maximum earth-fault current of the system is 100 A. The maximum earth fault current of the protected feeder is 10 A (Rf = 0 Ω). The applied active current forcing scheme uses a 15 A resistor, which is connected in parallel to the coil during the fault after a 1.0 second delay.

Solution: As a start condition for the neutral admittance protection, the internal residual overvoltage condition of EFPADM is used. The *Voltage start value* setting must be set above the maximum healthy-state Uo of 10% × Uph with a suitable margin.

Voltage start value = 0.15 pu

According to Figure 237, this selection ensures at least a sensitivity corresponding to a 2000 ohm fault resistance when the compensation degree varies between 80% and 120%. The greatest sensitivity is achieved when the compensation degree is close to full resonance.

An earth-fault current of 10 A can be converted into admittance.

$$\underline{Y}_{Fdtot} = \frac{10A}{15kV/\sqrt{3}} \approx j \cdot 1.15 \text{ mS}$$

A parallel resistor current of 15 A can be converted into admittance.

$$G_{cc} = \frac{15A}{15kV/\sqrt{3}} \approx 1.73 \text{ mS}$$

According to Equation 41, during an outside fault EFPADM measures the following admittance:

$$\underline{Y}o = -\underline{Y}_{Fdtot} \approx -j \cdot 1.15 \text{ mS}$$

According to Equation 46, during an inside fault EFPADM measures the admittance after the connection of the parallel resistor:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{CC} \approx (1.73 + j \cdot B) \text{ mS}$$

Where the imaginary part of the admittance, B, depends on the tuning of the coil (compensation degree).

The admittance characteristic is selected to be the combined overconductance and oversusceptance characteristic with four boundary lines:

Operation mode = "Go, Bo"

Directional mode = "Non-directional"

The admittance characteristic is set to cover the total admittance of the protected feeder with a proper margin, see Figure 239. Different setting groups can be used to allow adaptation of protection settings to different feeder and network configurations.

Conductance forward

This setting should be set based on the parallel resistor value of the coil. It must be set to a lower value than the conductance of the parallel resistor, in order to enable dependable operation. The selected value should move the boundary line from origin to include some margin for the admittance operation point due to CT/VTerrors, when fault is located outside the feeder.

Conductance forward: 15 A/(15 kV/sqrt(3)) × 0.2 = +0.35 mS corresponding to 3.0 A (at 15 kV). The selected value provides margin considering also the effect of CT/VT errors in case of outside faults. In case of smaller rated value of the parallel resistor, for example, 5 A (at 15 kV), the recommended security margin should be larger, for example 0.7, so that sufficient margin for CT/VT errors can be achieved.

Susceptance forward

This setting should be based on the minimum operate current of 1 A.

Susceptance forward: 1 A/(15 kV/sqrt(3)) = 0.1 mS

Susceptance reverse

This setting should be set based on the value of the maximum earth-fault current produced by the feeder (considering possible feeder topology changes) with a security margin. This ensures that the admittance operating point stays inside the "Box" characteristics during outside fault. The recommended security margin should not be lower than 1.5.

Susceptance reverse: - (10 A × 1.5/(15 kV/sqrt(3)) = -1.73 mS

Conductance reverse

This setting is used to complete the non-directional characteristics by closing the "Box" characteristic. In order to keep the shape of the characteristic reasonable and to allow sufficient margin for the admittance operating point during outside fault, it is recommended to use the same value as for setting *Susceptance reverse*.

Conductance reverse = -1.73 mS

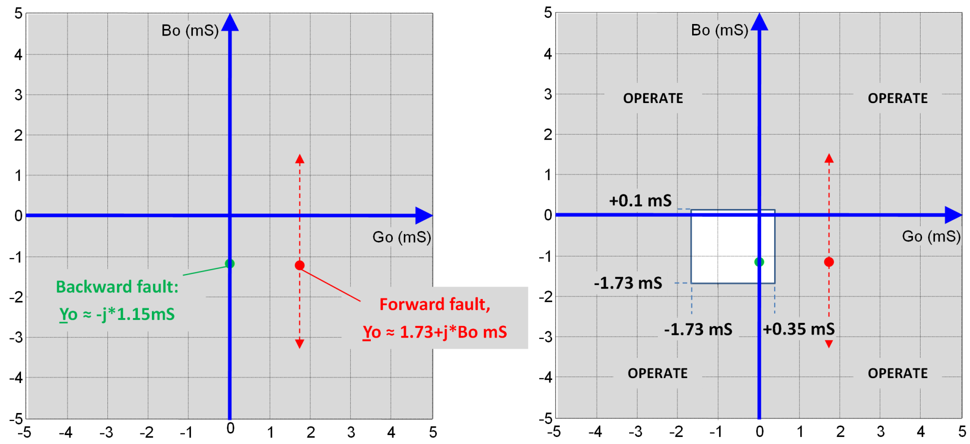


Figure 239: Admittances of the example

4.2.4.9 Signals

Table 497: EFPADM Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block all outputs (includes timer reset)
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze timer
RELEASE	BOOLEAN	0	External trigger signal to release neutral admittance protection
RESET	BOOLEAN	0	External reset signal to reset recorded data

Table 498: EFPADM Output signals

Name	Type	Description
OPERATE	BOOLEAN	Time delayed operate-signal
START	BOOLEAN	General start-signal
FAULT_DIR	INTEGER	Detected fault direction
COND_RES	REAL	Real part of calculated neutral admittance
SUS_RES	REAL	Imaginary part of calculated neutral admittance

4.2.4.10 Settings

Table 499: EFPADM Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation mode	Yo Go Bo Yo, Go Yo, Bo Go, Bo Yo, Go, Bo	-	-	Yo	Selection of characteristic mode
Directional mode	Non-directional Forward Reverse	-	-	Forward	Directional mode
Voltage start value	0.01 - 2.00	pu	0.01	0.15	Voltage start value
Circle conductance	-500.00 - 500.00	mS	0.01	0.00	Admittance circle midpoint, real part
Circle susceptance	-500.00 - 500.00	mS	0.01	0.00	Admittance circle midpoint, imaginary part
Circle radius	0.05 - 500.00	mS	0.01	1.00	Admittance circle radius
Conductance forward	-500.00 - 500.00	mS	0.01	1.00	Conductance threshold in forward direction
Conductance reverse	-500.00 - 500.00	mS	0.01	-1.00	Conductance threshold in reverse direction
Susceptance forward	-500.00 - 500.00	mS	0.01	1.00	Susceptance threshold in forward direction
Susceptance reverse	-500.00 - 500.00	mS	0.01	-1.00	Susceptance threshold in reverse direction
Operate delay time	0.06 - 200.00	s	0.01	0.60	Operate delay time

Table 500: EFPADM Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Conductance tilt Ang	-30 - 30	Deg	1	0	Tilt angle of conductance boundary line, positive value rotates anti clock-wise from vertical axis
Susceptance tilt Ang	-30 - 30	Deg	1	0	Tilt angle of susceptance boundary line, positive value rotates anti clock-wise from horizontal axis

Table 501: EFPADM Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 502: EFPADM Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Admittance Clc mode	Normal Delta	-	-	Normal	Admittance calculation mode
Min operate current	0.005 - 1.000	pu	0.001	0.005	Minimum operating current
Min operate voltage	0.01 - 1.00	pu	0.01	0.01	Minimum operating voltage
Reset delay time	0.00 - 60.00	s	0.01	0.04	Reset delay time
Pol reversal	No Yes	-	-	No	Rotate polarizing quantity

4.2.4.11 Measured values

Table 503: EFPADM Measured values

Name	Type	Default	Description
I_AMPL_RES	REAL	0.0	Amplitude of the residual current
I_ANGL_RES	REAL	0.0	Angle of the residual current
U_AMPL_RES	REAL	0.0	Amplitude of the residual voltage
U_ANGL_RES	REAL	0.0	Angle of the residual voltage
BLOCK	BOOLEAN	0	Block all outputs (includes timer reset)
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze timer
RELEASE	BOOLEAN	0	External trigger signal to release neutral admittance protection
RESET	BOOLEAN	0	External reset signal to reset recorded data

4.2.4.12 Monitored data

Table 504: EFPADM Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Time delayed operate-signal
START	BOOLEAN	0=FALSE 1=TRUE	-	General start-signal
FAULT_DIR	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Detected fault direction
CONFLICT	INTEGER	3=Both 0=No conflict 1=Conductance 2=Susceptance	-	Overlaping admittance boundary line settings

Table continues on next page

Name	Type	Values (Range)	Unit	Description
COND_RES	REAL	-	-	Real part of calculated neutral admittance
SUS_RES	REAL	-	-	Imaginary part of calculated neutral admittance
START_DUR	REAL	-	%	Ratio of start time / operate time
1 Recording time	GROUP SIGNAL	-	-	Record data of bank 1 for fault time stamp
1 FAULT_DIR	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Record data of bank 1 for detected fault direction
1 COND_RES (Go)	REAL	-	-	Record data of bank 1 for real part of neutral admittance
1 SUS_RES (Bo)	REAL	-	-	Record data of bank 1 for imaginary part of neutral admittance
1 I_AMPL_RES Pre Flt	REAL	-	A	Record data of bank 1 for magnitude of pre-fault residual current
1 I_ANGL_RES Pre Flt	REAL	-	deg	Record data of bank 1 for angle of pre-fault residual current
1 U_AMPL_RES Pre Flt	REAL	-	kV	Record data of bank 1 for magnitude of pre-fault residual voltage
1 U_ANGL_RES Pre Flt	REAL	-	deg	Record data of bank 1 for angle of pre-fault residual voltage
1 I_AMPL_RES fault	REAL	-	A	Record data of bank 1 for magnitude of fault-state residual current
1 I_ANGL_RES fault	REAL	-	deg	Record data of bank 1 for angle of fault-state residual current
1 U_AMPL_RES fault	REAL	-	kV	Record data of bank 1 for magnitude of fault-state residual voltage
1 U_ANGL_RES fault	REAL	-	deg	Record data of bank 1 for angle of fault-state residual voltage
1 START_DUR	REAL	-	%	Record data of bank 1 for ratio of started time / operate time
2 Recording time	GROUP SIGNAL	-	-	Record data of bank 2 for fault time stamp
2 FAULT_DIR	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Record data of bank 2 for detected fault direction

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 COND_RES (Go)	REAL	-	-	Record data of bank 2 for real part of neutral admittance
2 SUS_RES (Bo)	REAL	-	-	Record data of bank 2 for imaginary part of neutral admittance
2 I_AMPL_RES Pre Flt	REAL	-	A	Record data of bank 2 for magnitude of pre-fault residual current
2 I_ANGL_RES Pre Flt	REAL	-	deg	Record data of bank 2 for angle of pre-fault residual current
2 U_AMPL_RES Pre Flt	REAL	-	kV	Record data of bank 2 for magnitude of pre-fault residual voltage
2 U_ANGL_RES Pre Flt	REAL	-	deg	Record data of bank 2 for angle of pre-fault residual voltage
2 I_AMPL_RES fault	REAL	-	A	Record data of bank 2 for magnitude of fault-state residual current
2 I_ANGL_RES fault	REAL	-	deg	Record data of bank 2 for angle of fault-state residual current
2 U_AMPL_RES fault	REAL	-	kV	Record data of bank 2 for magnitude of fault-state residual voltage
2 U_ANGL_RES fault	REAL	-	deg	Record data of bank 2 for angle of fault-state residual voltage
2 START_DUR	REAL	-	%	Record data of bank 2 for ratio of started time / operate time
3 Recording time	GROUP SIGNAL	-	-	Record data of bank 3 for fault time stamp
3 FAULT_DIR	INTEGER	3=Both 0=Unknown 1=Forward 2=Backward	-	Record data of bank 3 for detected fault direction
3 COND_RES (Go)	REAL	-	-	Record data of bank 3 for real part of neutral admittance
3 SUS_RES (Bo)	REAL	-	-	Record data of bank 3 for real part of neutral admittance
3 I_AMPL_RES Pre Flt	REAL	-	A	Record data of bank 3 for magnitude of pre-fault residual current
3 I_ANGL_RES Pre Flt	REAL	-	deg	Record data of bank 3 for angle of pre-fault residual current

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3 U_AMPL_RES Pre Flt	REAL	-	kV	Record data of bank 3 for magnitude of pre-fault residual voltage
3 U_ANGL_RES Pre Flt	REAL	-	deg	Record data of bank 3 for angle of pre-fault residual voltage
3 I_AMPL_RES fault	REAL	-	A	Record data of bank 3 for magnitude of fault-state residual current
3 I_ANGL_RES fault	REAL	-	deg	Record data of bank 3 for angle of fault-state residual current
3 U_AMPL_RES fault	REAL	-	kV	Record data of bank 3 for magnitude of fault-state residual voltage
3 U_ANGL_RES fault	REAL	-	deg	Record data of bank 3 for angle of fault-state residual voltage
3 START_DUR	REAL	-	%	Record data of bank 3 for ratio of started time / operate time

4.2.4.13 Technical data

Table 505: EFPADM Technical data

Characteristic	Value
Operation accuracy[1]	At the frequency $f = f_n$
	±1.0% or ±0.01 mS (in range of 0.5...100 mS)
Start time[2]	Typically 65 ms (±15 ms)
Reset time	<50 ms
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Suppression of harmonics	-50dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

1) Io varied during the test. Uo = 1.0 × U_n = phase to earth voltage during earth-fault in compensated or unearthed network.
2) Includes the delay of the signal output contact. Results based on statistical distribution of 1000 measurements.

4.2.5 Rotor earth-fault protection MREFPTOC

4.2.5.1 Identification

Function description	IEC 61850	IEC 60617	ANSI/IEEE identification
Rotor earth-fault protection	MREFPTOC	Io>R	64R

4.2.5.2 Function block

Figure 240: Function block

4.2.5.3 Functionality

The rotor earth-fault protection function MREFPTOC is used to detect an earth fault in the rotor circuit of synchronous machines. MREFPTOC is used with the injection device REK510, which requires a secured 58, 100 or 230 V AC 50/60 Hz input source and injects a 100 V AC voltage via its coupling capacitors to the rotor circuit towards earth.

MREFPTOC consists of independent alarm and operating stages. The operating time characteristic is according to definite time (DT) for both stages.

MREFPTOC contains a blocking functionality. Blocking deactivates all outputs and resets timers.

4.2.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the rotor earth-fault protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

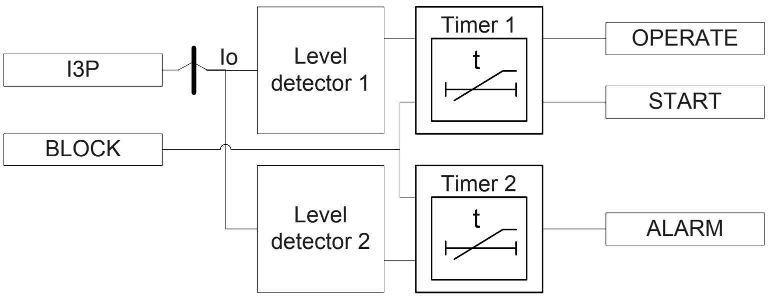


Figure 241: Functional module diagram

Level detector 1

The measured rotor earth-fault current (DFT value) is compared to the *Operate start value* setting. If the measured value exceeds that of the *Operate start value* setting, level detector 1 sends a signal to start the timer 1 module.

Level detector 2

The measured rotor earth-fault current (DFT value) is compared to the set *Alarm start value*. If the measured value exceeds that of the *Alarm start value* setting, level detector 2 sends a signal to start the timer 2 module.

For MREFPTOC, the earth-fault current is the current that flows due to the voltage injected by the injection device in the rotor circuit when an earth fault arises.

A considerable amount of harmonics, mainly 3rd and 6th, can occur in the excitation current under normal no-fault conditions, especially with the thyristor excitation and rotating diode rectifier systems. MREFPTOC uses DFT value calculation to filter DC and harmonic components which could otherwise give out false alarms or trips.

Timer 1

Once activated, the timer activates the `START` output. The timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time* in the DT mode, the `OPERATE` output is activated. If a drop-off situation occurs, that is, a fault suddenly disappears before the operating delay is exceeded, the timer reset state is activated. The reset time depends on the *Reset delay time* setting.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets the internal timers.

Timer 2

Once activated, the timer activates the alarm timer. The timer characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time* in the DT mode, the `ALARM` output is activated. If a drop-off situation occurs, that is, a fault suddenly disappears before the alarm delay is exceeded, the timer reset state is activated. The reset time depends on the *Alm Reset delay time* setting.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets the internal timers.

4.2.5.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the residual current or voltage-related settings, for example, "*Residual Grp 1*", "*Residual Grp 2*" and

"*Residual Grp 3*". One of the groups to be used with the "Base value Sel Res" setting must be selected.

4.2.5.6 Application

The rotor circuit of synchronous machines is normally isolated from the earth. The rotor circuit can be exposed to an abnormal mechanical or thermal stress due to, for example, vibrations, overcurrent and choked cooling medium flow. This can result in the breakdown of the insulation between the field winding and the rotor iron at the point exposed to excessive stress. If the isolation resistance is decreased significantly, this can be seen as an earth fault. For generators with slip rings, the rotor insulation resistance is sometimes reduced due to the accumulated carbon dust layer produced by the carbon brushes. As the circuit has a high impedance to earth, a single earth fault does not lead to any immediate damage because the fault current is small due to a low voltage. There is, however, a risk that a second earth fault appears, creating a rotor winding interturn fault and causing severe magnetic imbalance and heavy rotor vibrations that soon lead to a severe damage.

Therefore, it is essential that any occurrence of an insulation failure is detected and that the machine is disconnected as soon as possible. Normally, the device is tripped after a short time delay.

A 50/60 Hz voltage is injected via the injection device REK 510 to the rotor field winding circuit of the synchronous machine as shown in Figure 242. The injected voltage is 100 V AC via the coupling capacitors. A coupling capacitor prevents a DC current leakage through the injection device.

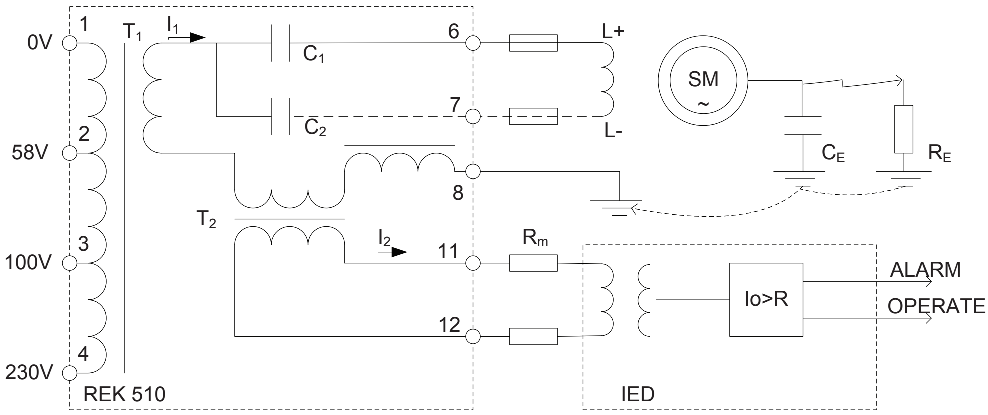


Figure 242: Principle of the rotor earth-fault protection with the current injection device

This auxiliary AC voltage forms a small charging current I_1 to flow via the coupling capacitors, resistances of the brushes and the leakage capacitance between the field circuit and earth. The field-to-earth capacitance C_E affects the level of the resulting current to an extent which is a few milliamperes during normal no-fault operating conditions.

If an earth fault arises in the rotor field circuit, this current increases and can reach a level of 130 mA at a fully developed earth fault (fault resistance R_E = 0, one coupling capacitor C_1 = 2μF is used). The integrated current transformer of the injection device REK 510 then amplifies this current with the ratio of 1:10 to a measurable level. MREFPTOC is used to measure this current.

An example of the measured curves with various field-to-earth leakage capacitance values is given in Figure 243.

It is recommended that the alarm and operation stages of MREFPTOC are both used. The alarm stage for giving an indication for weakly developed earth faults with a start value setting corresponds to a 10 kΩ fault resistance with a 10-second delay. The operation stage for a protection against fully developed earth faults with a start value setting corresponds to a 1-2 kΩ fault resistance with a 0.5-second delay.

The current setting values corresponding to the required operating fault resistances can be tested by connecting an adjustable fault-simulating resistor between the excitation winding poles and the earth. Whether only one of the coupling capacitors or both should be used in a parallel connection should be determined on a case-by-case basis, taking into consideration the consequences of a possibly excessive current at a direct earth fault.

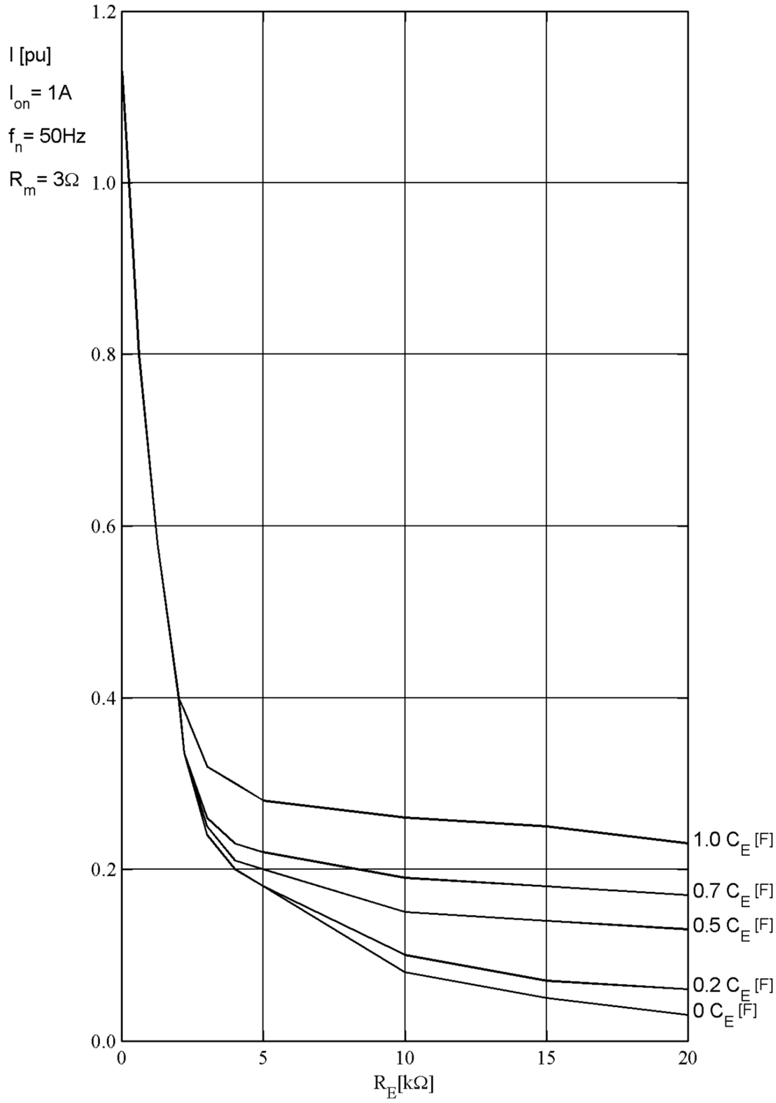


Figure 243: Measured current as a function of the rotor earth-fault resistance with various field-to-earth capacitance values with the measuring circuit resistance R_m = 3.0Ω, f_n = 50 Hz. Only one coupling capacitor is used.

4.2.5.7 Signals

Table 506: MREFPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs

Table 507: MREFPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started
ALARM	BOOLEAN	Alarm signal

4.2.5.8 Settings

Table 508: MREFPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Alarm start value	0.010 - 2.000	pu	0.001	0.010	Alarm start value for rotor earth fault current
Operate start value	0.010 - 2.000	pu	0.001	0.010	Operate start value for rotor earth fault current
Alarm delay time	0.04 - 200.00	s	0.01	10.00	Alarm delay time
Operate delay time	0.04 - 200.00	s	0.01	0.50	Operate delay time

Table 509: MREFPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 510: MREFPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 2	Base value selector, residual
Alm reset delay time	0.00 - 60.00	s	0.01	0.02	Alarm reset delay time
Reset delay time	0.00 - 60.00	s	0.01	0.02	Reset delay time

4.2.5.9 Measured values

Table 511: MREFPTOC Measured values

Name	Type	Default	Description
I_AMPL_MREF	REAL	0.0	Rotor earth fault current amplitude (DFT)
BLOCK	BOOLEAN	0	Block signal for all binary outputs

4.2.5.10 Monitored data

Table 512: MREFPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal

4.2.5.11 Technical data

Table 513: MREFPTOC Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5% of the set value or $\pm 0.002 \times I_n$
Start time[1)2)]	Typically 25 ms (±15 ms)
Reset time	<50 ms
Reset ratio	Typically 0.96
Retardation time	<50 ms
Operate time accuracy	±1.0% of the set value of ±20 ms
Suppression of harmonics	-50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

1) Current before fault = $0.0 \times I_n$, f_n = 50 Hz, earth-fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.2.6 Harmonics based earth-fault protection HAEFPTOC

4.2.6.1 Identification

Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Harmonics based earth-fault protection	HAEFPTOC	Io>HA	51NHA

4.2.6.2 Function block

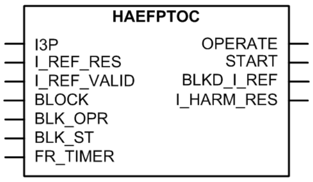


Figure 244: Function block

4.2.6.3 Functionality

Harmonics based earth-fault protection HAEFPTOC is used instead of traditional earth-fault protection in networks where a fundamental frequency component of the earth-fault current is low due to compensation.

By default, HAEFPTOC is used in standalone mode. Substation-wide application can be achieved using horizontal communication where the detection of a faulty feeder is done by comparing the harmonic earth-fault current measurements.

The function starts when the harmonic content of the earth-fault current exceeds the set limit. The operation time characteristic is either definite time (DT) or inverse definite minimum time (IDMT). If the horizontal communication is used for the exchange of current values between the IEDs, the function operates according to the DT characteristic.

HAEFPTOC contains a blocking functionality to block function outputs, timer or the function itself.

4.2.6.4 Operation principle

The *Operation* setting is used to enable or disable the function. When "On" is selected, the function is enabled and when "Off" is selected, the function is disabled.

The operation of the harmonic earth-fault protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

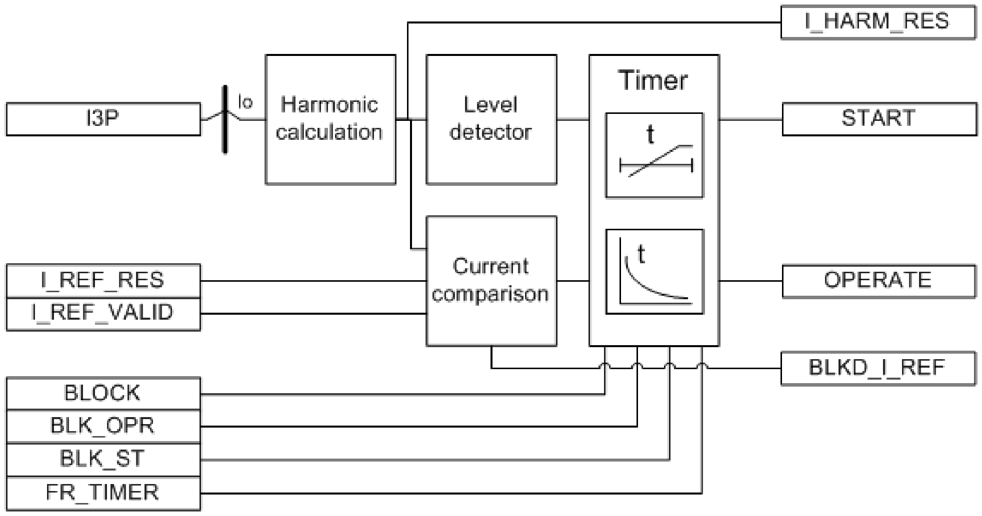


Figure 245: Functional module diagram

Harmonic calculation

This module feeds the measured residual current to the high-pass filter. The frequency range is limited to start from twice the fundamental frequency of the network (for example, in a 50 Hz network the cutoff frequency is 100 Hz), that is, summing the harmonic components of the network from the second harmonic. The output of the filter, later referred to as the harmonic current, is fed to the Level detector and Current comparison modules.

The harmonic current I_HARM_RES is available in the monitored data view. The value is also sent over horizontal communication to the other IEDs on the parallel feeders configured in the protection scheme.

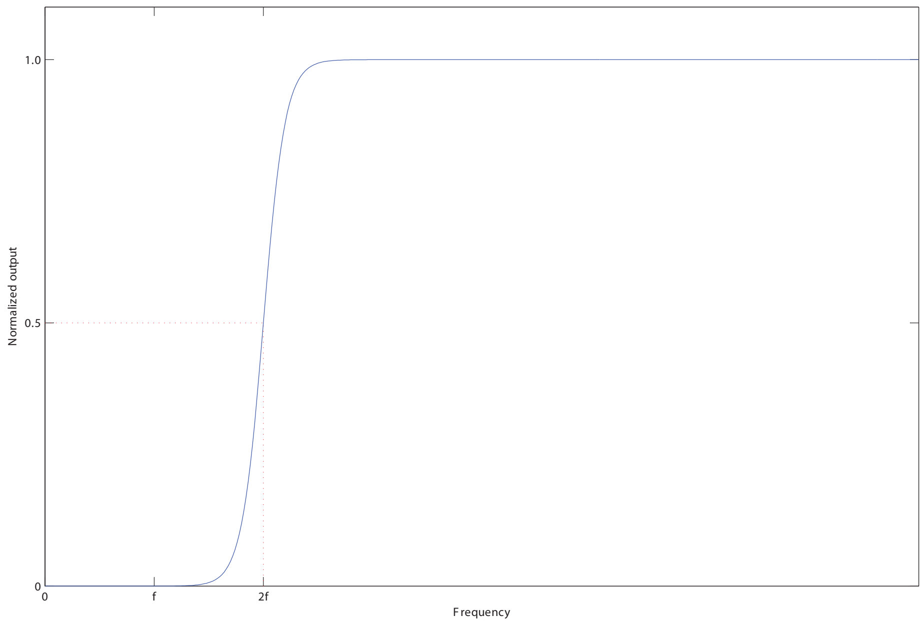


Figure 246: High-pass filter

Level detector

The harmonic current is compared to the *Start value* setting. If the value exceeds the value of the *Start value* setting, the level detector sends an enabling signal to the timer module.

Current comparison

The maximum of the harmonic currents reported by other parallel feeders in the substation, that is, in the same busbar, is fed to the function through the I_REF_RES input. If the locally measured harmonic current is higher than I_REF_RES, the enabling signal is sent to the timer.

If the locally measured harmonic current is lower than I_REF_RES, the fault is not in the feeder. The detected situation blocks the timer internally. Simultaneously, the BLKD_I_REF output is activated.

The module also supervises the communication channel validity through I_REF_VALID input which is reported to the timer.

Timer

Once activated, the timer activates the START output. Functionality and the time characteristics depend on the selected value of the *Enable reference use* setting.

The *Enable reference use* setting forces the function to use the DT characteristics where the operating time is set with the *Minimum operate time* setting.

If the communication fails for some reason, the function switches to use the *Operation curve type* setting. If DT is selected, *Operate delay time* is used. If the IDMT curve is selected, the time characteristics are according to the selected curve and the *Minimum operate time* setting is used for restricting a too fast operation time.

In case of a communication failure, the start duration may change substantially depending on the settings.

When the programmable IDMT curve is selected, the operation time characteristics are defined with the *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E* parameters.

Table 514: Values of the Enable reference use setting

Enable reference use	Functionality	
Standalone		In the standalone mode, depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of the *Operate delay time* setting in the DT mode or the value defined by the inverse time curve, the OPERATE output is activated.
Reference use	Communication valid	While using horizontal communication, the function is forced to use the DT characteristics. When the operation timer has reached the value of the *Minimum operate time* setting and simultaneously the enabling signal from the Current comparison module is active, the OPERATE signal is activated
	Communication invalid	Function operates as in the standalone mode.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the value of the *Reset delay time* setting is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation.

The "Inverse reset" selection is only supported with ANSI or the programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operation and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operation time for IDMT. The setting is applicable only when the IDMT curves are used. *Enable reference use* set to "Yes" forces the function to use the DT characteristics where the operating time is set with the *Minimum operate time* setting.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve but always at least the value of the *Minimum operate time* setting. More information can be found in the IDMT curves for overcurrent protection.

Timer calculates the start duration value "START_DUR", which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

When the function input BLOCK is activated, it forces the sent harmonic current analog GOOSE data quality to “operatorBlocked”. At the receiving end IED, the analog GOOSE harmonic current is forced to zero.
The activation of other block inputs BLK_OPR, BLK_ST and FR_TIMER, does not cause sent analog GOOSE data quality change. At the receiving end IED, the analog GOOSE harmonic current is reported as it is measured at the sending end IED.

4.2.6.5 Base value

In this function block, some of the settings are set in per unit (p.u.). These p.u. values are related to certain base values, for example, the values given in A, kV and kVA. The IED supports alternative base value groups for the residual current or voltage-related settings, for example “Residual Grp 1”, “Residual Grp 2” and “Residual Grp 3”. One of the groups should be selected to use with the *Base value Sel Res* settings.

4.2.6.6 Application

During an earth fault, HAEFPTOC calculates the maximum harmonic current for the protected feeder. The value is sent over an analog GOOSE to other IEDs of the busbar in the substation. At the configuration level, all values received over the analog GOOSE are compared through the MAX function to find the maximum value. The maximum value is sent back to HAEFPTOC as the `I_REF_RES` input. The operation of HAEFPTOC is allowed in case `I_REF_RES` is lower than the locally measured harmonic current. If `I_REF_RES` exceeds the locally measured harmonics current, the operation of HAEFPTOC is blocked.

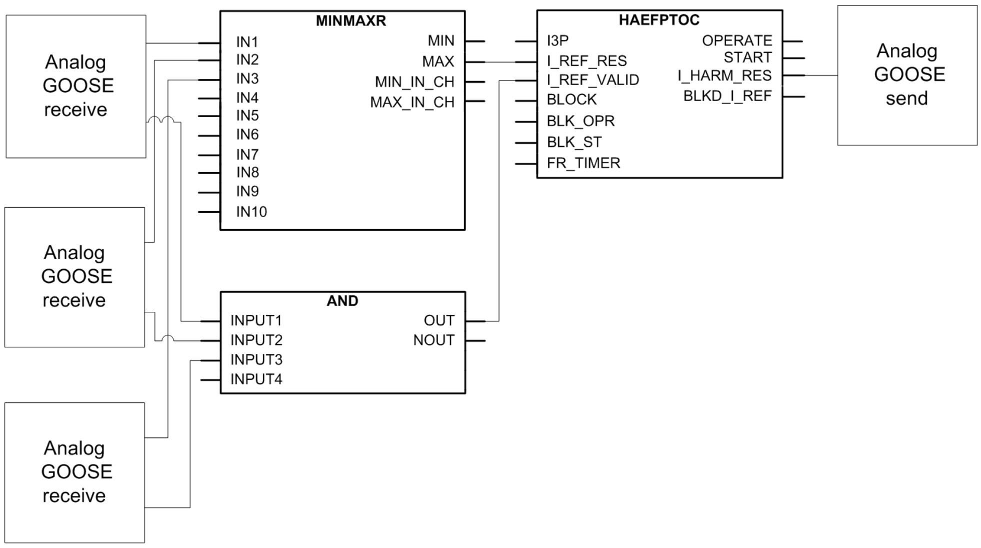


Figure 247: Protection scheme based on the analog GOOSE communication with three analog GOOSE receivers

4.2.6.7 Signals

Table 515: HAEFPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
I_REF_RES	REAL	0.0	Reference current
I_REF_VALID	BOOLEAN	1	Reference input validity
BLOCK	BOOLEAN	0	Block all outputs (includes timer reset)
Table continues on next page			

Name	Type	Default	Description
BLK_OPR	BOOLEAN	0	Block of operate signal
BLK_ST	BOOLEAN	0	Block of start signal
FR_TIMER	BOOLEAN	0	Freeze signal for timers

Table 516: HAEFPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal
START	BOOLEAN	Start signal
BLKD_I_REF	BOOLEAN	Current comparison status indicator blocked/not blocked
I_HARM_RES	REAL	Calculated harmonics current

4.2.6.8 Settings

Table 517: HAEFPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Enable reference use	No Yes	-	-	No	Enable using current reference from other IED's instead of stand-alone
Start value	0.05 - 5.00	pu	0.01	0.10	Current threshold value
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	ANSI Ext. inv. ANSI Very inv. ANSI Norm. inv. ANSI Mod. inv. ANSI Def. Time L.T.E. inv. L.T.V. inv. L.T. inv. IEC Norm. inv. IEC Very inv. IEC inv. IEC Ext. inv. IEC S.T. inv. IEC L.T. inv. IEC Def. Time Programmable RI type RD type	-	-	IEC Def. Time	Selection of time delay curve type
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type
Operate delay time	0.10 - 200.00	s	0.01	0.60	Operate delay time
Minimum operate time	0.10 - 200.00	s	0.01	0.50	Minimum operate time for IDMT curves and reference use

Table 518: HAEFPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On

Table 519: HAEFPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.2.6.9 Measured values

Table 520: HAEFPTOC Measured values

Name	Type	Default	Description
I_REF_RES	REAL	0.0	Reference current
I_REF_VALID	BOOLEAN	1	Reference input validity
BLOCK	BOOLEAN	0	Block all outputs (includes timer reset)
BLK_OPR	BOOLEAN	0	Block of operate signal
BLK_ST	BOOLEAN	0	Block of start signal
FR_TIMER	BOOLEAN	0	Freeze signal for timers

4.2.6.10 Monitored data

Table 521: HAEFPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal
BLKD_I_REF	BOOLEAN	0=FALSE 1=TRUE	-	Current comparison status indicator blocked/not blocked
I_HARM_RES	REAL	-	A	Calculated harmonics current
START_DUR	REAL	-	%	Ratio of operate time

4.2.6.11 Technical data

Table 522: HAEFPTOC technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$ ±5% of the set value or ±0.004 × I_n
Start time 1)2)	Typically 83 ms
Reset time	<40 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Operate time accuracy in IDMT mode 3)	±5.0% of the set value or ±20 ms
Suppression of harmonics	-80 dB at $f = f_n$ -3 dB at $f = 11 \times f_n$

1) Fundamental frequency current = 1.0 × I_n. Harmonics current before fault = 0.0 × I_n, harmonics fault current 2.0 × *Start value*. Results based on statistical distribution of 1000 measurement.
2) Includes the delay of the signal output contact
3) Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 2...20

4.2.7 Wattmetric earth-fault protection WPWDE

4.2.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Wattmetric earth-fault protection	WPWDE	Po>->	32N

4.2.7.2 Function block

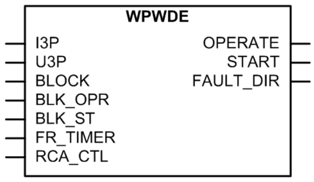


Figure 248: Function block

4.2.7.3 Functionality

The wattmetric earth-fault protection function WPWDE can be used to detect earth faults in networks with a high-impedance earthing, unearthed networks or compensated networks (Peterson coil-earthed networks). It can be used as an alternative solution to the traditional residual current-based earth-fault protection functions, for example, the IoCos mode in the directional earth-fault protection function DEFxPDEF.

The function measures the earth-fault power IoUoCosφ and gives an operating signal when the residual current, residual voltage and earth-fault power exceed the set limits and the angle between the residual current and residual voltage (φ) is inside the set operating region, that is, forward or backward region. The operating time characteristic can be selected to be either definite time (DT) or a special wattmetric-type inverse definite minimum type (wattmetric type IDMT).

The wattmetric earth-fault protection is very sensitive to current transformer errors and it is recommended that a core balance CT is used for measuring the residual current.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.2.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the wattmetric earth-fault protection function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

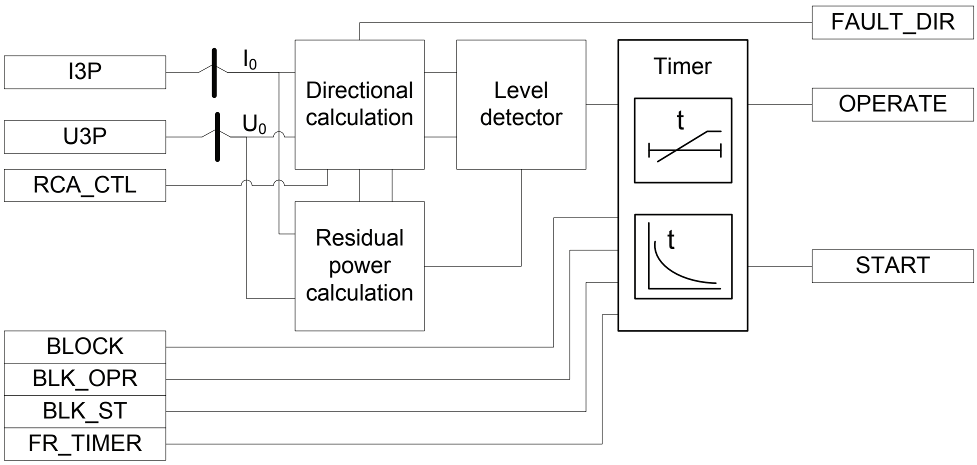


Figure 249: Functional module diagram

Directional calculation

The directional calculation module monitors the angle between the operating quantity (residual current) and polarizing quantity (residual voltage). When the angle after considering the *Characteristic angle* setting is in the operation section, the module sends an enable signal to the level detector. The directional operation is selected with the *Directional mode* setting. Either the "Forward" or "Reverse" operation mode can be selected. The direction of fault is calculated based on the phase angle difference between the operating quantity and polarizing quantity, the value (ANGLE) is available through the monitored data view.

The polarizing quantity for a directional earth fault is shifted by 180˚ and hence it is represented as –Uo in the phasor diagrams.

If the angle difference lies between -90˚ to 0˚ or 0˚ to +90˚, a forward direction fault is considered. If the phase angle difference lies within -90˚ to -180˚ or +90˚ to +180˚, a reverse direction fault is detected. Thus, the normal width of a sector is 180˚.

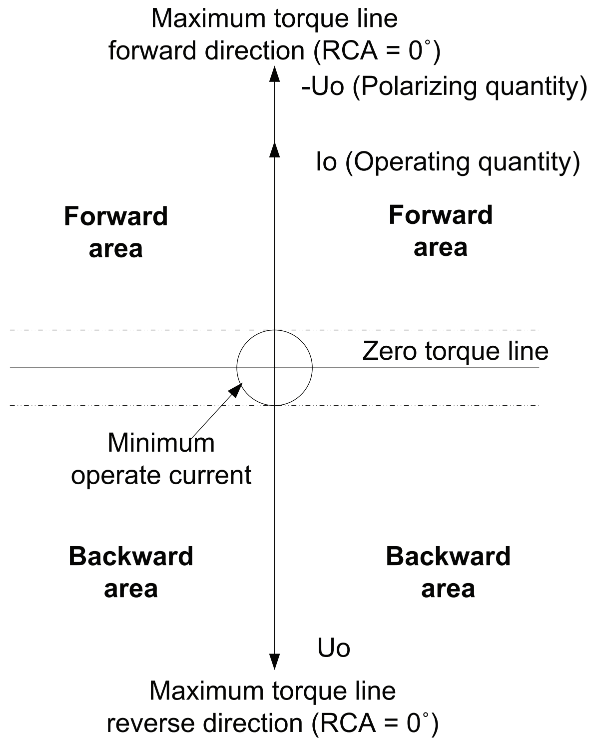


Figure 250: Definition of the relay characteristic angle

The phase angle difference is calculated based on the *Characteristic angle* setting (also known as Relay Characteristic Angle (RCA) or Relay Base Angle (RBA) or Maximum Torque Angle (MTA)). The *Characteristic angle* setting is done based on the method of earthing employed in the network. For example, in case of an unearthed network, the *Characteristic angle* setting is set to -90˚, in case of a compensated network, the *Characteristic angle* setting is set to 0˚. In general, *Characteristic angle* is selected so that is close to the expected fault angle value, which results maximum sensitivity. *Characteristic angle* can be set anywhere between -179˚ to +180˚. Thus the effective phase angle (Φ) for calculating the residual power considering the characteristic angle is

$$\phi = \left(\angle(-Uo) - \angle Io - Characteristic\ angle\right)$$

(Equation 52)

In addition, the characteristic angle can be changed via the control signal `RCA_CTL`. The `RCA_CTL` input is used in the compensated networks where the compensation coil sometimes is temporarily disconnected. When the coil is disconnected, the compensated network becomes isolated and the *Characteristic angle* setting must be changed. This can be done automatically with the `RCA_CTL` input, which results in the addition of -90˚ in the *Characteristic angle* setting.

The value (ANGLE_RCA) is available in the monitored data view.

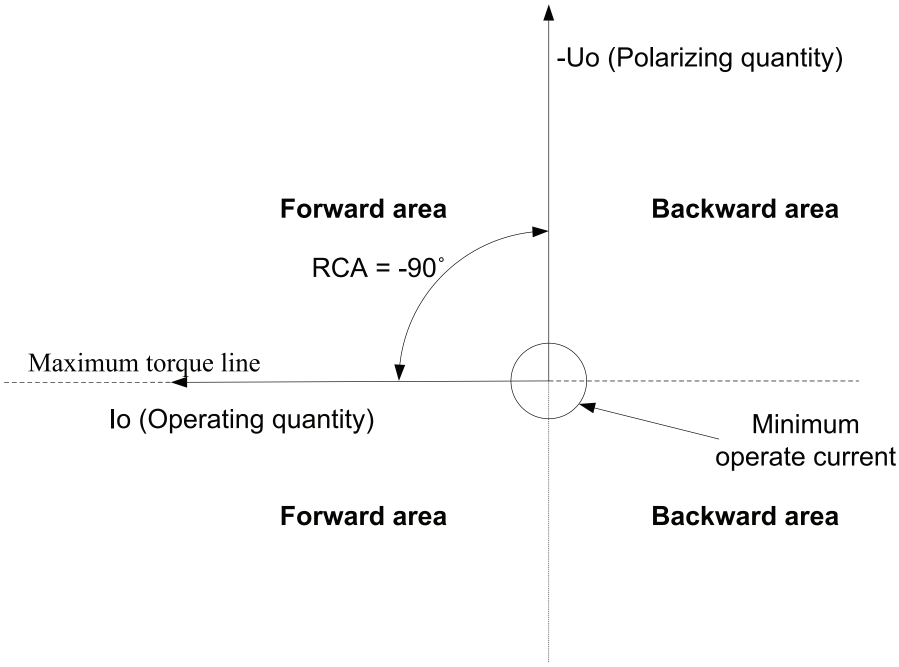


Figure 251: Definition of relay characteristic angle, RCA = -90˚ in an isolated network

Characteristic angle should be set to a positive value if the operating signal lags the polarizing signal and to a negative value if the operating signal leads the polarizing signal.

Type of network	Characteristic angle recommended
Compensated network	0˚
Unearthed network	-90˚

In unearthed networks, when the characteristic angle is -90˚, the measured residual power is reactive (varmetric power).

The fault direction is also indicated by the integer output FAULT_DIR (also available in the monitored data view), which indicates 0 if a fault is not detected, 1 for faults in the forward direction and 2 for faults in the backward direction.

The direction of the fault is detected only when the correct angle calculation can be made. If the magnitude of the operating quantity or polarizing quantity is not high enough, the direction calculation is not reliable. Hence, the magnitude of the operating quantity is compared to the *Min operate current* setting and the magnitude of the polarizing quantity is compared to *Min operate voltage*, and if both the operating quantity and polarizing quantity are higher than their respective limit, a valid angle is calculated and the residual power calculation module is enabled.

The *Correction angle* setting can be used to improve the selectivity when there are inaccuracies due to the measurement transformer. The setting decreases the operation sector. The *Correction angle* setting should be done carefully as the phase angle error of the measurement transformer varies with the connected burden as well as with the magnitude of the actual primary current that is being measured. An example of how *Correction angle* alters the operating region is as shown:

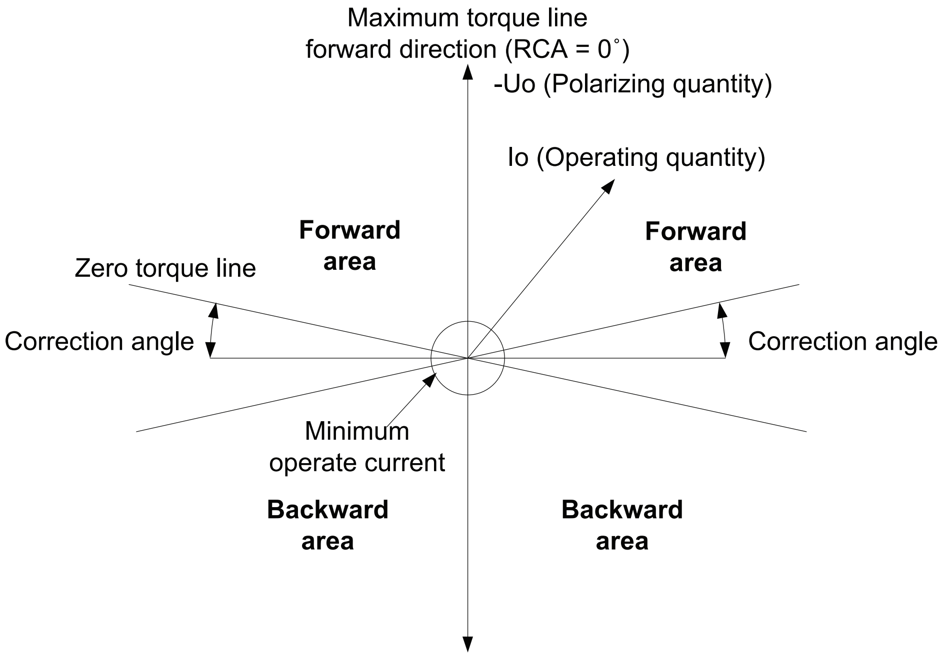


Figure 252: Definition of correction angle

The polarity of the polarizing quantity can be changed (rotated by 180˚) by setting *Pol reversal* to "True" or by switching the polarity of the residual voltage measurement wires.

Residual power calculation

The residual power calculation module calculates the magnitude of residual power Io·Uo·CosΦ. Angle Φ is the angle between the operating quantity and polarizing quantity, compensated with a characteristic angle. The angle value is received from the directional calculation module. The directional calculation module enables the residual power calculation only if the minimum signal levels for both operating quantity and polarizing quantity are exceeded. However, if the angle calculation is not valid, the calculated residual power is zero. Residual power (RES_POWER) is calculated continuously and it is available in the monitored data view.

Level detector

The level detector compares the magnitudes of the measured operating quantity, polarizing quantity and calculated residual power to the set *Current start value*, *Voltage start value* and *Res power start value* respectively. When all three quantities exceed the limits, the level detector enables the timer module.

Timer

Once activated, the timer activates the `START` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or wattmetric IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated. If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The reset time is identical for both DT or wattmeter IDMT. The reset time depends on the *Reset delay time* setting.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets internal timers. The binary input `BLK_ST` can be used to block the `START` signal. The binary input `BLK_OPR` can be used to block the `OPERATE` signal. The operation timer counting can be frozen to the prevailing value by activating the `FR_TIMER` input.

4.2.7.5 Timer characteristics

In the wattmetric IDMT mode, the OPERATE output is activated based on the timer characteristics:

$$t[s] = \frac{k * P_{ref}}{P_{cal}}$$

(Equation 53)

t[s]	operation time in seconds
k	set value of *Time multiplier*
P_{ref}	set value of *Reference power*
P_{cal}	calculated residual power

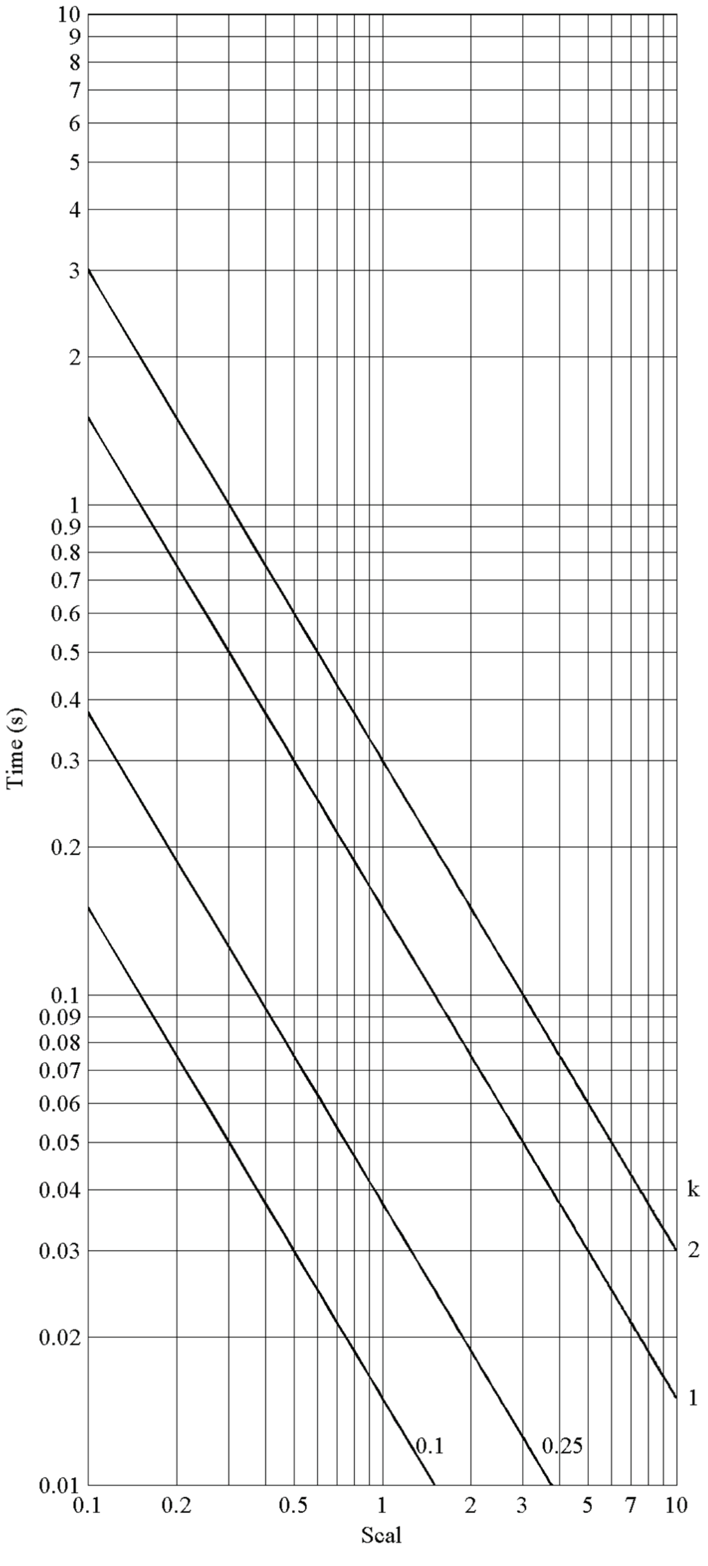


Figure 253: Operation time curves for wattmetric IDMT for S_{ref} set at 0.15 xPn

4.2.7.6 Measuring modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

4.2.7.7 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the residual current or voltage-related settings, for example, "*Residual Grp 1*", "*Residual Grp 2*" and "*Residual Grp 3*". One of the groups to be used with the "Base value Sel Res" setting must be selected.

4.2.7.8 Application

The wattmetric method is one of the commonly used directional methods for detecting the earth faults especially in compensated networks. The protection uses the residual power component IoUoCosφ (φ is the angle between the polarizing quantity and operating quantity compensated with a relay characteristic angle).

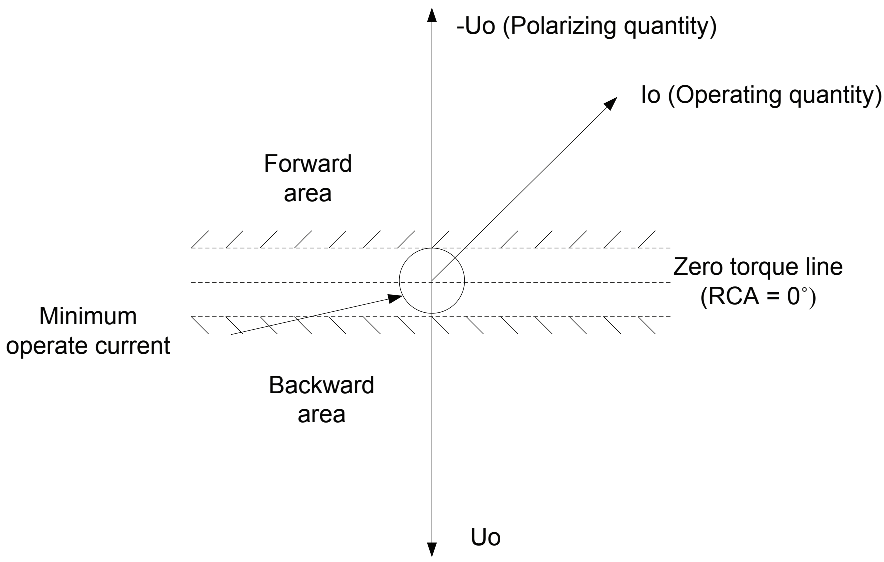


Figure 254: Characteristics of wattmetric protection

In a fully compensated radial network with two outgoing feeders, the earth-fault currents depend mostly on the system earth capacitances (C_0) of the lines and the compensation coil (L). If the coil is tuned exactly to the system capacitance, the fault current has only a resistive component. This is due to the resistances of the coil and distribution lines together with the system leakage resistances (R_0). Often a resistor (R_L) in parallel with the coil is used for increasing the fault current.

When a single phase-to-earth fault occurs, the capacitance of the faulty phase is bypassed and the system becomes unsymmetrical. The fault current is composed of the currents flowing through the earth capacitances of two healthy phases. The protection relay in the healthy feeder tracks only the capacitive current flowing through its earth capacitances. The capacitive current of the complete network (sum of all feeders) is compensated with the coil. An undercompensated network where the coil current $I_L = I_{Ctot} - I_{Cfd}$ (I_{Ctot} is the total earth-fault current of the network and I_{Cfd} is the earth-fault current of the healthy feeder) is as shown:

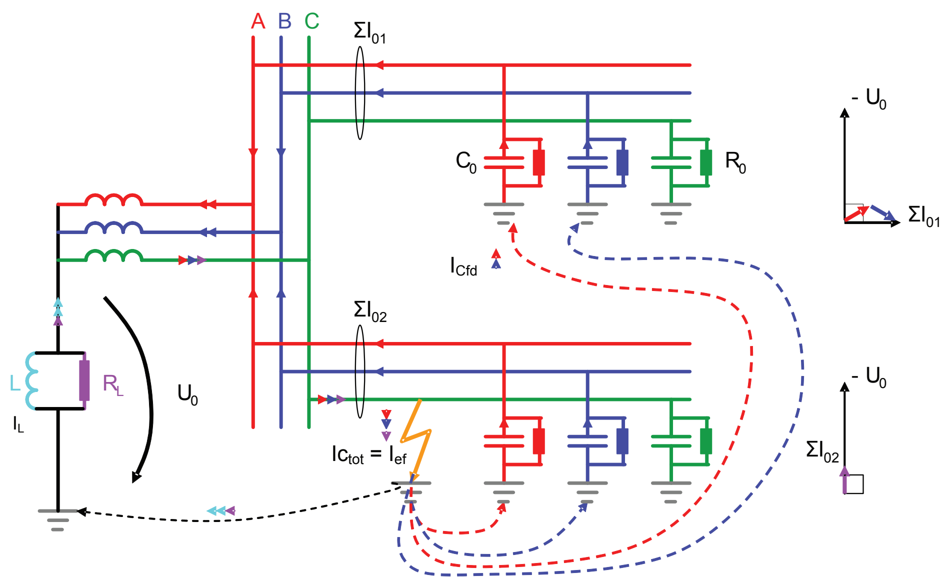


Figure 255: Typical radial compensated network employed with wattmetric protection

The wattmetric function is activated when the residual active power component exceeds the set limit. However, to ensure a selective operation it is also required that the residual current and residual voltage also exceed the set limit.

The sensitivity of the wattmetric method is determined by the magnitude of the residual voltage, which in turn is determined by the fault resistance and maximum healthy-state residual voltage. The threshold value of the residual voltage must be set above the maximum healthy-state residual voltage value with a proper margin. When the fault resistance values are high, there is a reduction in the residual voltage, which reduces the active residual power.

It is highly recommended that core balance CTs are used for measuring Io when using the wattmetric method. When a low transformation ratio is used, the CT can suffer accuracy problems and even a distorted secondary current waveform with some core balance CTs. Therefore, to ensure a sufficient accuracy of the residual current measurement and consequently a better selectivity of the scheme, the core balance current transformer should preferably have a transformation ratio of at least 70:1. Lower transformation ratios such as 50:1 or 50:5 are not recommended, unless the phase displacement errors and CT amplitude are checked first.

It is not recommended to use the directional wattmetric protection in case of a ring or meshed system as the wattmetric requires a radial power flow to operate.

The relay characteristic angle needs to be set based on the system earthing. In an unearthed network, that is, the network is only coupled to earth via the capacitances between the phase conductors and earth, the characteristic angle is chosen as -90º.

In compensated networks, the capacitive fault current and inductive resonance coil current compensate each other, meaning that the fault current is mainly resistive and has zero phase shift compared to the residual voltage. In such networks, the characteristic angle is chosen as 0º. Often the magnitude of active component is small and must be increased by means of a parallel resistor in a compensation coil. In networks where the neutral point is earthed through a low resistance, the characteristic angle is always 0º.

As the amplitude of the residual current is independent of the fault location, the selectivity of the earth-fault protection is achieved with time coordination.

Use of wattmetric protection gives a possibility to use the dedicated inverse definite minimum time characteristics. This is applicable in large high-impedance earthed networks with a large capacitive earth-fault current.

In a network employing a low-impedance earthed system, a medium-size neutral point resistor is used. Such a resistor gives a resistive earth-fault current component of about 200 - 400 A for an excessive earth fault. In such a system, the directional residual power protection gives better possibilities for selectivity enabled by the inverse time power characteristics.

Along with the wattmetric protection, it is recommended that the normal non-directional residual current function and non-directional residual voltage function are also used (can be with definite or inverse time delay). The non-directional residual current function compares the residual current without checking any phase angles and gives a quick protection under cross-country faults. The start value setting for this non-directional current function should be higher than the setting for all single-phase earth faults with a short IDMT time delay. This is an alternative to the distance protection with the phase preference logic. The zero-sequence current for cross-country faults flowing through the feeder is high compared to the zero-sequence current of the single-phase earth fault. Under this condition, the core balance CT tends to be saturated as it is not designed for a large zero-sequence current which results in an inaccurate measurement. Hence, the phase currents are used to calculate the residual current. Non-directional residual voltage function with a long timer setting acts as a backup protection.

Due to the residual connection of the three-phase CTs and the open delta connection of the three-phase VTs, the third harmonic currents and voltages of each phase add up and pollute the residual current and voltage measurements. The DFT measuring mode is used to enable a sensitive setting.

4.2.7.9 Signals

Table 523: WPWDE Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
RCA_CTL	BOOLEAN	0	Relay characteristic angle control

Table 524: WPWDE Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started
FAULT_DIR	INTEGER	Detected fault direction

4.2.7.10 Settings

Table 525: WPWDE Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Directional mode	Forward Reverse	-	-	Forward	Directional mode
Current start value	0.01 - 5.00	pu	0.01	0.01	Start value for residual current
Voltage start value	0.010 - 1.000	pu	0.001	0.010	Start value for residual voltage
Power start value	0.003 - 1.000	pu	0.001	0.003	Start value for residual active power
Reference power	0.050 - 1.000	pu	0.001	0.150	Reference value of residual power for Wattmetric IDMT curves
Characteristic angle	-179 - 180	Deg	1	-90	Characteristic angle
Time multiplier	0.05 - 2.00	-	0.01	1.00	Time multiplier for Wattmetric IDMT curves
Operating curve type	ANSI Def. Time IEC Def. Time WattMetric IDMT	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.06 - 200.00	s	0.01	0.06	Operate delay time for definite time

Table 526: WPWDE Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 527: WPWDE Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Measurement mode	RMS DFT Peak-to-Peak	-	-	DFT	Selects used current measurement mode
Correction angle	0.0 - 10.0	Deg	0.1	2.0	Angle correction
Min operate current	0.010 - 5.000	pu	0.001	0.010	Minimum operate residual current for deciding fault direction
Min operate voltage	0.01 - 1.00	pu	0.01	0.01	Minimum operate residual voltage for deciding fault direction
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time
Pol reversal	No Yes	-	-	No	Rotate polarizing quantity

4.2.7.11 Measured values

Table 528: WPWDE Measured values

Name	Type	Default	Description
I_RMS_RES	REAL	0.0	Residual current amplitude (RMS)
I_AMPL_RES	REAL	0.0	Residual current amplitude (DFT)
I_ANGL_RES	REAL	0.0	Residual current phase angle
I_PTOP_RES	REAL	0.0	Residual current amplitude (PTOP)
U_AMPL_RES	REAL	0.0	Residual voltage amplitude (DFT)
U_ANGL_RES	REAL	0.0	Residual voltage phase angle
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers
RCA_CTL	BOOLEAN	0	Relay characteristic angle control

4.2.7.12 Monitored data

Table 529: WPWDE Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
FAULT_DIR	INTEGER	0=Unknown 1=Forward 2=Backward	-	Detected fault direction
DIRECTION	INTEGER	0=Unknown 1=Forward 2=Backward	-	Direction information
ANGLE_RCA	REAL	-	deg	Angle between operating angle and characteristic angle
ANGLE	REAL	-	deg	Angle between polarizing and operating quantity
RES_POWER	REAL	-	MW	Calculated residual active power
START_DUR	REAL	-	%	Ratio of start time / operate time

4.2.7.13 Technical data

Table 530: WPWDE Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±3.0% of the set value or $\pm 0.002 \times S_n$
Start time1)2)	Typically 65 ms (±15 ms)
Reset time	<45 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode	±5.0% of the set value or ±20 ms
Suppression of harmonics	-50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

1) Io varied during the test. $Uo = 1.0 \times U_n$ = phase to earth voltage during earth-fault in compensated or un-earthed network. The residual power value before fault = 0.0 pu, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.
2) Includes the delay of the signal output contact.

4.2.8 Third harmonic-based stator earth-fault protection H3EFPSEF

4.2.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Third harmonic-based stator earth-fault protection	H3EFPSEF	dUo(3H)>/ Uo(3H)<	27/59THD

4.2.8.2 Function block

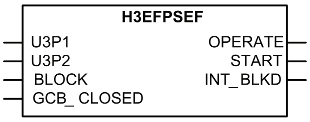


Figure 256: Function block

4.2.8.3 Functionality

The third harmonic-based stator earth-fault protection H3EFPSEF is used to detect stator earth fault at the neutral point and at least up to 15-20% from the neutral point along the stator winding. H3EFPSEF compares the third harmonic voltages produced by the generator itself at both neutral and terminal side of the generator for detecting earth fault.

H3EFPSEF provides two alternative protection methods:

- Differential of the third harmonic component measured both at generator neutral and terminal side.
- Neutral side third harmonic undervoltage.

H3EFPSEF operates with the definite time DT characteristics.

H3EFPSEF contains a blocking functionality. Blocking deactivates all outputs and reset timers.

4.2.8.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the third harmonic-based stator earth-fault protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

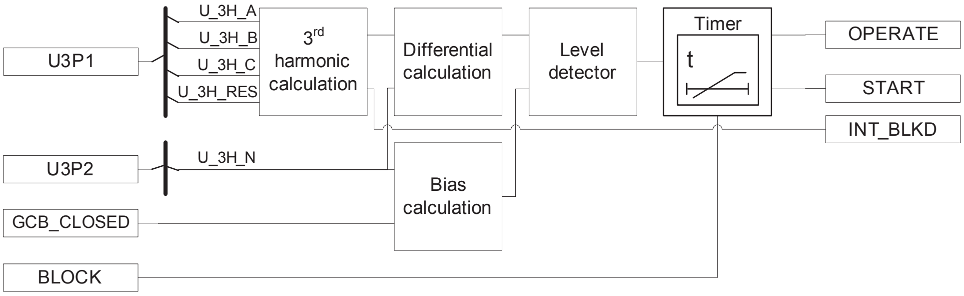


Figure 257: Functional module diagram

Third harmonic calculation (terminal side)

This module calculates the magnitude and phase angle of the third harmonic voltage at the generator terminal $\bar{U}_{3H\_T}$. Calculation of the third harmonic voltage depends on the availability of terminal side voltage and is specified by the *Voltage selection* setting.

- *Voltage selection* setting is set to "No voltage" if phase-to-earth voltages are not available at the terminal side. Even in a situation where only phase-to-phase voltages are available, *Voltage selection* is set to "No Voltage" because phase-to-phase voltages do not contain a third harmonic component. With *Voltage selection* set to "No Voltage", third harmonic-based earth-fault protection is based on third harmonic neutral side undervoltage protection.
- *Voltage selection* setting is set to "Measured ResU" if the terminal side voltage is fed from an open delta voltage connection of the voltage transformer. In this case, the terminal side third harmonic voltage $\bar{U}_{3H\_T}$ is same as the measured open delta voltage $\bar{U}_{3H\_RES}$. This is the recommended option for calculating the terminal side third harmonic voltage.

$$\overline{U}_{3H\_T} = \overline{U}_{3H\_RES}$$

(Equation 54)

- *Voltage selection* setting is set to "Calculated ResU" if all three phase-to-earth voltages are available. In this case, the terminal side third harmonic voltage is calculated as a vector average of the third harmonic voltage of all three phases.

$$\overline{U}_{3H\_T} = \frac{1}{3} \times (\overline{U}_{3H\_A} + \overline{U}_{3H\_B} + \overline{U}_{3H\_C})$$

(Equation 55)

- If only one phase-to-earth voltage is available, the *Voltage selection* setting is set to the respective phase, that is, "Phase A" or "Phase B" or "Phase C" based on the available phase. In this case, the magnitude of the terminal side third harmonic voltage is assumed to be equal to the third harmonic voltage of the phase available.

$$\overline{U}_{3H\_T} = \overline{U}_{3H\_A} \text{ or } \overline{U}_{3H\_B} \text{ or } \overline{U}_{3H\_C}$$

(Equation 56)

The function is internally blocked if the magnitude of calculated $\bar{U}_{3H\_T}$ is lower than the set *Voltage block value*, this also activates the INT_BLKD output.

Differential calculation

The amplitude of the third harmonic differential voltage can be calculated

$$UD_{3H} = \left|\bar{U}_{3H\_T} + \bar{U}_{3H\_N}\right|$$

(Equation 57)

where:

UD_{3H}	Magnitude of the third harmonic differential voltage
$\bar{U}_{3H\_T}$	Neutral side third harmonic voltage phasor
$\bar{U}_{3H\_N}$	Terminal side third harmonic voltage phasor

The magnitude of the third harmonic differential voltage UD_3H and the phase angle difference between the terminal side and neutral side third harmonic voltage U_3HANGL_T_N are available in the monitored data view.

Bias calculation

The amplitude of the third harmonic bias voltage can be calculated

$$UB_{3H} = Beta \times \left|\bar{U}_{3H\_N}\right|$$

(Equation 58)

where:

UB_{3H}	Magnitude of the third harmonic bias voltage
Beta	Setting to achieve the required degree of security under healthy conditions
$\bar{U}_{3H\_N}$	Neutral side third harmonic voltage phasor

The above third harmonic bias voltage calculation is valid under all operating conditions if there is no generator circuit breaker between generator and transformer. But if the generator circuit breaker is used, it is needed to reduce the sensitivity of the protection when it is open. The use of the generator circuit breaker is defined by *Generator CB used* setting set to "Yes" and the open position is sensed when the binary input GCB_CLOSED available is FALSE.

With the generator breaker in the open position, function desensitizes the protection by multiplying the value of the *Beta* setting with the set constant *CB open factor* setting.

$$UB_{3H} = CB\ open\ factor \times Beta \times \left|\bar{U}_{3H\_N}\right|$$

(Equation 59)

Neutral side third harmonic voltage is measured via a voltage transformer between the generator neutral point and the earth. The magnitude of the third harmonic biased voltage `UB_3H` is available in the monitored data view.

Level detector

In the third harmonic differential method, the level detector compares the third harmonic differential voltage with the third harmonic bias voltage. If the differential voltage exceeds the biased voltage, the module sends an enabling signal to start the timer.

If the terminal voltage is not available, that is, *Voltage selection* is set to "No voltage" the module compares the neutral side third harmonic voltage `U_3H_N` to the set *Voltage N 3.H Lim*.

Timer

Once activated, the timer activates the `START` output. The Timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the `START` output is deactivated.

The timer calculates the start duration `START_DUR` value, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets internal timers.

4.2.8.5 Base values

In this function block, some of the settings are set in per unit (p.u). These p.u. values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "Phase Grp 1", "Phase Grp 2" and "Phase Grp 3". Similarly, "Residual Grp 1", "Residual Grp 2" and "Residual Grp 3" are supported for the residual current or voltage-related settings. One of the groups to be used with the *Base value Sel phase* or *Base value Sel Res* settings must be selected.

4.2.8.6 Application

Mechanical and thermal stress deteriorates stator winding insulation, which can eventually cause an earth fault between the winding and stator core.

The fault current magnitude in case of stator earth fault depends on the grounding type. Common practice in most countries is to earth the generator neutral side through a resistor. The resistor is selected such as to limit the maximum earth fault current in the range of 5-10A.

The same can be done by connecting a single phase voltage transformer between the neutral side and earth, and with an equivalent resistor on the secondary side of the transformer.

In a normal operating condition, that is, when there is no earth fault, the residual voltage is close to zero with no zero-sequence current flowing in the generator. When a phase-to-earth fault occurs, the residual voltage increases and the current flows through the neutral. The simplest way to protect the stator winding against an earth fault is by providing residual overvoltage protection (or residual/neutral overcurrent protection). However, at best these simple schemes can protect only 95% of the stator winding, leaving 5% of the neutral end unprotected. This is because the voltage generated in the faulted winding decreases as the fault point becomes closer to the neutral point and it is not enough to drive the protection. Under certain unfavorable conditions, the blind zone may extend up to 20% from the neutral point.

An earth fault close to the neutral point is not dangerous, but an undetected fault may develop into an interturn fault or phase-to-phase fault. Also an undetected earth fault near the neutral point is bypassing the high-impedance grounding, and then another earth fault at the terminal results in a catastrophic situation.

Therefore, it is important to extend the protection to full 100%. The third harmonic voltage-based protection is one such protection which provides effective protection during an earth fault at the neutral point, and at least in the range up to 15 - 20% from the neutral point along the stator winding.

To achieve a complete stator earth fault protection, two protection functions should always run in parallel

- Fundamental frequency-based residual overvoltage protection ROVPTOV
- Third harmonic voltage-based protection H3EFPSEF.

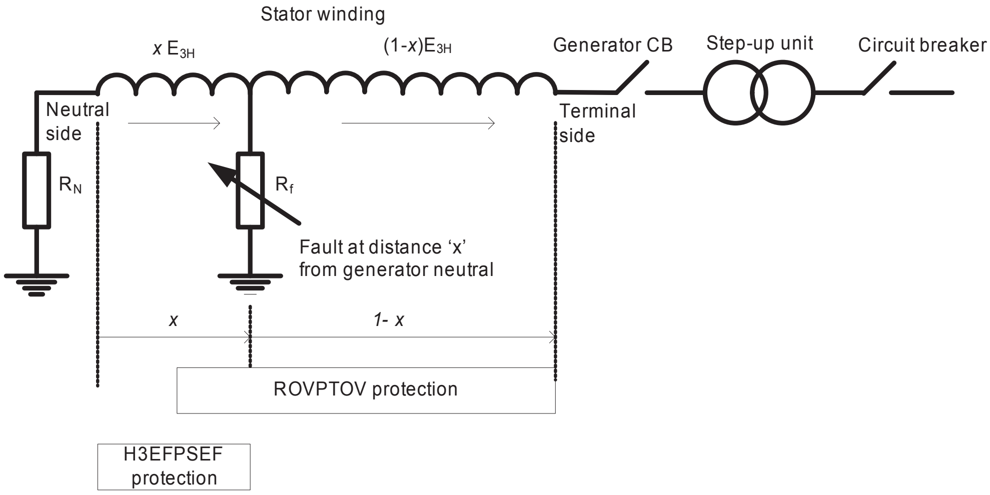


Figure 258: Complete stator earth fault protection

Third harmonic voltage-based differential protection

The voltage generated by a generator is not a perfect sinusoidal wave but contains triplen harmonics voltages. These triplen harmonics appear in each phase with the same magnitude and angle, due to which they do not sum to zero and thus also appear in the neutral side of the generator as a zero-sequence quantity. Among all the triplen harmonics voltages generated, the third harmonic voltage has the highest magnitude with the magnitude varying between 1% and 10% of the terminal voltage, depending on the generator design philosophy. However, for a particular generator the magnitude of third harmonics on the neutral side and terminal side depends also on the active power generated.

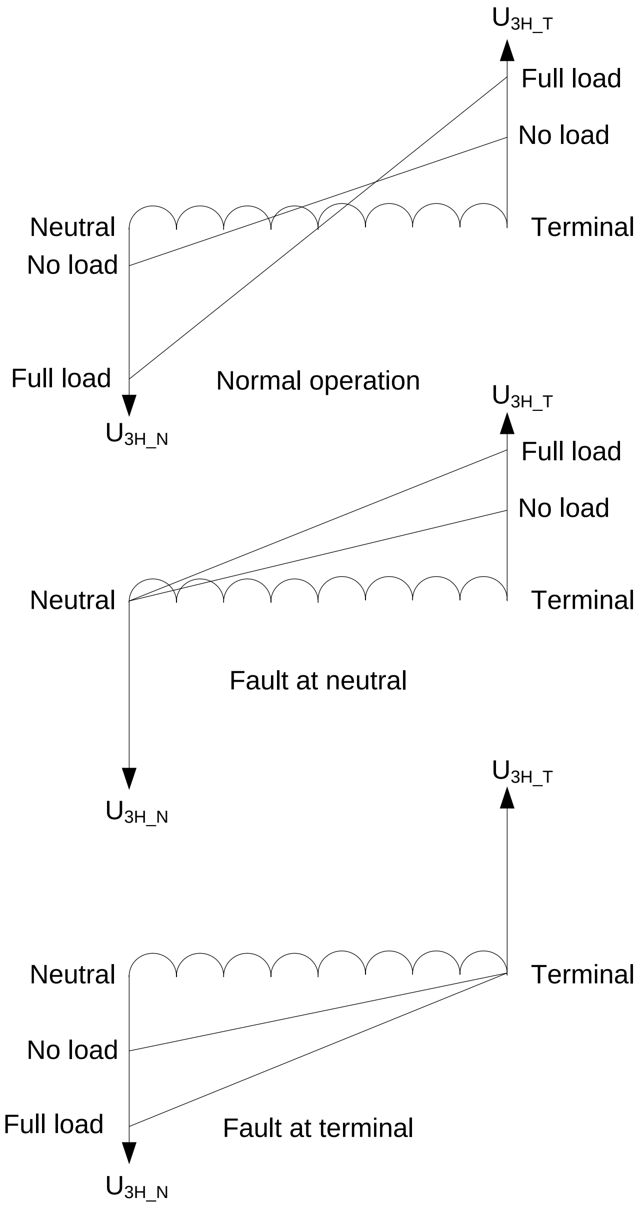


Figure 259: Typical example of the third-harmonic voltage measured at the generator neutral and terminals under different conditions

The operating equation of the protection

$$\left|\bar{U}_{3H\_T} + \bar{U}_{3H\_N}\right| - Beta \times \left|\bar{U}_{3H\_N}\right| = 0$$

(Equation 60)

The third harmonic voltages $\bar{U}_{3H\_T}$ and $\bar{U}_{3H\_N}$ are the phasor with its real and imaginary parts. $\bar{U}_{3H\_T}$ is approximately in the opposite direction to that of the $\bar{U}_{3H\_N}$, however the actual no-fault angle between those two phasors depends on the type of generator earthing. For example, the angle is about 145 degrees for a high-resistance-earthed unit generator.

The equation defines the "operate" and "restrain" regions of the protection. The third harmonic differential protection operates according to the equation:

$$\left|\bar{U}_{3H\_T} + \bar{U}_{3H\_N}\right| \geq Beta \times \left|\bar{U}_{3H\_N}\right|$$

(Equation 61)

$\bar{U}_{3H\_N}$	Neutral side third harmonic voltage phasor
$\bar{U}_{3H\_T}$	Terminal side third harmonic voltage phasor
Beta	Setting to achieve a required degree of security under healthy conditions
$\lvert\bar{U}_{3H\_T}+\bar{U}_{3H\_N}\rvert$	Magnitude of the third harmonic differential voltage
$Beta \cdot \lvert\bar{U}_{3H\_N}\rvert$	Magnitude of the third harmonic bias (restrain) voltage

Factor *Beta*, which is a setting, can be determined from the condition.

$$\frac{Beta \times \left|\bar{U}_{3H\_N}\right|}{\left|\bar{U}_{3H\_T} + \bar{U}_{3H\_N}\right|} = K$$

(Equation 62)

Where K is the security factor, for example K = 1.5. Equation 61 must be satisfied in the normal, healthy condition of the protected generator, with a high enough value for K, so that no unwanted operation of the protection should be expected, no matter what the load is on the generator.

To assure a reliable functioning of the protection, it is necessary that the generator produces third harmonic voltage which is at least 1% of the generator rated voltage.

There may be situations that the VTs on the terminal side are connected between phase-to-phase. Phase-to-phase voltages do not contain a third harmonic component and hence the above differential protection cannot work. In such case, the *Voltage selection* setting is set to "No Voltage" and H3EFPSEF operates as a simple neutral side third harmonic undervoltage protection.

When H3EFPSEF is reduced to work as only a third harmonic neutral point undervoltage protection, it is necessary to block the function during startup and shutdown of generator and also when there is no sufficient voltage.

Calculating Beta value

The setting *Beta* gives the proportion of the third harmonic voltage in the neutral point of the generator to be used as bias quantity. *Beta* must be set so that there is no risk of trip during the normal, non-faulted operation of the generator. If *Beta* is set high, this limits the portion of the stator winding covered by the protection. In most cases, the default setting 3.00 gives an acceptable sensitivity for an earth fault near the neutral point of the stator winding. However, to assure the best performance, measurements during the normal operation of the generator are to be made during commissioning.

1. The value of the *Beta* setting must be set to 1.00.
2. Loading of the generator is done at 5 to 10 different load points and the third harmonic differential and bias voltage are measured. Both quantities can be obtained from the monitored data view of the function.
3. A graph indicating differential and bias voltages as a functions of the load on the generator must be plotted.
4. Based on the graph, such value of the *Beta* setting must be selected that the bias voltage, even in the worst condition, is at least 30% to 50% higher than the differential voltage.

The angle between the third harmonic voltage phasors $\bar{U}_{3H\_T}$ and $\bar{U}_{3H\_N}$ is 150°, and with the *Beta* setting value "1.0", protection guarantees a stability margin of 25%. This requires the value of *Beta* to be increased so as to increase the stability of protection. The recommended value of the *Beta* setting is at least 1.2.

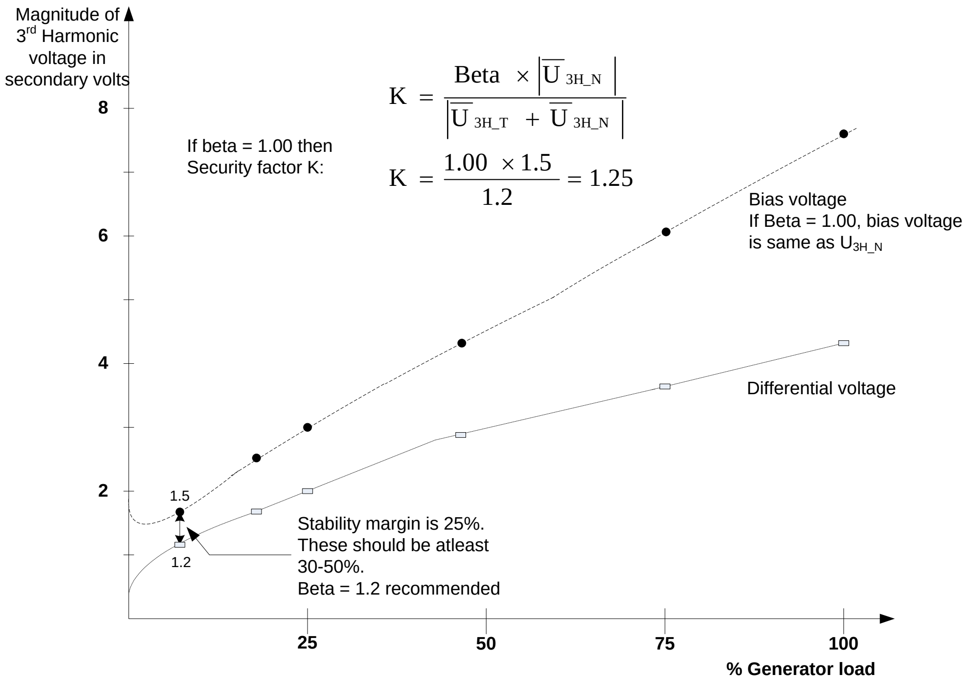


Figure 260: Typical example of variation of the bias voltage and differential voltage with a change in the active generated load (the angle between the third harmonic terminal and neutral voltage is 150°)

Calculating CB Open factor

One of the factors, though not major, governing the magnitude of the generated third harmonic voltage is the generator terminal capacitance. If there is no generator breaker, the capacitive coupling to earth is the same under all operating conditions. However, the generator breaker normally exists between the protected generator and its power transformer.

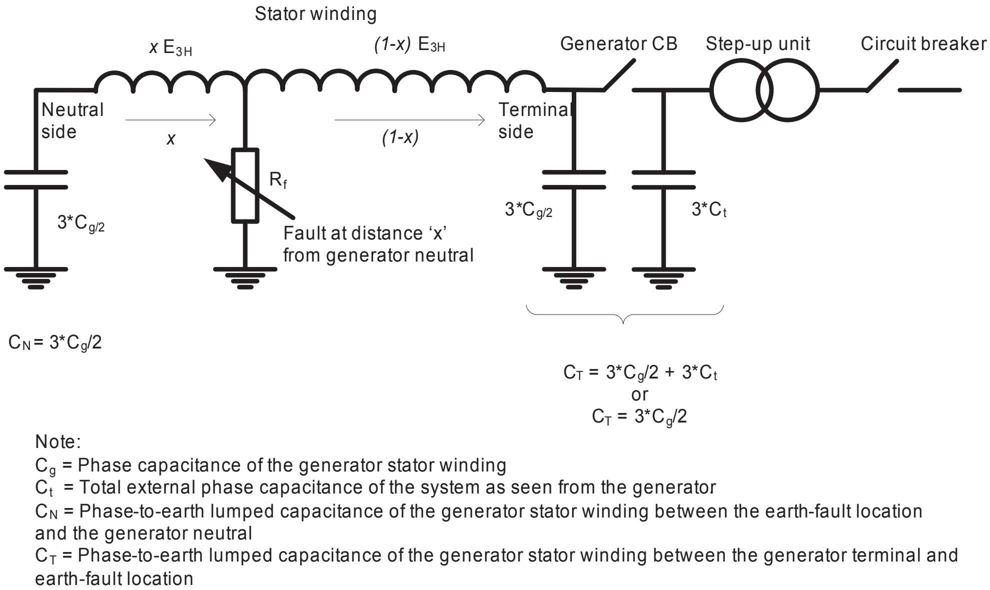


Figure 261: Capacitance seen at generator terminal and neutral side.

When there is a generator breaker, the capacitive coupling to earth differs between the operating conditions when the generator is running with the generator breaker open (before synchronization) and with the circuit breaker closed.

With the generator breaker open, the total capacitance is smaller compared to normal operating conditions. This means that the neutral side third harmonic voltage is reduced compared to the normal operating condition. Therefore, there is a need to reduce the sensitivity of the protection. When generator breaker is open, H3EFPSEF desensitizes the protection by multiplying the *Beta* setting with a set constant *CB open factor* setting.

$$\left|\overline{U}_{3H\_T} + \overline{U}_{3H\_N}\right| \geq \text{CB open factor} \times \text{Beta} \times \left|\overline{U}_{3H\_N}\right|$$

(Equation 63)

The *CB Open factor* setting is obtained during commissioning.

1. For a particular value of *Beta* the third harmonic neutral voltage is measured with the generator in the no-load condition and the circuit breaker in the closed position.
2. With the same condition, the third harmonic neutral voltage with the circuit breaker in the open position is measured.
3. *CB Open factor* should be set equal to the ratio of the third harmonic neutral voltage measured with the circuit breaker in the closed position to that in the open.

4.2.8.7 Signals

Table 531: H3EFPSEF Input signals

Name	Type	Default	Description
U3P1	GROUP SIGNAL	-	Group signal for voltage inputs terminal side
U3P2	GROUP SIGNAL	-	Group signal for voltage input neutral side
BLOCK	BOOLEAN	0	Block signal for all binary outputs
GCB_CLOSED	BOOLEAN	0	Generator CB in closed position

Table 532: H3EFPSEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
INT_BLKD	BOOLEAN	Protection internally blocked

4.2.8.8 Settings

Table 533: H3EFPSEF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Beta	0.50 - 10.00	-	0.01	3.00	Portion of neutral side 3rd harmonic used as bias
Voltage N 3.H Lim	0.005 - 0.200	-	0.001	0.010	Start value for 3rd harmonic residual undervoltage protection
Operate delay time	0.08 - 300.00	s	0.01	0.08	Operate delay time

Table 534: H3EFPSEF Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Voltage selection	No Voltage Measured ResU Calculated ResU Phase A Phase B Phase C	-	-	Measured ResU	Type of voltage connection available at generator terminal
CB open factor	1.00 - 10.00	-	0.01	1.00	Multiplication factor for Beta when CB is in open condition

Table 535: H3EFPSEF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On

Table 536: H3EFPSEF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Generator CB used	No Yes	-	-	Yes	Defines if generator circuit breaker exists
Voltage block value	0.010 - 0.100	xUn	0.001	0.010	Low level blocking for 3rd harmonic differential protection.
Reset delay time	0.02 - 60.00	s	0.01	0.02	Reset delay time

4.2.8.9 Measured values

Table 537: H3EFPSEF Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block signal for all binary outputs
GCB_CLOSED	BOOLEAN	0	Generator CB in closed position

4.2.8.10 Monitored data

Table 538: H3EFPSEF Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate
START	BOOLEAN	0=FALSE 1=TRUE	-	Start
INT_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Protection internally blocked
UD_3H_AMPL	REAL	-	kV	Third harmonic differential voltage amplitude
UB_3H_AMPL	REAL	-	kV	Third harmonic bias voltage amplitude
U_3H_T_AMPL	REAL	-	kV	Terminal side third harmonic voltage amplitude
U_3H_N_AMPL	REAL	-	kV	Neutral side third harmonic voltage amplitude
U_3HANGL_T_N	REAL	-	deg	Phase angle btw 3rd harmonic terminal and neutral voltage
START_DUR	REAL	-	%	Start duration

4.2.8.11 Technical data

Table 539: H3EFPSEF Technical data

Characteristic	Value
Operation accuracy	At the frequency f = f_n ±5% of the set value or ±0.004 × U_n
Start time [1)2)]	Typically 23 ms (±15 ms)
Reset time	<45 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	±1.0% of the set value of ±20 ms

1) f_n= 50 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.2.9 Multi-frequency admittance-based earth-fault protection MFADPSDE

4.2.9.1 Identification

Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE identification
Multi-frequency admittance-based earth-fault protection	MFADPSDE	I0> –>Y	67YN

4.2.9.2 Function block

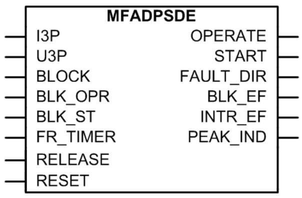


Figure 262: Function block

4.2.9.3 Functionality

The multi-frequency admittance-based earth-fault protection MFADPSDE provides selective directional earth-fault protection for high-impedance earthed networks, that is, for compensated, unearthed and high resistance earthed systems. It can be applied for the earth-fault protection of overhead lines and underground cables.

The operation of MFADPSDE is based on multi-frequency neutral admittance measurement, utilizing cumulative phasor summing technique. This concept provides extremely secure, dependable and selective earth-fault protection also in cases where the residual quantities are highly distorted and contain non-fundamental frequency components.

The sensitivity that can be achieved is comparable with traditional fundamental frequency based methods such as IoCos/IoSin (DEFxPTOC), Watt/Varmetric (WPWDE) and neutral admittance (EFPADM).

Besides faults with dominantly fundamental frequency content, MFADPSDE is also capable in detecting transient, intermittent and restriking earth faults. MFADPSDE can be used as an alternative solution to transient or intermittent function INTRPTEF.

MFADPSDE supports fault direction indication both in operate and non-operate direction, which may be utilized during fault location process. Further, the inbuilt transient detector may be used to identify restriking or intermittent earth faults, and discriminate them from permanent/continuous earth faults.

The operation characteristic is defined by a tilted operation sector, which is universally valid for unearthed and compensated networks.

The operating time characteristic is according to the definite time (DT).

MFADPSDE contains a blocking functionality to block function outputs, timers or the function itself.

4.2.9.4 Operation principle

The *Operation* setting is used to enable or disable the function. When "On" is selected, the function is enabled and when "Off" is selected, the function is disabled.

The operation of multi-frequency admittance-based earth-fault protection MFADPSDE can be described using a module diagram. All the modules in the diagram are explained in the following sections.

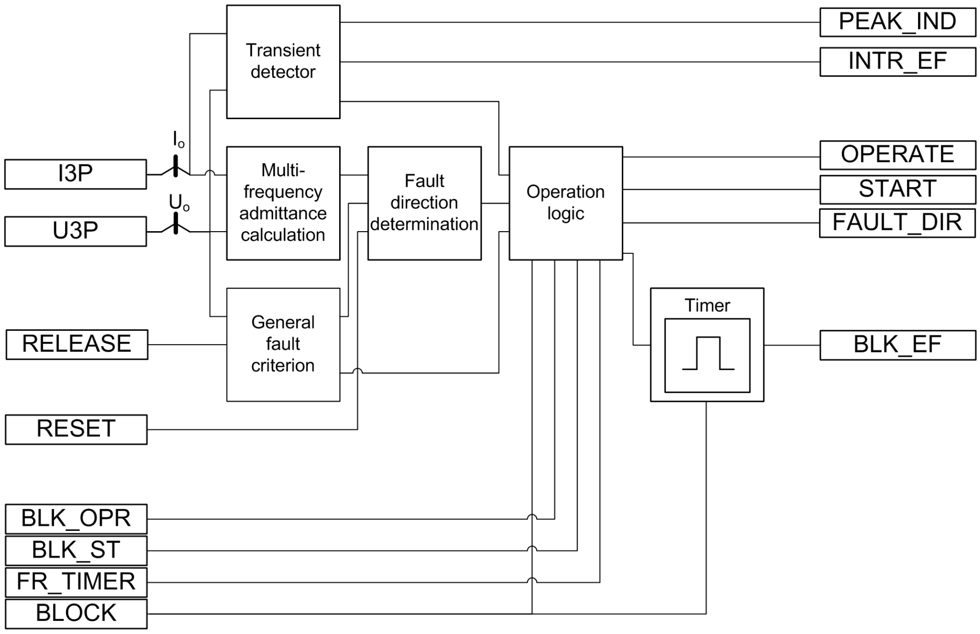


Figure 263: Functional module diagram

General Fault Criterion

The General Fault Criterion (GFC) module monitors the presence of earth-fault in the network and it is based on the value of the fundamental frequency zero-sequence voltage defined as the vector sum of fundamental frequency phase voltage phasors divided by three.

$$\underline{U}_0^1 = \left(\overline{U_A^1} + \overline{U_B^1} + \overline{U_C^1}\right)/3$$

(Equation 64)

When the magnitude of $\underline{U}_o^1$ exceeds setting *Voltage start value*, an earth-fault is detected. The GFC module reports the exceeded value to the Fault direction determination module and Operation logic. The reporting is referenced as General Fault Criterion release.

The setting *Voltage start value* defines the basic sensitivity of the MFADPSDE function. To avoid unselective start or operation, *Voltage start value* must always be set to a value which exceeds the maximum healthy-state zero-sequence voltage value, taking into consideration of possible network topology changes, compensation coil and parallel resistor switching status and compensation degree variations.

As an alternative for internal residual zero-sequence overvoltage based start-condition, MFADPSDE function can also be externally released by utilizing the `RELEASE` input. In this case, the external release signal overrides the *Voltage start value* setting and sets the internal limit to minimum value.

Multi-frequency admittance calculation

Multi-frequency admittance calculation module calculates neutral admittances utilising fundamental frequency and the 2nd, 3rd, 5th, 7th and 9th harmonic components of residual current and zero-sequence voltage. The following admittances are calculated, if the magnitude of a particular harmonic in residual current and zero-sequence voltage are measurable by the IED.

Fundamental frequency admittance (conductance and susceptance)

$$\overline{Y_0^1} = \frac{3 \cdot \overline{I_0^1}}{-\overline{U_0^1}} = G_o^1 + j \cdot B_o^1$$

(Equation 65)

Harmonic susceptance

$$\text{Im}\left[\overline{Y_0^n}\right] = \text{Im}\left[\frac{3 \cdot \overline{I_0^n}}{-\overline{U_0^n}}\right] = j \cdot B_o^n$$

(Equation 66)

where n = 2, 3, 5, 7 and 9

$\overline{Y_0^1}$ is the fundamental frequency neutral admittance phasor

$\overline{I_0^1}$ is the fundamental frequency zero-sequence current phasor $(= (\overline{I_A^1} + \overline{I_B^1} + \overline{I_C^1}) / 3)$

$\overline{U_0^1}$ is the fundamental frequency zero-sequence voltage phasor $(= (\overline{U_A^1} + \overline{U_B^1} + \overline{U_C^1}) / 3)$

G_o^1 is the fundamental frequency conductance, $\text{Re}\left(\overline{Y_0^1}\right)$

B_o^1 is the fundamental frequency susceptance, $\text{Im}\left(\overline{Y_0^1}\right)$

$\overline{Y_0^n}$ is the nth harmonic frequency neutral admittance phasor

$\overline{I_0^n}$ is the nth harmonic frequency zero-sequence current phasor

$\overline{U_0^n}$ is the nth harmonic frequency zero-sequence voltage phasor

B_o^n is the nth harmonic frequency susceptance, $\text{Im}\left(\overline{Y_0^n}\right)$

For fault direction determination, the fundamental frequency admittance and harmonic susceptances are summed together in phasor format. The result is the sum admittance phasor defined as below.

$$\overline{Y}_{osum} = \mathrm{Re}\left[\overline{Y_0^1}\right] + j \cdot \mathrm{Im}\left[\overline{Y_0^1} + \sum_{n=2}^{9} \overline{Y_0^n}\right] = G_o^1 + j \cdot B_{osum}$$

(Equation 67)

The polarity of the polarizing quantity (residual voltage) can be changed (rotated by 180 degrees) by setting the *Pol reversal* parameter to "True" or by switching the polarity of the residual voltage measurement wires.

Fault direction determination

If an earth-fault is detected by the GFC module, the fault direction is evaluated based on the calculated sum admittance phasor $\overline{Y}_{osum}$ obtained from the Multi-frequency admittance calculation module. To obtain dependable and secure fault direction determination regardless of the fault type (transient, intermittent, restriking, permanent, high or low ohmic), the fault direction is calculated using a special filtering algorithm, Cumulative Phasor Summing (CPS) technique. This filtering method is advantageous during transient, intermittent and restriking earth-faults with dominantly non-sinusoidal or transient content. It is equally valid during continuous (stable) earth-faults.

The concept of CPS is illustrated in Figure 264. It is the result of adding values of the measured sum admittance phasors together in phasor format in chronological order during the fault. Using the discrete sum admittance phasors $\overline{Y}_{osum}$ in different time instants ($t_1 ... t_5$), the corresponding accumulated sum admittance phasor $\overline{Y}_{osum\_CPS}$ is calculated. This phasor is used as directional phasor in determining the direction of the fault.

$$\overline{Y}_{osum\_CPS}(t_1) = \overline{Y}_{osum}(t_1)$$

(Equation 68)

$$\overline{Y}_{osum\_CPS}(t_2) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2)$$

(Equation 69)

$$\overline{Y}_{osum\_CPS}(t_3) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2) + \overline{Y}_{osum}(t_3)$$

(Equation 70)

$$\overline{Y}_{osum\_CPS}(t_4) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2) + \overline{Y}_{osum}(t_3) + \overline{Y}_{osum}(t_4)$$

(Equation 71)

$$\overline{Y}_{osum\_CPS}(t_5) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2) + \overline{Y}_{osum}(t_3) + \overline{Y}_{osum}(t_4) + \overline{Y}_{osum}(t_5)$$

(Equation 72)

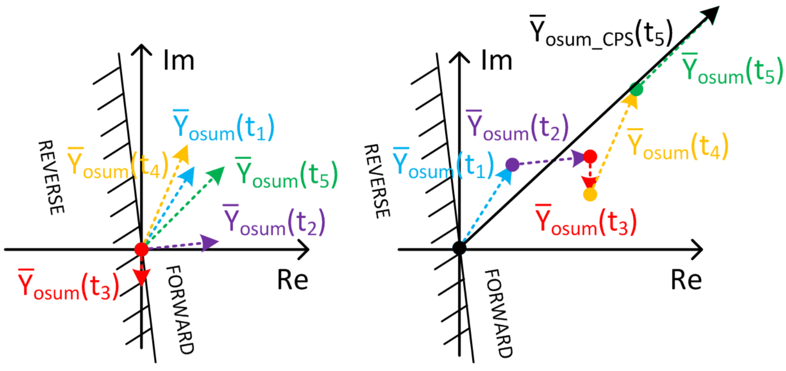


Figure 264: Principle of Cumulative Phasor Summing (CPS)

The advantage of the CPS technique is that it provides a stable directional phasor quantity regardless of the fact that individual phasors can vary in magnitude and phase angle in time due to a non-stable fault type such as restriking or intermittent earth-fault. This is also true for harmonic components included in the sum admittance phasor. Harmonics have typically a highly fluctuating character.

The advantage of harmonic components is that they provide more distinctive directional determination in compensated networks than the fundamental frequency component. This comes from the fact that for the higher frequencies, the compensation coil appears as very high impedance and the harmonics are not affected by compensation coil and degree of compensation. When harmonics are present, they cause the sum admittance phasor to behave as in case of an unearthed network, where directional phasors point in fully opposite directions in the faulty and healthy feeder.

The direction of the MFADPSDE function is defined with setting *Directional mode* as “Forward” or “Reverse”. The operation characteristic is defined by tilted operation sector as illustrated in Figure 265. The characteristic provides universal applicability, that is, it is valid both in compensated and unearthed networks, also if the compensation coil is temporarily switched off. The tilt of the operation sector is defined with setting *Tilt angle* to compensate the measurement errors of residual current and voltage transformers. The typical setting value of 5 degrees is recommended, but it should always reflect the actual maximum expected measurement errors.

In case of unearthed network operation, adequate tilt angle must be allowed to ensure dependable operation of MFADPSDE.

In Figure 265, phasors 1...4 demonstrate the behavior of the directional phasor in different network fault conditions.

- Phasor 1 depicts the direction of accumulated sum admittance phasor in case of earth-fault outside the protected feeder (assuming that the admittance of the protected feeder is dominantly capacitive). The result is valid regardless of the fault type (low ohmic, high(er) ohmic, permanent, intermittent or restriking). In case harmonic components are present in the fault quantities, they would turn the phasor align to the negative $\mathrm{Im}(\overline{Y}o)$ axis.
- Phasor 2 depicts the direction of accumulated sum admittance phasor in case of earth-fault inside the protected feeder when the network is unearthed. The result is also valid in compensated networks when there are harmonic components present in the fault quantities (typically low ohmic permanent or intermittent or restriking fault). In this case, the result is valid regardless of network’s actual compensation degree. Harmonics would turn the phasor align to the positive $\mathrm{Im}(\overline{Y}o)$ axis.
- Phasors 3 and 4 depict the direction of accumulated sum admittance phasor in case of higher-ohmic earth-fault in the protected feeder without harmonics in the fault quantities when the network is compensated. As there are no harmonic components present, the phase angle of the accumulated phasor is determined by the compensation degree of the network. With high degree of overcompensation, the phasor turns towards the negative $\mathrm{Im}(\overline{Y}o)$ axis (as phasor 4).

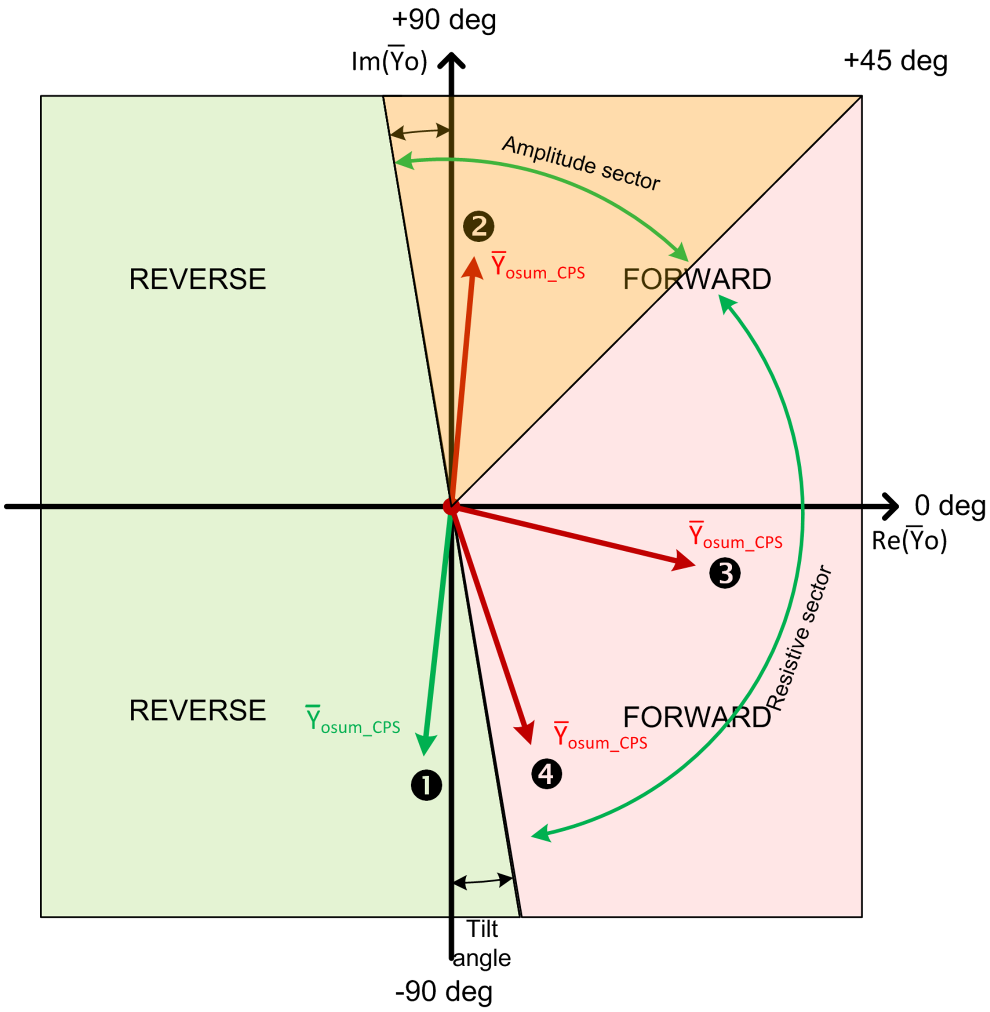


Figure 265: Directional characteristic of MFADPSDE

The residual current is recommended to be measured with accurate core balance current transformer to minimize the measurement errors, especially phase displacement. This is especially important, when high sensitivity of protection is targeted.

The characteristic *Tilt angle* should reflect the measurement errors, that is, the larger the measurement errors, the larger the *Tilt angle* setting should be. Typical setting value of 5 degrees is recommended.

The detected fault direction is available as output `FAULT_DIR` or in the monitored data view as parameter *DIRECTION*.

To adapt the fault direction determination to possible fault direction change during the fault, for example, during manual fault location process, a cyclic accumulation of sum admittance phasors is conducted. The duration of this directional evaluation cycle is 1.2 · *Reset delay time* (minimum of 600 ms). If the fault direction based on the cyclic phasor accumulation is opposite to the function direction output for *Reset delay time* or 500 ms (minimum of 500 ms), the function is reset and fault direction calculation of MFADPSDE is restarted.

In case the earth-fault protection is alarming, the function MFADPSDE includes also a `RESET` input, which can be utilised to externally re-trigger the fault direction determination, if re-evaluation of fault direction during a persistent earth-fault is required. It is also recommended to connect the start-signal of non-directional earth-fault protection (EFxPTOC), set to operate in case of a cross-country fault, to `RESET` input of MFADPSDE to reset phasor accumulation during a cross-country fault. MFADPSDE is then able to adapt to possible fault direction change more rapidly, if single phase earth-fault still persists in the system after the other faulty feeder has been tripped (cross-country fault has been transformed back to a single phase earth-fault).

The direction of the MFADPSDE function is supervised by a settable current magnitude threshold. The operate current used in the magnitude supervision is measured with a special filtering method, which provides very stable residual current estimate regardless of the fault type. This stabilized current estimate is the result from fundamental frequency admittance calculation utilizing the CPS technique. The stabilized current value is obtained (after conversion) from the corresponding admittance value by multiplying it with the system nominal phase-to-earth voltage value, which is entered as a base value for the residual voltage ($U_{baseres}$). The equations for calculating the stabilized values of the fundamental frequency admittance and the corresponding current are given below.

$$\overline{Y^{1}_{o\ stab}} = \frac{3 \cdot \overline{I^{1}_{0\,CPS}}}{-\overline{U^{1}_{0\,CPS}}} = \mathrm{Re}\left[\overline{Y^{1}_{o\ stab}}\right] + j \cdot \mathrm{Im}\left[\overline{Y^{1}_{o\ stab}}\right] = G^{1}_{ostab} + j \cdot B^{1}_{ostab}$$

(Equation 73)

$$\overline{I^{1}_{o\ stab}} = (G^{1}_{ostab} + j \cdot B^{1}_{ostab}) \cdot U_{baseres} = I^{1}_{oCosstab} + j \cdot I^{1}_{oSinstab}$$

(Equation 74)

$\overline{Y^{1}_{o\ stab}}$ is the stabilized fundamental frequency admittance estimate, which is result from fundamental frequency admittance calculation utilizing the Cumulative Phasor Summing (CPS) technique.

$\overline{I^{1}_{0\,CPS}}$ is the fundamental frequency zero-sequence current phasor calculated utilizing the Cumulative Phasor Summing (CPS) technique.

$\overline{U^{1}_{0\,CPS}}$ is the fundamental frequency zero-sequence voltage phasor calculated utilizing the Cumulative Phasor Summing (CPS) technique.

$G^1_{o\,stab}$ is the real-part of stabilized fundamental frequency conductance estimate.

$B^1_{o\,stab}$ is the imaginary part of stabilized fundamental frequency susceptance estimate.

$\overline{I^1_{o\,stab}}$ is the stabilized fundamental frequency residual current estimate, which is obtained (after conversion) from the corresponding admittance value by multiplying it with the system nominal phase-to-earth voltage value.

$\overline{I^1_{o\,Cosstab}}$ is the real-part of stabilized fundamental frequency residual current estimate.

$\overline{I^1_{o\,Sinstab}}$ is the imaginary-part of stabilized fundamental frequency residual current estimate.

The main advantage of the filtering method is that due to the admittance calculation, the resulting current value does not depend on the value of fault resistance, that is, the estimated current magnitude equals the value that would be measured during a solid earth-fault ($R_f = 0\ \Omega$). Another advantage of the method is that it is capable of estimating correct current magnitude also during intermittent or restriking faults.

The setting *Min Fwd Op current* defines the minimum operate current in case the operation direction is set forward. The setting *Min Rev Op current* defines the minimum operate current in case the operation direction is set to reverse.

With previously described special filtering technique, the settings *Min Fwd Op current* and *Min Rev Op current* are based on fundamental frequency residual current values.

Setting *Operating quantity* defines whether the current magnitude supervision is based on either the “Adaptive” or “Amplitude” methods.

When “Adaptive” is selected, the method adapts the principle of magnitude supervision automatically to the system earthing condition. In case the phase angle of accumulated sum admittance phasor is greater than 45 degrees, the set minimum operate current threshold is compared to the amplitude of $\overline{I^1_{o\,stab}}$ (see Figure 266). In case the phase angle of accumulated sum admittance phasor is below 45 degrees, the set minimum operate current threshold is compared to the resistive component of $\overline{I^1_{o\,stab}}$. This automatic adaptation of the magnitude supervision enables secure and dependable directional determination in compensated networks, and it is also valid when the network is unearthed (compensation coil is switched off).

In case operation direction is set to reverse, the resistive and amplitude sectors are mirrored in the operation characteristics.

When “Amplitude” is selected, the set minimum operate current threshold is compared to the amplitude of $\overline{I^{1}_{o\ stab}}$. This selection can be used in unearthed networks.

In compensated networks, setting *Operating quantity* should be set to “Adaptive”. This enables secure and dependable directional determination on compensated networks and it is also valid when compensation coil is switched off and network becomes unearthed.

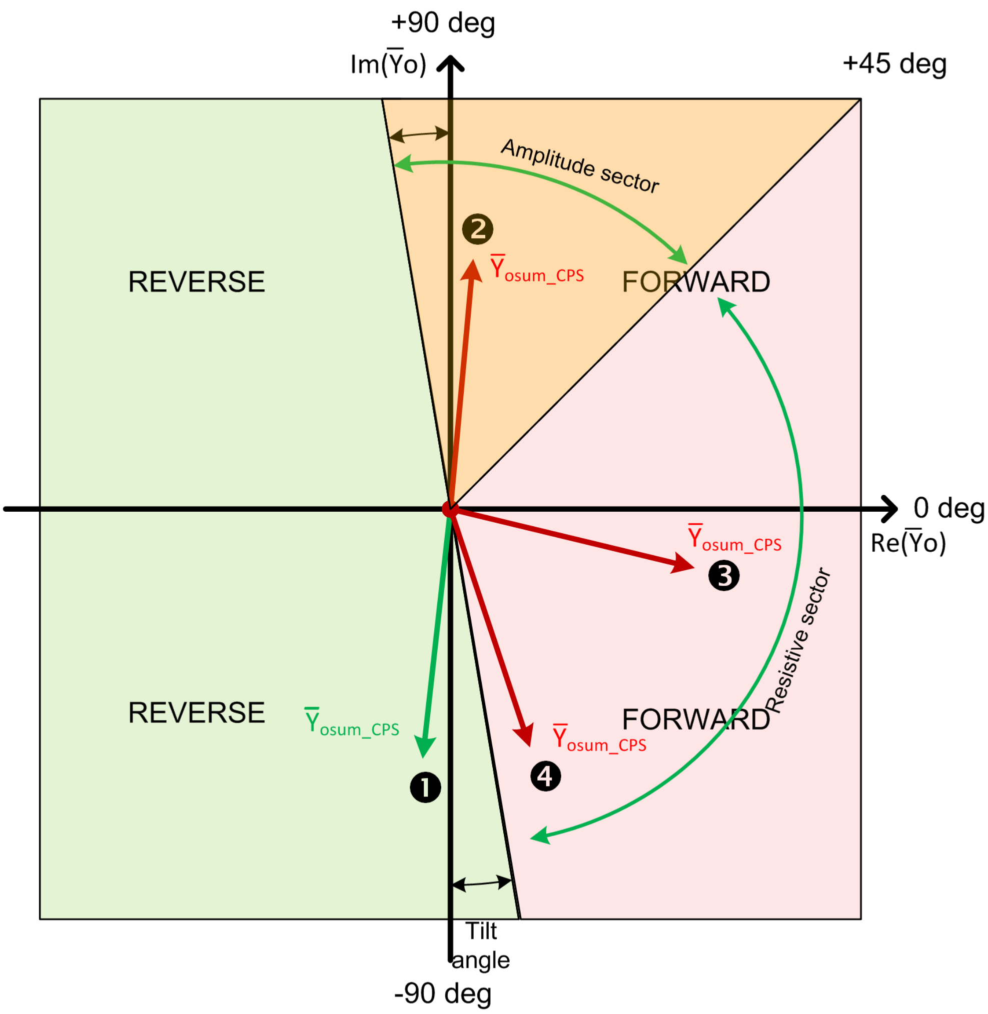


Figure 266: Illustration of amplitude and resistive current sectors if Operating quantity is set “Adaptive” and Directional mode is set “Forward”

The setting rules for current thresholds are given below.

In case the “Adaptive” operating quantity is selected, the setting *Min Fwd Op current* (*Min Rev Op current*) should be set to value:

$$[pu] < p \cdot IRtot$$

IRtot is the total resistive earth-fault current of the network corresponding to the resistive current of the parallel resistor of the coil and the natural losses of the system (typically in order of 1...5 % of the total capacitive earth-fault current of the network).

p = security factor = 0.5…0.7

This setting should be set based on the total resistive earth-fault current of the network including the parallel resistor of the coil and the network losses. It must be set to a value which is lower than total resistive earth-fault current in order to enable dependable operation.

For example, if the resistive current of the parallel resistor is 10 A (at primary voltage level), then a value of 0.5 · 10 A = 5 A could be used. The same setting is also applicable in case the coil is disconnected and the network becomes unearthed (as in this case this setting is compared to the amplitude of $\overline{I^{1}_{o\,stab}}$). The selected setting value must never exceed the ampere value of the parallel resistor in order to allow operation in the faulty feeder. In case of smaller ampere value of the parallel resistor, for example 5 A, the recommended security factor should be larger, for example 0.7, so that sufficient margin for CT and VT errors can be achieved.

In case the “Amplitude” operating quantity is selected, the setting should be selected based on the capacitive earth-fault current values produced by the background network in case of a solid earth-fault with a security margin.

The main task of the current magnitude supervision module is to secure the correct directional determination of an earth-fault, so that only the faulty feeder is disconnected or alarmed. Therefore, the threshold values should be selected carefully and not set too high as this can inhibit the disconnection of the faulty feeder.

The residual current should be measured with accurate core balance current transformer to minimize the measurement errors, especially phase displacement.

Transient detector

The Transient detector module is used for detecting transients in the residual current and zero-sequence voltage signals. Whenever transient is detected, this is indicated with the PEAK_IND output. When the number of detected transients equals or exceeds the *Peak counter limit* setting (without the function being reset, depending on the drop-off time set with the *Reset delay time* setting), INTR_EF output is activated. This indicates detection of restriking or intermittent earth-fault in the network. Transient detector affects the operation of MFADPSDE (START and OPERATE outputs) when operation mode is “Intermittent EF”. For other operation modes, (“General EF”, “Alarming EF”), PEAK_IND and INTR_EF outputs can be used for monitoring purposes. The operation of the Transient detector is illustrated in Figure 267.

Several factors affect the magnitude and frequency of fault transients, such as the fault inception angle on the voltage wave, fault location, fault resistance and the parameters of the feeders and the supplying transformers. If the fault is permanent (non-transient) in nature, the initial fault transient in current and voltage can be measured, whereas the intermittent fault creates repetitive transients. The practical sensitivity of transient detection is limited to approximately few hundreds of ohms of fault resistance. Therefore the application of transient detection is limited to low ohmic earth-faults.

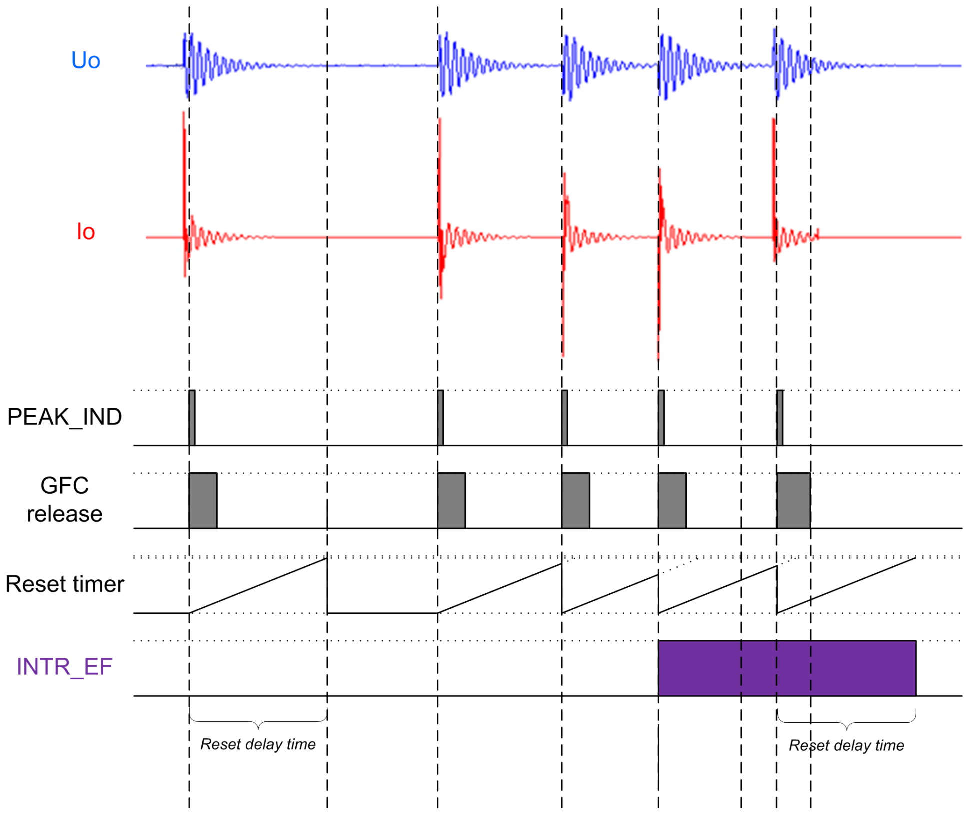


Figure 267: Example of operation of Transient detector: indication of detected transient by PEAK_IND output and detection of restriking or intermittent earth-fault by INTR_EF output (setting Peak counter limit = 3)

Operation logic

MFADPSDE supports three operation modes selected with setting Operation mode: “General EF”, “Alarming EF” and “Intermittent EF”.

Operation mode “General EF” is applicable in all kinds of earth-faults in unearthed and compensated networks. It is intended to detect all kinds of earth-faults regardless of their type (transient, intermittent or restriking, permanent, high or low ohmic). The setting *Voltage start value* defines the basic sensitivity of the MFADPSDE function.

In “General EF” mode, the operate timer is started in the following conditions.

- Earth-fault is detected by the General Fault Criterion (GFC)
- Fault direction equals *Directional mode* setting
- Estimated stabilized fundamental frequency residual current exceeds set minimum operate current level (forward direction *Min Fwd Op current* and reverse direction *Min Rev Op current*)

The `START` output is activated once *Start delay time* has elapsed. `OPERATE` output is activated once *Operate delay time* has elapsed and the above three conditions are valid. Reset timer is started if any of the above three conditions is not valid. In case fault is transient and self-extinguishes, `START` output stays activated until the elapse of reset timer (setting Reset delay time). After `OPERATE` output activation, `START` and `OPERATE` outputs are reset immediately, if any of the above three conditions is not valid. The start duration value START_DUR, available in the monitored data view, indicates the percentage ratio of the start situation and the set operating time. The start duration value START_DUR available in the monitored data view, indicates the percentage ratio of the start situation and the set operating time.

In case detection of temporary earth-faults is not desired, the activation of `START` output can be delayed with setting *Start delay time*. The same setting can be also used to avoid restarting of the function during long lasting post-fault oscillations, if time constant of post-fault oscillations is very long (network losses and damping is low).

To keep the operate timer activated between current spikes during intermittent or restriking earth-fault, the *Reset delay time* should be set to a value exceeding the maximum expected time interval between fault spikes (obtained at full resonance condition). Recommended value is at least 300 ms.

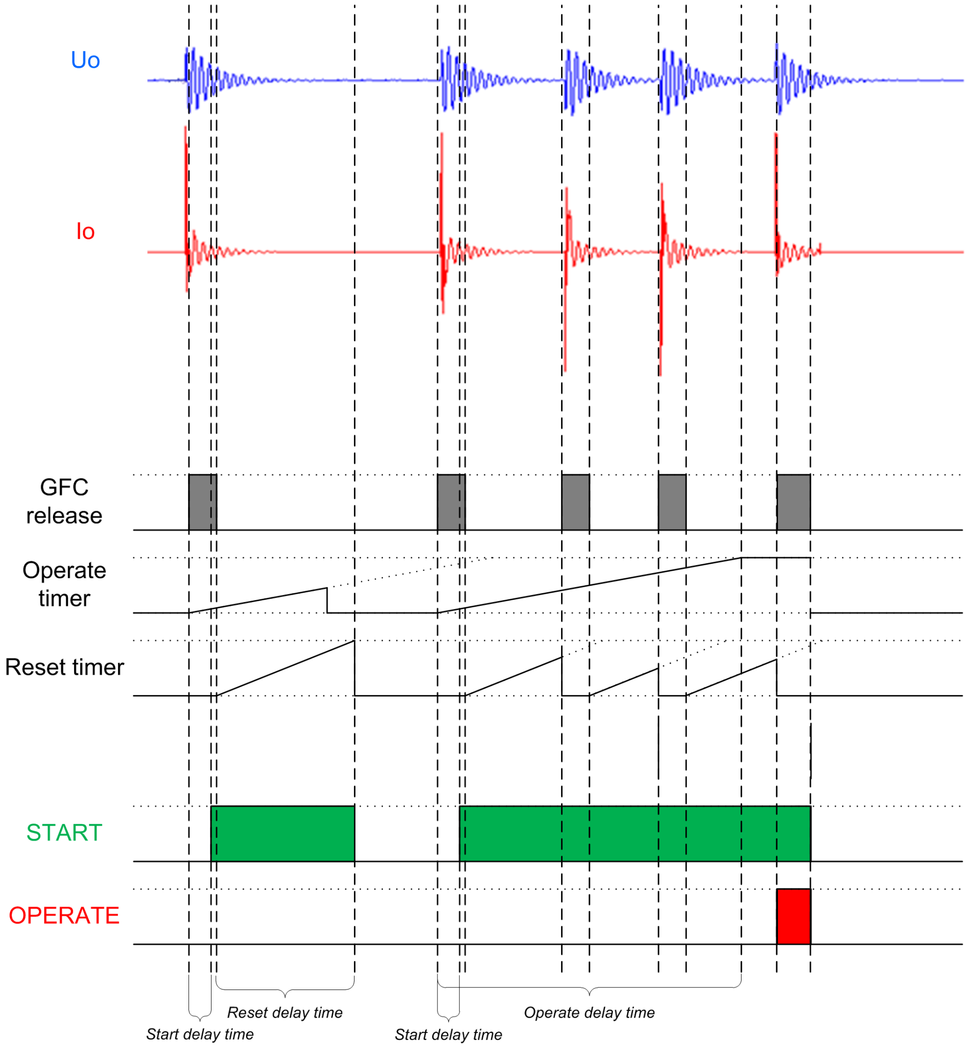


Figure 268: Operation in "General EF" mode

Operation mode "Alarming EF" is applicable in all kinds of earth-faults in unearthed and compensated networks, where fault detection is only alarming. It is intended to detect all kinds of earth-faults regardless of their type (transient, intermittent or restriking, permanent, high or low ohmic). The setting *Voltage start value* defines the basic sensitivity of the MFADPSDE function. In "Alarming EF" mode, the operate timer is started during the following conditions.

- Earth-fault is detected by the GFC
- Fault direction equals *Directional mode setting*
- Estimated stabilized fundamental frequency residual current exceeds set minimum operate current level (forward direction *Min Fwd Op current* and reverse direction *Min Rev Op current*)

The `START` output is activated once *Start delay time* has elapsed. `OPERATE` output is not valid in the "Alarming EF" mode. Reset timer is started if any of the above three conditions are not valid. In case the fault is transient and self-extinguishes, START output stays activated until the elapse of reset timer (setting *Reset delay time*).

In case detection of temporary earth-faults is not desired, the activation of START output can be delayed with setting *Start delay time*.

To keep the operate timer activated between current spikes during intermittent or restriking earth-fault, the *Reset delay time* should be set to a value exceeding the maximum expected time interval between fault spikes (obtained at full resonance condition). The recommended value is at least 300 ms.

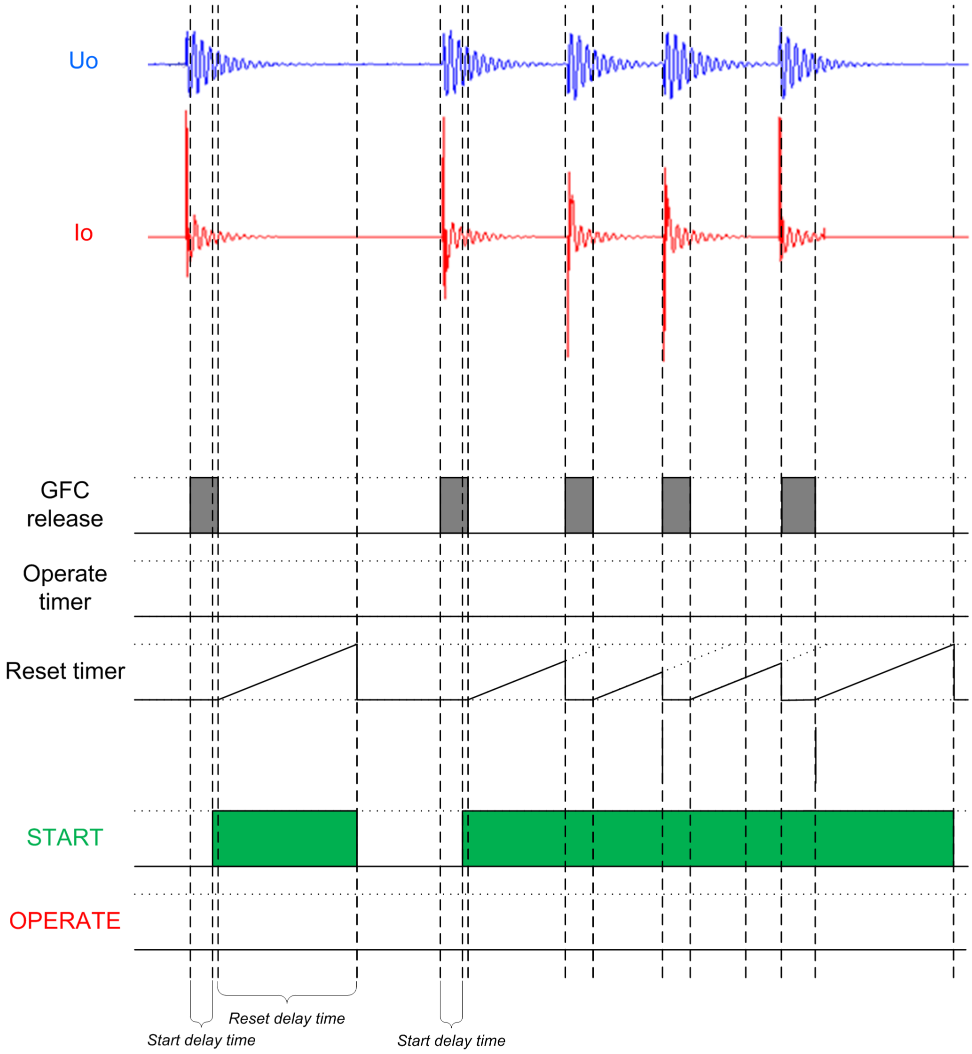


Figure 269: Operation in Alarming EF mode

Operation mode "Intermittent EF" is dedicated for detecting restriking or intermittent earth-faults. For operation, a required number of intermittent earth-fault transients set with the *Peak counter limit* setting must be detected. Therefore, transient faults or permanent faults with only initial fault ignition transient are not detected in "Intermittent EF" mode. The application of "Intermittent EF" mode is limited to low ohmic intermittent or restriking earth-faults.

In the "Intermittent EF" mode, the operate timer is started when following conditions are met.

- Transient is detected by the Transient detector (indicated with PEAK_IND output)
- Earth-fault is detected by the GFC at time of transient
- Fault direction equals *Directional mode* setting
- Estimated stabilized fundamental frequency residual current exceeds set minimum operate current level (forward direction *Min Fwd Op current* and reverse direction *Min Rev Op current*)

When a required number of intermittent earth-fault transients set with the *Peak counter limit* setting are detected without the function being reset (depends on the drop-off time set with the *Reset delay time* setting), the START output is activated. The INTR_EF output is activated to indicate the fault type is intermittent or restriking earth-fault. The operate timer is kept activated as long as transients occur during the drop-off time defined by setting *Reset delay time*.

The OPERATE output is activated when *Operate delay time* has elapsed, required number of transients has been detected, earth-fault is detected by the GFC, fault direction matches the *Directional mode* setting and estimated stabilized fundamental frequency residual current exceeds set *Minimum operate current* setting.

The *Reset delay time* starts to elapse from each detected transient. Function is reset if time between current peaks is more that *Reset delay time* or if the General Fault Criterion release is reset. After OPERATE output activation, START and OPERATE outputs are reset immediately at the falling edge of General Fault Criterion release, that is, when zero-sequence voltage falls below *Voltage start value*. This should be considered if “Intermittent EF" mode is applied in case earth-faults are only alarmed to avoid repetitive start and operate events.

To keep the operate timer activated between current spikes during intermittent or restriking earth-fault, *Reset delay time* should be set to a value exceeding the maximum expected time interval between (obtained at full resonance condition). The recommended value is at least 300 ms.

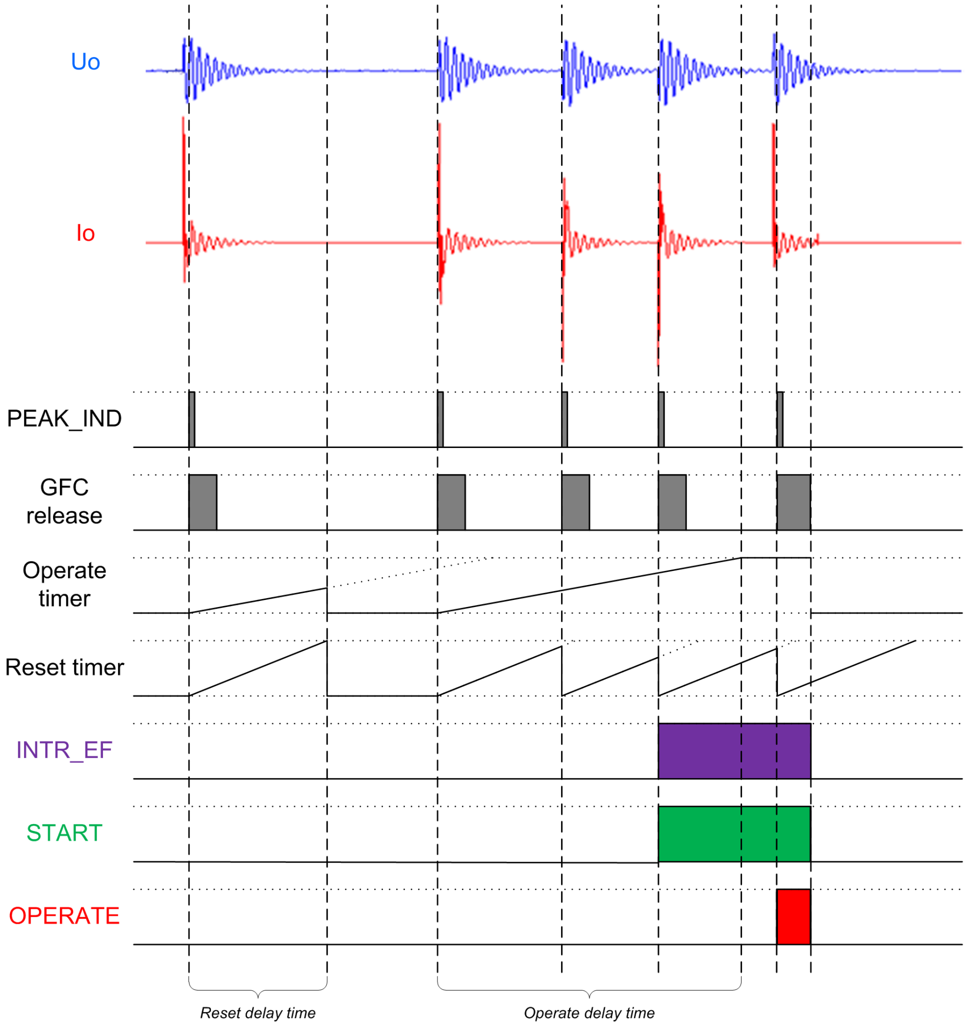


Figure 270: Operation in “Intermittent EF” mode, Peak counter limit = 3

The binary input BLOCK is used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST is used to block the start signals. The binary input BLK_OPR is used to block the operating signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

Timer

If the detected fault direction is opposite to the set directional mode and GFC release is active, BLK_EF output is activated once *Start delay time* has elapsed. Reset timer is activated at the falling edge of General Fault Criterion release, that is, when zero-sequence voltage falls below *Voltage start value*. BLK_EF is reset once the reset delay time elapses. Activation of the BLOCK input deactivates the BLK_EF output and resets Timer.

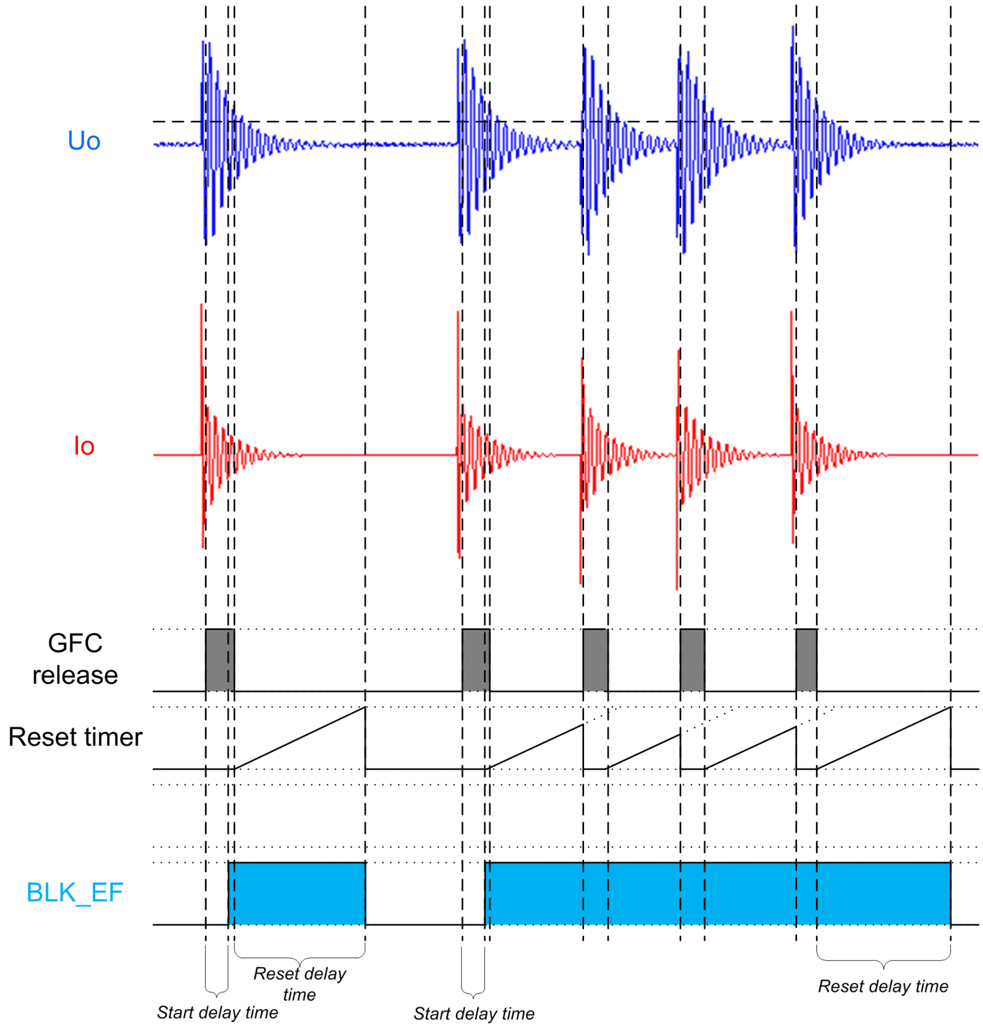


Figure 271: Activation of BLK_EF output (indication that fault is located opposite to the set operate direction)

Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example, the values given in A, kV and kVA. The IED supports alternative base value groups for the residual current or voltage-related settings, for example, "Residual Grp 1", "Residual Grp 2" and "Residual Grp 3". One of the groups to be used with the *Base value Sel Res* setting must be selected.

4.2.9.5 Application

MFADPSDE provides selective directional earth-fault protection for high-impedance earthed networks, that is, for compensated, unearthed and high resistance earthed systems. It can be applied for the earth-fault protection of overhead lines and underground cables.

The operation of MFADPSDE is based on multi-frequency neutral admittance measurement utilizing cumulative phasor summing technique. This concept provides extremely secure, dependable and selective earth-fault protection also in cases where the residual quantities are highly distorted and contain non-fundamental frequency components. MFADPSDE is well-suited for compensated networks where measurement signals may have such characteristics, for example, during intermittent earth-faults.

MFADPSDE is capable of operating with both low ohmic and higher ohmic earth faults, where the sensitivity limit is defined with residual overvoltage condition. This allows earth faults with several kilohms of fault resistance to be detected in a symmetrical system. The sensitivity that can be achieved is comparable with traditional fundamental frequency based methods such as the IoCos/IoSin (DEFxPTOC), Watt/Varmetric (WPWDE) and neutral admittance (EFPADM).

Besides faults with dominantly fundamental frequency content, MFADPSDE is also capable in detecting transient, intermittent or restriking earth faults. MFADPSDE can be used as an alternative solution to transient or intermittent function INTRPTEF.

MFADPSDE supports Fault direction indication in operate and non-operate direction which may be utilized during fault location process. The inbuilt ransient detector can be used to identify restriking or intermittent earth faults, and discriminate them from permanent or continuous earth-faults.

The direction of MFADPSDE can be set as forward or reverse. The operation characteristic is defined by a tilted operation sector, which is universally valid both in unearthed and compensated networks. The tilt of the operation sector should be selected based on the measurement errors of the applied residual current and voltage measurement transformers.

The operating time characteristic is according to the definite time (DT).

The function contains a blocking functionality to block function outputs, timers or the function itself.

MFADPSDE supports both tripping and alarming mode of operation. For alarming earth-fault protection application, the function contains a dedicated operation mode.

MFADPSDE provides reliability and sensitivity of protection with a single function. This enables simpler implementation of protection schemes as separate fault type dedicated earth-fault functions and coordination between them are not necessarily required. Other advantages of MFADPSDE includes versatile applicability, good selectivity, good sensitivity and easy setting principles.

One instance (stage) of MFADPSDE function is available.

4.2.9.6 Signals

Table 540: MFADPSDE Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Block of operate signal
BLK_ST	BOOLEAN	0	Block of start signal
FR_TIMER	BOOLEAN	0	Freeze operation timer
RELEASE	BOOLEAN	0	External trigger signal to release protection
RESET	BOOLEAN	0	External reset for directional calculation

Table 541: MFADPSDE Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal
START	BOOLEAN	Start signal
FAULT_DIR	INTEGER	Detected fault direction
BLK_EF	BOOLEAN	Block signal for EF to indicate opposite fault direction
INTR_EF	BOOLEAN	Intermittent earth-fault indication
PEAK_IND	BOOLEAN	Current transient detection indication

4.2.9.7 Settings

Table 542: MFADPSDE Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Directional mode	Forward Reverse	-	-	Forward	Directional mode
Voltage start value	0.01 - 1.00	pu	0.01	0.10	Voltage start value
Operate delay time	0.06 - 200.00	s	0.01	0.5	Operate delay time

Table 543: MFADPSDE Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Operating quantity	Adaptive Amplitude	-	-	Adaptive	Operating quantity selection

Table 544: MFADPSDE Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On
Operation mode	Intermittent EF General EF Alarming EF	-	-	General EF	Operation mode

Table 545: MFADPSDE Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Min Fwd Op current	0.01 - 1.00	pu	0.01	0.01	Minimum operate current forward direction
Min Rev Op current	0.01 - 1.00	pu	0.01	0.01	Minimum operate current reverse direction
Tilt angle	2.0 - 20.0	Deg	0.1	5.0	Characteristic tilt angle
Peak counter limit	3 - 20	-	1	3	Peak counter limit for restriking EF detection
Reset delay time	0.000 - 60.000	s	0.001	0.5	Reset delay time
Start delay time	0.030 - 60.000	s	0.001	0.030	Start delay time
Pol reversal	No Yes	-	-	No	Rotate polarizing quantity

4.2.9.8 Measured values

Table 546: MFADPSDE Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Block of operate signal
BLK_ST	BOOLEAN	0	Block of start signal
FR_TIMER	BOOLEAN	0	Freeze operation timer
RELEASE	BOOLEAN	0	External trigger signal to release protection
RESET	BOOLEAN	0	External reset for directional calculation

4.2.9.9 Monitored data

Table 547: MFADPSDE Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal
FAULT_DIR	INTEGER	0=Unknown 1=Forward 2=Backward 3=Both	-	Detected fault direction
BLK_EF	BOOLEAN	0=FALSE 1=TRUE	-	Block signal for EF to indicate opposite fault direction
INTR_EF	BOOLEAN	0=FALSE 1=TRUE	-	Intermittent earth-fault indication
PEAK_IND	BOOLEAN	0=FALSE 1=TRUE	-	Current transient detection indication
DIRECTION	INTEGER	0=Unknown 1=Forward 2=Backward 3=Both	-	Direction information
ANGLE	REAL	-	deg	Angle between polarizing and operating quantity
START_DUR	REAL	-	%	Ratio of start time / operate time

4.2.9.10 Technical data

Table 548: MFADPSDE technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$ ±1.5% of the set value or ±0.002 × U_n
Start time [1)]	Typically 50 ms (±10 ms)
Reset time	<40 ms
Operate time accuracy	±1.0% of the set value or ±20 ms

1) Includes the delay of the signal output contact. Results based on statistical distribution of 1000 measurements.

4.3 Differential protection

4.3.1 Transformer differential protection for two winding transformers TR2PTDF

4.3.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Transformer differential protection for two winding transformers	TR2PTDF	3dI>T	87T

4.3.1.2 Function block

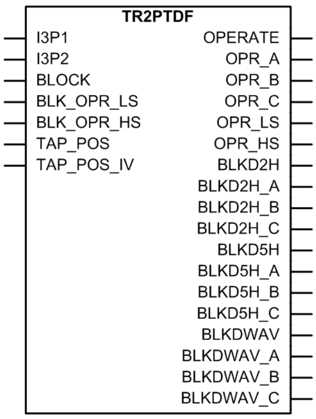


Figure 272: Function block

4.3.1.3 Functionality

The transformer differential protection TR2PTDF is designed to protect two-winding transformers and generator-transformer blocks. TR2PTDF includes low biased and high instantaneous stages.

The biased low stage provides a fast clearance of faults while remaining stable with high currents passing through the protected zone increasing errors on current measuring. The second harmonic restraint, together with the waveform based algorithms, ensures that the low stage does not operate due to the transformer inrush currents. The fifth harmonic restraint ensures that the low stage does not operate on apparent differential current caused by a harmless transformer over-excitation.

The instantaneous high stage provides a very fast clearance of severe faults with a high differential current regardless of their harmonics.

The setting characteristic can be set more sensitive with the aid of tap changer position compensation. The correction of transformation ratio due to the changes in tap position is done automatically based on the tap changer status information provided to the function through input.

4.3.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of transformer differential protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

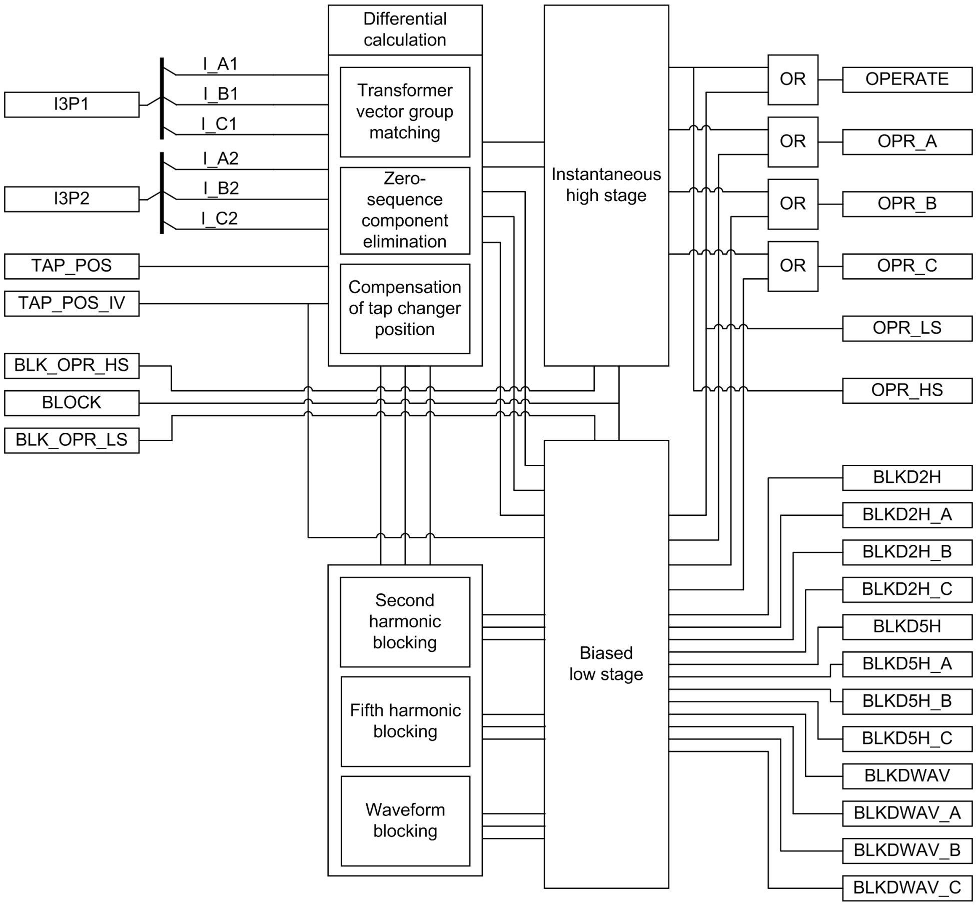


Figure 273: Functional module diagram. Group signals I3P1 and I3P2 are used for feeding the necessary analog signals to the function. I_x1 and I_x2 represent the phase currents of winding 1 and winding 2.

Differential calculation

TR2PTDF operates phase-wise on a difference of incoming and outgoing currents. The positive direction of the currents is towards the protected object.

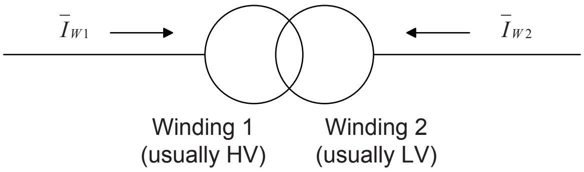


Figure 274: Positive direction of the currents

$$I_d = \left|\bar{I}_{W1} + \bar{I}_{W2}\right|$$

(Equation 75)

In a normal situation, no fault occurs in the area protected by TR2PTDF. Then the currents $\bar{I}_{W1}$ and $\bar{I}_{W2}$ are equal and the differential current I_d is zero. In practice, however, the differential current deviates from zero in normal situations. In the power transformer protection, the differential current is caused by CT inaccuracies, variations in tap changer position (if not compensated), transformer no-load current and instantaneous transformer inrush currents. An increase in the load current causes the differential current, caused by the CT inaccuracies and the tap changer position, to grow at the same percentage rate.

In a biased differential IED in normal operation or during external faults, the higher the load current is the higher is the differential current required for tripping. When an internal fault occurs, the currents on both sides of the protected object are flowing into it. This causes the biasing current to be considerably smaller, which makes the operation more sensitive during internal faults.

$$I_b = \frac{\left|\bar{I}_{W1} - \bar{I}_{W2}\right|}{2}$$

(Equation 76)

If the biasing current is small compared to the differential current or if the phase angle between the winding 1 and winding 2 phase currents is close to zero (in a normal situation, the phase difference is 180 degrees), a fault has most certainly occurred in the area protected by the differential IED. Then the operation value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

The values displayed on the monitored data view for windings current, bias current and differential current are per unit.

Transformer vector group matching

The phase difference of the winding 1 and winding 2 currents that is caused by the vector group of the power transformer is numerically compensated. The matching of the phase difference is based on the phase shifting and the numerical delta connection inside the IED. The *Winding 2 type* parameter determines the connections of the phase windings on the low voltage side (”Y”, ”YN”, ”D”, ”Z”, ”ZN”). Similarly, the *Winding 1 type* parameter determines the connection on winding 1 (”Y”, ”YN”, ”D”, ”Z”, ”ZN”).

The vector group matching can be implemented either on both, winding 1 and winding 2, or only on winding 1 or winding 2, at intervals of 30° with the *Clock number* setting.

When the vector group matching is Yy0 and the *CT connection type* is according to "Type 2", the phase angle of the phase currents connected to the IED does not change. When the vector group matching is Yy6, the phase currents are turned 180° in the IED.

Example 1

Vector group matching of a Ynd11-connected power transformer on winding 1, *CT connection type* according to type 1. The *Winding 1 type* setting is ”YN”, *Winding 2 type* is ”D” and *Clock number* is “Clk Num 11”. This is compensated internally by giving winding 1 internal compensation value +30° and winding 2 internal compensation value 0°:

$$\bar{I}_{L1mHV} = \frac{\bar{I}_{L1} - \bar{I}_{L2}}{\sqrt{3}}$$

$$\bar{I}_{L2mHV} = \frac{\bar{I}_{L2} - \bar{I}_{L3}}{\sqrt{3}}$$

$$\bar{I}_{L3mHV} = \frac{\bar{I}_{L3} - \bar{I}_{L1}}{\sqrt{3}}$$

(Equation 77)

Example 2

But if vector group is Yd11 and *CT connection type* is according to type 1, the compensation is a little different. The *Winding 1 type* setting is ”Y”, *Winding 2 type* is “D” and *Clock number* is “Clk Num 11”. This is compensated internally by giving winding 1 internal compensation value 0° and winding 2 internal compensation value -30°;

$$\bar{I}_{L1mLV} = \frac{\bar{I}_{L1} - \bar{I}_{L3}}{\sqrt{3}}$$

$$\bar{I}_{L2mLV} = \frac{\bar{I}_{L2} - \bar{I}_{L1}}{\sqrt{3}}$$

$$\bar{I}_{L3mLV} = \frac{\bar{I}_{L3} - \bar{I}_{L2}}{\sqrt{3}}$$

(Equation 78)

The "Y" side currents stay untouched, while the "d" side currents are compensated to match the currents actually flowing in the windings.

In this example there is no neutral current on either side of the transformer (assuming there are no earthing transformers installed). In the previous example, however, the matching is done differently to have the winding 1 neutral current compensated at the same time.

Zero-sequence component elimination

If *Clock number* is "Clk Num 2", "Clk Num 4", "Clk Num 8" or "Clk Num 10", the vector group matching is always done on both, winding 1 and winding 2. The combination results in the correct compensation. In this case the zero-sequence component is always removed from both sides automatically. The *Zro A elimination* parameter cannot change this.

If *Clock number* is "Clk Num 1", "Clk Num 5", "Clk Num 7" or "Clk Num 11", the vector group matching is done on one side only. A possible zero-sequence component of the phase currents at earth faults occurring outside the protection area is eliminated in the numerically implemented delta connection before the differential current and the biasing current are calculated. This is why the vector group matching is almost always made on the star connected side of the "Ynd" and "Dyn" connected transformers.

If *Clock number* is "Clk Num 0" or "Clk Num 6", the zero-sequence component of the phase currents is not eliminated automatically on either side. Therefore, the zero-sequence component on the star connected side that is earthed at its star point has to be eliminated by using the *Zro A elimination* parameter.

The same parameter has to be used to eliminate the zero-sequence component if there is, for example, an earthing transformer on the delta-connected side of the "Ynd" power transformer in the area to be protected. In this case, the vector group matching is normally made on the side of the star connection. On the side of the delta connection, the elimination of the zero-sequence component has to be separately selected.

By using the *Zro A elimination* parameter, the zero-sequence component of the phase currents is calculated and reduced for each phase current:

$$\bar{I}_{L1m} = \bar{I}_{L1} - \frac{1}{3} x \left(\bar{I}_{L1} + \bar{I}_{L2} + \bar{I}_{L3} \right)$$
$$\bar{I}_{L2m} = \bar{I}_{L2} - \frac{1}{3} x \left(\bar{I}_{L1} + \bar{I}_{L2} + \bar{I}_{L3} \right)$$
$$\bar{I}_{L3m} = \bar{I}_{L3} - \frac{1}{3} x \left(\bar{I}_{L1} + \bar{I}_{L2} + \bar{I}_{L3} \right)$$

(Equation 79)

In many cases with the earthed neutral of a "wye" winding, it is possible to make the compensation so that a zero-sequence component of the phase currents is automatically eliminated. For example, in a case of a "Ynd" transformer, the compensation is made on the winding 1 side to automatically eliminate the zero-sequence component of the phase currents on that side (and the "d" side does not have them). In those cases, explicit elimination is not needed.

Compensation of tap changer position

The position of the tap changer used for voltage control can be compensated and the position information is provided for the protection function through the tap position indication function TPOSSLTC1.

Typically, the tap changer is located within the high voltage winding, that is, winding 1, of the power transformer. The *Tapped winding* parameter specifies whether the tap changer is connected to the high voltage side winding or the low voltage side winding. This parameter is also used to enable and disable the automatic adaptation to the tap changer position. The possible values are "Not in use", "Winding 1", "Winding 2".

The *Tap nominal* parameter tells the number of the tap, which results in the nominal voltage (and current). When the current tap position deviates from this value, the input current values on the side where the tap changer resides are scaled to match the currents on the other side.

A correct scaling is determined by the number of steps and the direction of the deviation from the nominal tap and the percentage change in voltage resulting from a deviation of one tap step. The percentage value is set using the *Step of tap* parameter.

The operating range of the tap changer is defined by the *Min winding tap* and *Max winding tap* parameters. The *Min winding tap* parameter tells the tap position number resulting in the minimum effective number of winding turns on the side of the transformer where the tap changer is connected. Correspondingly, the *Max winding tap* parameter tells the tap position number resulting in the maximum effective number of winding turns.

The *Min winding tap* and *Max winding tap* parameters help the tap position compensation algorithm know in which direction the compensation is being made. This ensures also that if the current tap position information is corrupted for some reason, the automatic tap changer position adaptation does not try to adapt to any unrealistic position values.

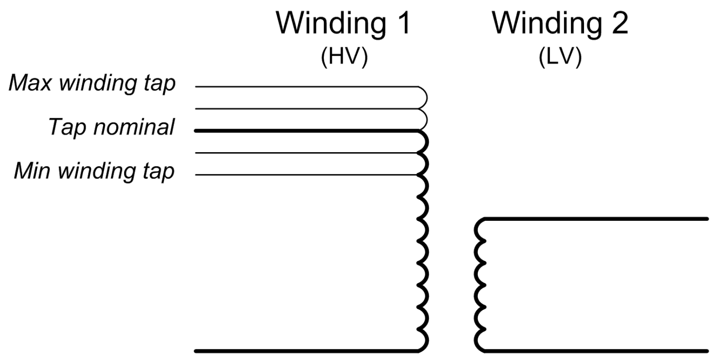


Figure 275: Simplified presentation of the high voltage and medium voltage windings with demonstration of the Max winding tap, Min winding tap and Tap nominal parameters

The position value in the `TAP_POS` input is valid if the value of the `TAP_POS_IV` input is “FALSE.” When the value of the `TAP_POS_IV` input is “TRUE,” the position information in `TAP_POS` is not used but the last value before `TAP_POS_IV` changed to “TRUE” is used instead. In addition, the minimum sensitivity of the biased stage, set by the *Low operate value* setting, is automatically desensitized with the total range of the tap position correction. The new acting low operate value is

$$Desensitized\ Low\ operate\ value = Low\,operate\,value + ABS(Max\,Winding\ tap - Min\,winding\ tap) \times Step\ of\ tap$$

(Equation 80)

Second harmonic blocking

The transformer magnetizing inrush currents occur when energizing the transformer after a period of de-energization. The inrush current can be many times the rated current and the halving time can be up to several seconds. To the differential protection, the inrush current represents a differential current, which would cause the differential protection to operate almost always when the transformer is connected to the network. Typically, the inrush current contains a large amount of second harmonics.

Blocking the operation of the TR2PTDF biased low stage at a magnetizing inrush current is based on the ratio of the amplitudes of the second harmonic digitally filtered from the differential current and the fundamental frequency (Id2f /Id1f).

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of another transformer running in parallel with the protected transformer already connected to the network.

The ratio of the second harmonic to a fundamental component can vary considerably between the phases. Especially when the delta compensation is done for a Ynd1 connected transformer and the two phases of the inrush currents are otherwise equal but opposite in phase angle, the subtraction of the phases in a delta compensation results in a very small second harmonic component.

Some measures have to be taken in order to avoid the false tripping of a phase having too low a ratio of the second harmonic to the fundamental component. One way could be to always block all the phases when the second harmonic blocking conditions are fulfilled in at least one phase. The other way is to calculate the weighted ratios of the second harmonic to the fundamental component for each phase using the original ratios of the phases. The latter option is used here. The second harmonic ratios I_2H_RAT_x are given in monitored data.

The ratio to be used for second harmonic blocking is, therefore, calculated as a weighted average on the basis of the ratios calculated from the differential currents of the three phases. The ratio of the concerned phase is of most weight compared to the ratios of the other two phases. In this IED, if the weighting factors are four, one and one, four is the factor of the phase concerned. The operation of the biased stage on the concerned phase is blocked if the weighted ratio of that phase is above the set blocking limit *Start value 2.H* and if blocking is enabled through the *Restraint mode* parameter.

Using separate blocking for the individual phases and weighted averages calculated for the separate phases provides a blocking scheme that is stable at the connection inrush currents.

If the peak value of the differential current is very high, the limit for the second harmonic blocking is desensitized (in the phase in question) by increasing it proportionally to the peak value of the differential current.

The connection of the power transformer against a fault inside the protected area does not delay the operation of the tripping, because in such a situation the blocking based on the second harmonic of the differential current is prevented by a separate algorithm based on a different waveform and a different rate of change of the normal inrush current and the inrush current containing the fault current. The algorithm does not eliminate the blocking at inrush currents, unless there is a fault in the protected area.

The feature can also be enabled and disabled with the *Harmonic deblock 2.H* parameter.

Fifth harmonic blocking

The inhibition of TR2PTDF operation in the situations of overexcitation is based on the ratio of the fifth harmonic and the fundamental component of the differential current (Id5f/Id1f). The ratio is calculated separately for each phase without weighting the factors. If the ratio exceeds the setting value of *Start value 5.H* and if blocking is enabled through the *Restraint mode* parameter, the operation of the biased stage of TR2PTDF in the concerned phase is blocked.

At dangerous levels of overvoltage, which can cause damage to the transformer, the blocking can be automatically eliminated. If the ratio of the fifth harmonic and the fundamental component of the differential current exceeds the *Stop value 5.H* parameter, the blocking removal is enabled. The enabling and disabling of deblocking feature is also done through the *Harmonic deblock 5.H* parameter.

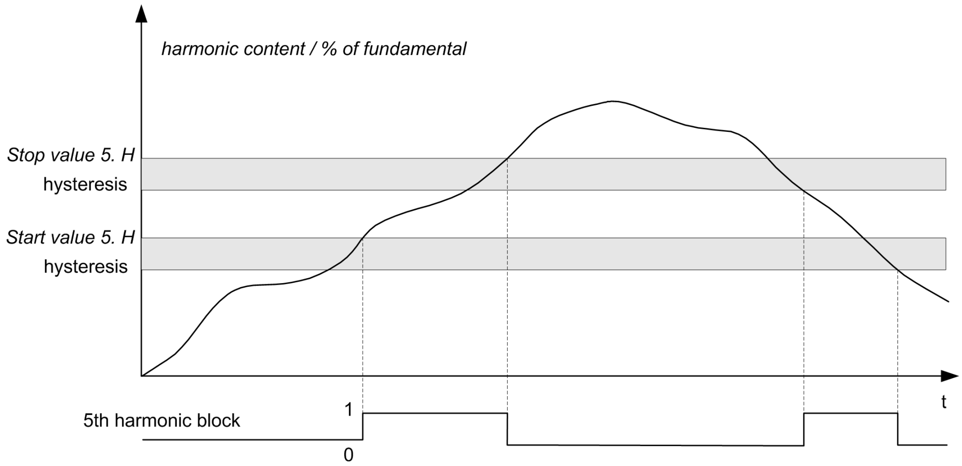


Figure 276: The limits and operation of the fifth harmonic blocking when both blocking and deblocking features are enabled using the Harmonic deblock 5.H control parameter.

The fifth harmonic blocking has a hysteresis to avoid rapid fluctuation between "TRUE" and "FALSE". The blocking also has a counter, which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

Also the fifth harmonic deblocking has a hysteresis and a counter which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

Waveform blocking

The biased low stage can always be blocked with waveform blocking. The stage can not be disabled with the *Restraint mode* parameter. This algorithm has two parts. The first part is intended for external faults while the second is intended for inrush situations. The algorithm has criteria for a low current period during inrush where also the differential current (not derivative) is checked.

Biased low stage

The current differential protection needs to be biased because the possible appearance of a differential current can be due to something else than an actual fault in the transformer (or generator).

In the case of transformer protection, a false differential current can be caused by:

- CT errors
- Varying tap changer positions (if not automatically compensated)
- Transformer no-load current
- Transformer inrush currents

- Transformer overexcitation in overvoltage
- Underfrequency situations
- CT saturation at high currents passing through the transformer.

The differential current caused by CT errors or tap changer positions increases at the same percent ratio as the load current.

In the protection of generators, the false differential current can be caused by:

- CT errors
- CT saturation at high currents passing through the generator.

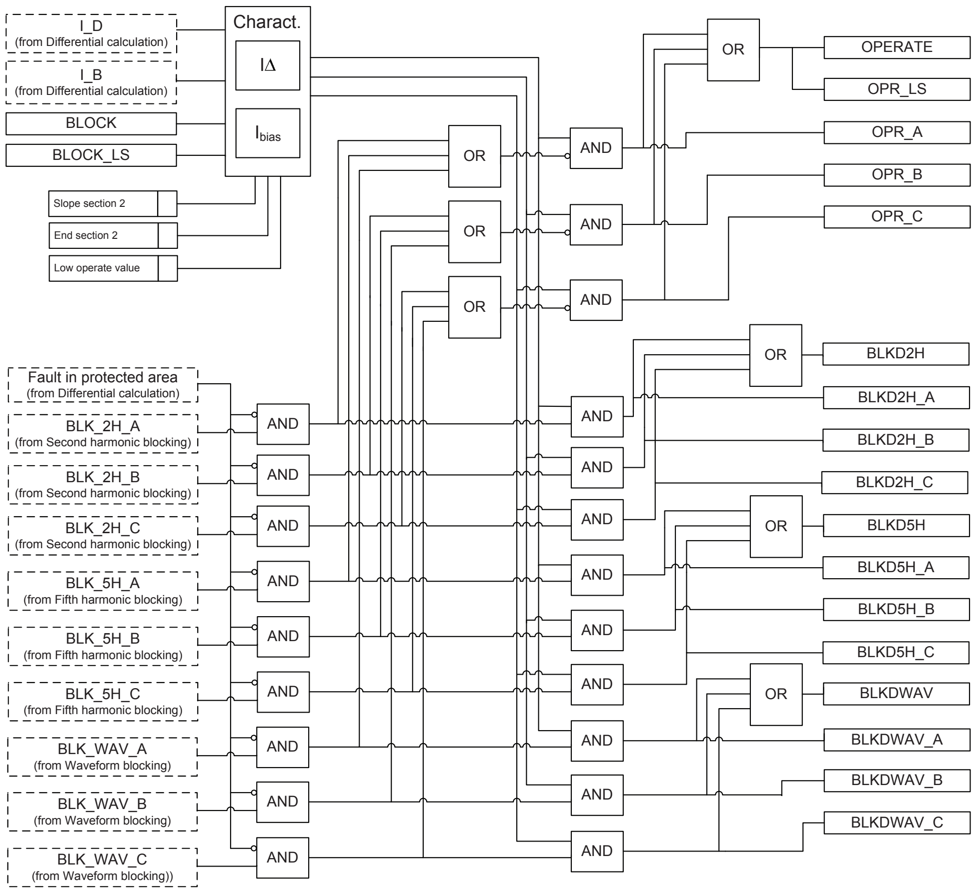


Figure 277: Operation logic of the biased low stage

The high currents passing through a protected object can be caused by the short circuits outside the protected area, the large currents fed by the transformer in motor startup or the transformer inrush situations. Therefore, the operation of the differential protection is biased in respect to the load current. In biased differential protection, the higher the differential current required for the protection to operate, the higher the load current.

The operating characteristic of the biased low stage is determined by *Low operate value*, *Slope section 2* and the setting of the second turning point of the operating characteristic curve, *End section 2* (the first turning point and the slope of the last part of the characteristic are fixed). The settings are the same for all the phases. When the differential current exceeds the operating value determined by the operating characteristic, the differential function awakes. If the differential current stays above the operating value continuously for a short period, the OPR_LS output is activated. The OPERATE output is always activated when the OPR_LS output is activated and the outputs OPR_A, OPR_B and OPR_C are activated according to the faulted phase detected by the biased low stage.

The stage can be blocked internally by the second or fifth harmonic restraint, or by special algorithms detecting inrush and current transformer saturation at external faults. When the operation of the biased low stage is blocked by the second harmonic blocking functionality, the outputs BLKD2H_A, BLKD2H_B, BLKD2H_C and the combined output BLKD2H are activated according to the phase information.

When operation of the biased low stage is blocked by the fifth harmonic blocking functionality, the outputs BLKD5H_A, BLKD5H_B, BLKD5H_C and the combined output BLKD5H are activated according to the phase information. Correspondingly, when the operation of the biased low stage is blocked by the waveform blocking functionality, the outputs BLKDWAV_A, BLKDWAV_B, BLKDWAV_C and the combined output BLKDWAV are activated according to the phase information.

When required, the operate outputs of the biased low stage can be blocked by the BLK_OPR_LS or BLOCK external control signals.

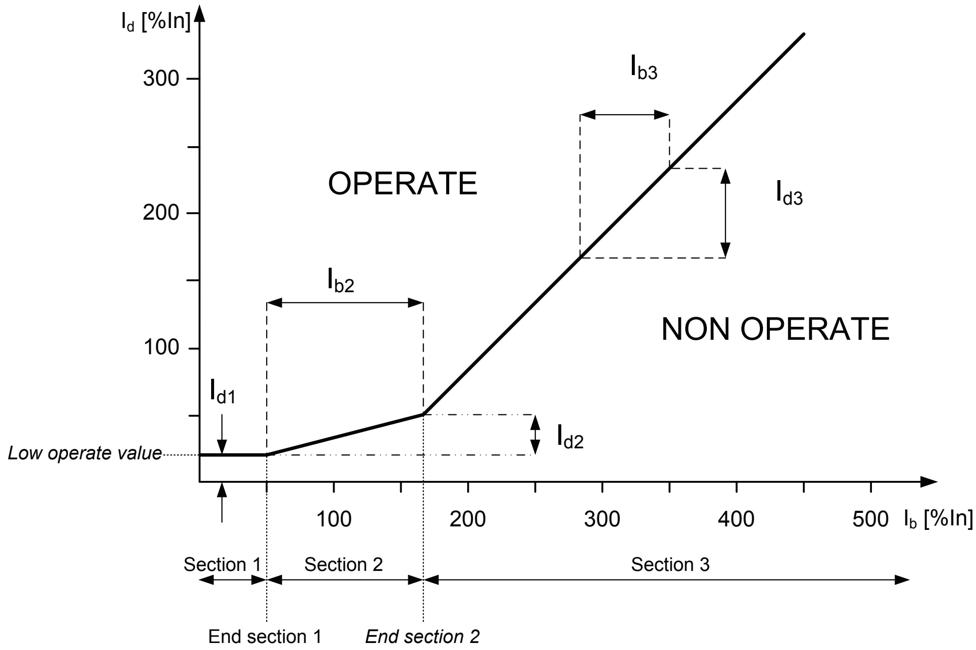


Figure 278: Operation characteristic for biased operation of TR2PTDF

$$Low\,operate\,value = Id1 / In \times 100\%$$

(Equation 81)

$$Slope\ \ section\,2 = \frac{I_{d2}}{I_{b2}} \cdot 100\%$$

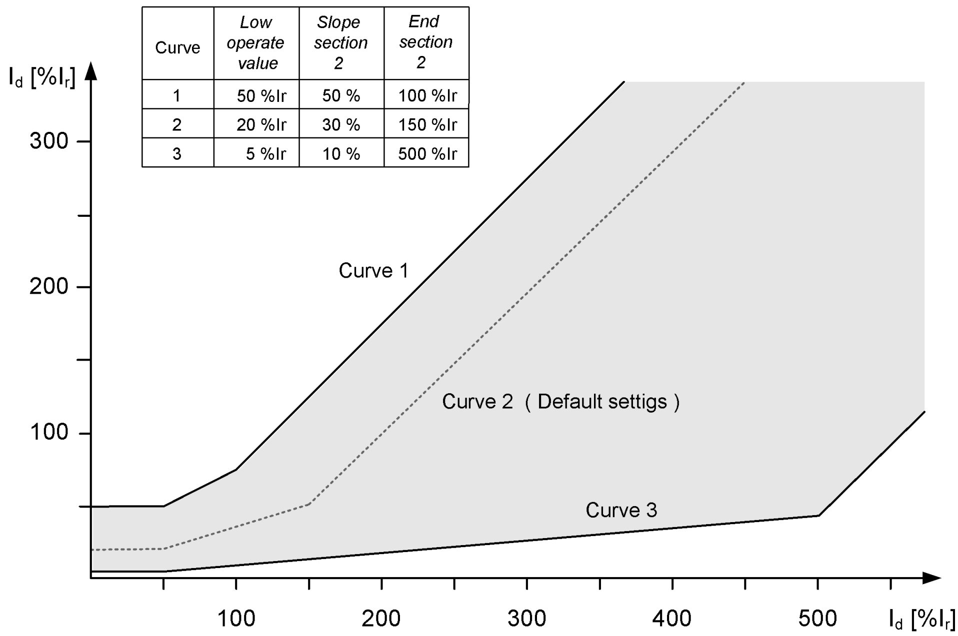
(Equation 82)

The second turning point *End section 2* can be set in the range of 100 percent to 500 percent.

The slope of the differential function's operating characteristic curve varies in the different sections of the range.

- In section 1, where 0.0 < Ib/In < End section 1, End section 1 being fixed to 50 percent Ir, the differential current required for tripping is constant. The value of the differential current is the same as the *Low operate value* selected for the function. *Low operate value* basically allows the no-load current of the power transformer and small inaccuracies of the current transformers, but it can also be used to influence the overall level of the operating characteristic. At the rated current, the no-load losses of the power transformer are about 0.2 percent. If the supply voltage of the power transformer suddenly increases due to operational disturbances, the magnetizing current of the transformer increases as well. In general the magnetic flux density of the transformer is rather high at rated voltage and a rise in voltage by a few percent causes the magnetizing current to increase by tens of percent. This should be considered in *Low operate value*

- In section 2, where End section 1 < Ib/In < End section 2, is called the influence area of *Slope section 2*. In this section, variations in the starting ratio affect the slope of the characteristic, that is, how big a change in the differential current is required for tripping in comparison with the change in the load current. The starting ratio should consider CT errors and variations in the transformer tap changer position (if not compensated). Too high a starting ratio should be avoided, because the sensitivity of the protection for detecting inter-turn faults depends basically on the starting ratio.
- In section 3, where Ib/In > End section 2, the slope of the characteristic is constant. The slope is 100%, which means that the increase in the differential current is equal to the corresponding increase in the biasing current.



Curve	*Low operate value*	*Slope section 2*	*End section 2*
1	50 %Ir	50 %	100 %Ir
2	20 %Ir	30 %	150 %Ir
3	5 %Ir	10 %	500 %Ir

Figure 279: Setting range for biased low stage

If the biasing current is small compared to the differential current of the phase angle between the winding 1 and winding 2 phase currents is close to zero (in a normal situation, the phase difference is 180 degrees), a fault has most likely occurred in the area protected by TR2PTDF. Then the internal blocking signals of the biased stage are inhibited.

Instantaneous high stage

The instantaneous high stage operation can be enabled and disabled with the *Enable high set* setting. The corresponding parameter values are "TRUE" and "FALSE."

The operation of the instantaneous high stage is not biased. The instantaneous stage operates and the output OPR_HS is activated when the amplitude of the fundamental frequency component of the differential current exceeds the set *High operate value* or when the instantaneous value of the differential current exceeds 2.5 times the value of *High operate value*. The factor 2.5 (=1.8 x √2) is due to the maximum asymmetric short circuit current.

If the biasing current is small compared to the differential current or the phase angle between the winding 1 and winding 2 phase currents is close to zero (in a normal situation, the phase difference is 180 degrees), a fault has occurred in the area protected by TR2PTDF. Then the operation value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

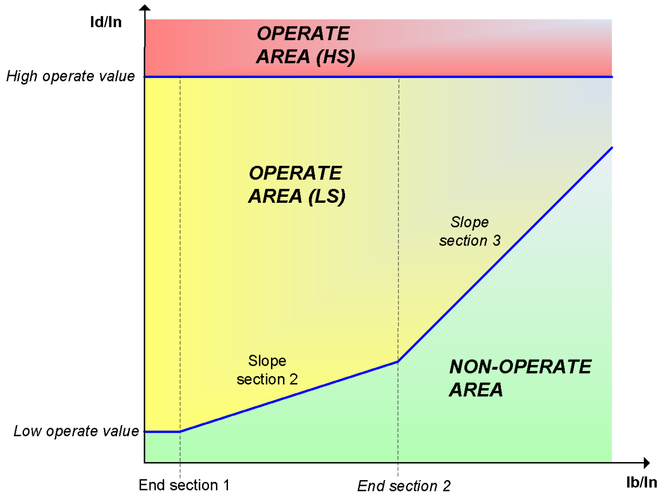


Figure 280: Operating characteristics of the protection. (LS) stands for the biased low stage and (HS) for the instantaneous high stage

The OPERATE output is activated always when the OPR_HS output activates and outputs OPR_A, OPR_B and OPR_C are activated according to the faulted phase detected by the instantaneous high stage.

The internal blocking signals of the differential function do not prevent the operate signal of the instantaneous differential current stage. When required, the operate outputs of the instantaneous high stage can be blocked by the BLK_OPR_HS and BLOCK external control signals.

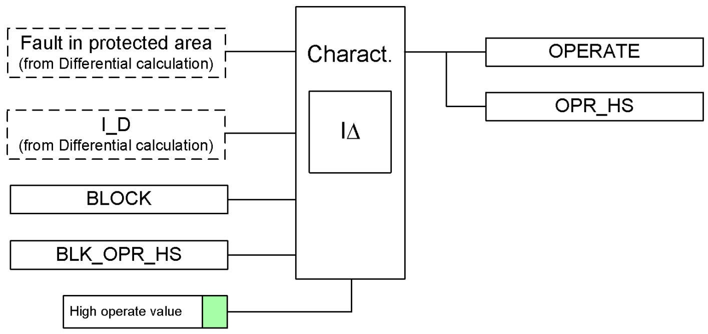


Figure 281: Operation logic of instantaneous high stage

Reset of the blocking signals (de-block)

All three blocking signals, that is, waveform and second and fifth harmonic, have a counter, which holds the blocking on for a certain time after the blocking conditions have ceased to be fulfilled. The deblocking takes place when those counters have elapsed. This is a normal case of deblocking.

The blocking signals can be reset immediately if a very high differential current is measured or if the phase difference of the compared currents (the angle between the compared currents) is close to zero after the automatic vector group matching has been made (in a normal situation, the phase difference is 180 degrees). This does not, however, reset the counters holding the blockings, so the blocking signals may return when these conditions are not valid anymore.

External blocking functionality

TR2PTDF has three inputs for blocking.

- When the `BLOCK` input is active ("TRUE"), the operation of the function is blocked but measurement output signals are still updated.
- When the `BLK_OPR_LS` input is active ("TRUE"), TR2PTDF operates normally except that the `OPR_LS` output is not active or activated in any circumstance. Additionally, the outputs `OPERATE`, `OPR_A`, `OPR_B` and `OPR_C` can be activated only by the instantaneous high stage (if not blocked as well).
- When the `BLK_OPR_HS` input is active ("TRUE"), TR2PTDF operates normally except that the `OPR_HS` output is not active or activated in any circumstance. Additionally, the outputs `OPERATE`, `OPR_A`, `OPR_B` and `OPR_C` can be activated only by the biased low stage (if not blocked as well).

4.3.1.5 Application

TR2PTDF is a unit protection function serving as the main protection for transformers in case of winding failure. The protective zone of a differential protection includes the transformer, the bus-work or the cables between the current transformer and the power transformer. When bushing current transformers are used for the differential IED, the protective zone does not include the bus work or cables between the circuit breaker and the power transformer.

In some substations, there is a current differential protection for the busbar. The busbar protection includes bus work or cables between the circuit breaker and the power transformer. Internal electrical faults are very serious and cause immediate damage. Short circuits and earth faults in windings and terminals are normally detected by the differential protection. If enough turns are short-circuited, the interturn faults, which are flashovers between the conductors within the same physical winding, are also detected. The interturn faults are the most difficult transformer-winding faults to detect with electrical protections. A small interturn fault including a few turns results in an undetectable amount of current until the fault develops into an earth-fault. Therefore, it is important that the differential protection has a high level of sensitivity and that it is possible to use a sensitive setting without causing unwanted operations for external faults.

It is important that the faulty transformer is disconnected as fast as possible. As TR2PTDF is a unit protection function, it can be designed for fast tripping, thus providing a selective disconnection of the faulty transformer. TR2PTDF should never operate to faults outside the protective zone.

TR2PTDF compares the current flowing into the transformer to the current leaving the transformer. A correct analysis of fault conditions by TR2PTDF must consider the changes to voltages, currents and phase angles. The traditional transformer differential protection functions required auxiliary transformers for the correction of the phase shift and turns ratio. The numerical microprocessor based differential algorithm implemented in TR2PTDF compensates for both the turns ratio and the phase shift internally in the software.

The differential current should theoretically be zero during normal load or external faults if the turns ratio and the phase shift are correctly compensated. Several different phenomena other than internal faults cause unwanted and false differential currents. The main reasons for unwanted differential currents are:

- Mismatch due to varying tap changer positions
- Different characteristics, loads and operating conditions of the current transformers
- Zero sequence currents that only flow on one side of the power transformer
- Normal magnetizing currents
- Magnetizing inrush currents
- Overexcitation magnetizing currents.

TR2PTDF is designed mainly for the protection of two-winding transformers. TR2PTDF can also be utilized for the protection of generator-transformer blocks as well as short cables and overhead lines. If the distance between the measuring points is relatively long in line protection, interposing CTs can be required to reduce the burden of the CTs.

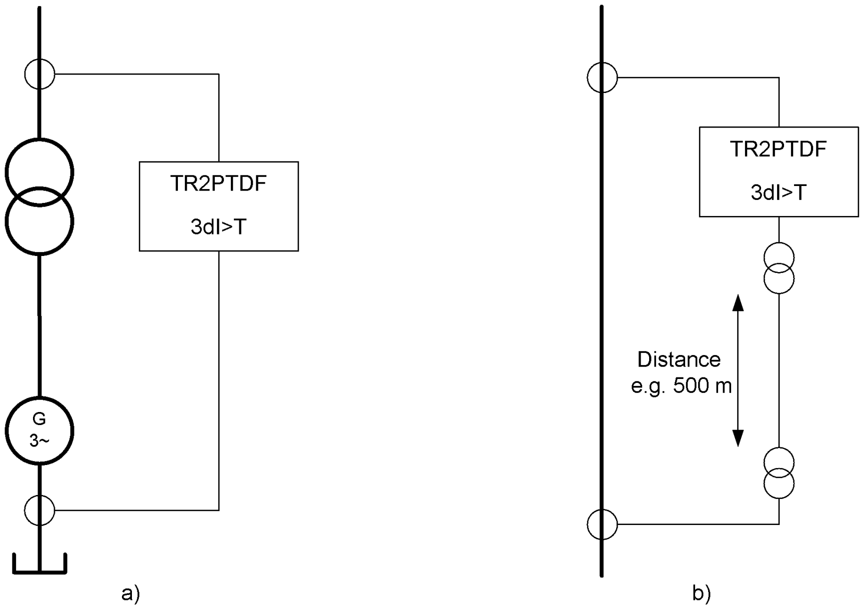


Figure 282: Differential protection of a generator-transformer block and short cable/line

TR2PTDF can also be used in three-winding transformer applications or two-winding transformer applications with two output feeders.

On the double-feeder side of the power transformer, the current of the two CTs per phase must be summed by connecting the two CTs of each phase in parallel. Generally this requires the interposing CTs to handle the vector group and/or ratio mismatch between the two windings/feeders.

The accuracy limit factor for the interposing CT must fulfill the same requirements as the main CTs. Please note that the interposing CT imposes an additional burden to the main CTs.

The most important rule in these applications is that at least 75 percent of the short-circuit power has to be fed on the side of the power transformer with only one connection to the IED.

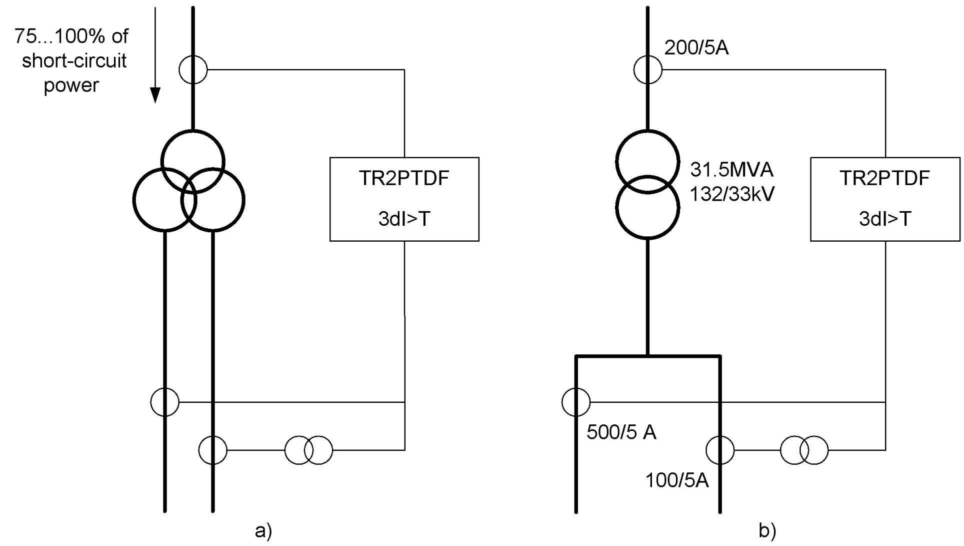


Figure 283: Differential protection of a three-winding transformer and a transformer with two output feeders

TR2PTDF can also be used for the protection of the power transformer feeding the frequency converter. An interposing CT is required for matching the three-winding transformer currents to a two-winding protection relay.

The fundamental frequency component is numerically filtered with a Fourier filter, DFT. The filter suppresses frequencies other than the set fundamental frequency, and therefore the IED is not adapted for measuring the output of the frequency converter, that is, TR2PTDF is not suited for protecting of a power transformer or motor fed by a frequency converter.

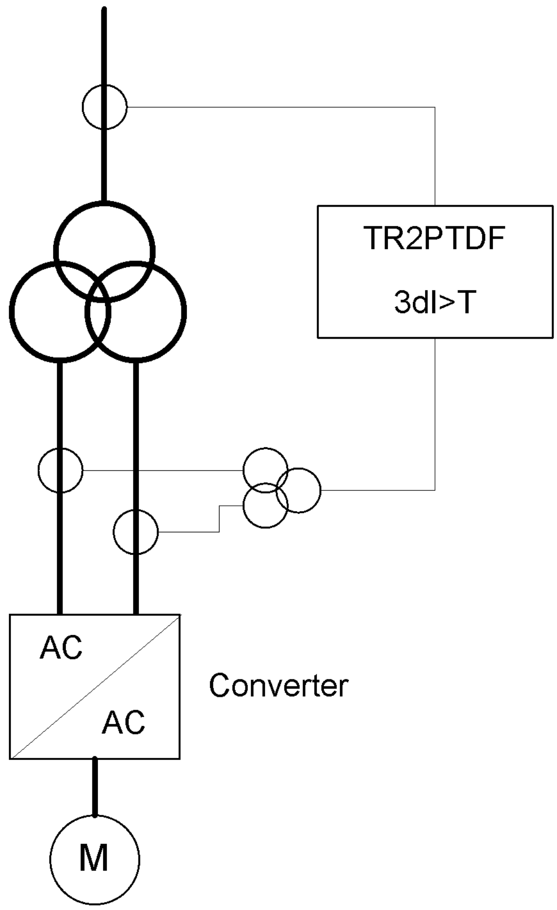


Figure 284: Feeding frequency converter

Transforming ratio correction of current transformers

Often the CT secondary currents differ from the rated current at the rated load of the power transformer. The CT transforming ratios can be corrected on both sides of the power transformer with the base value settings.

$$I_{nT} = \frac{S_n}{\sqrt{3} \times U_n}$$

(Equation 83)

I_{nT} rated load of the power transformer

S_n rated power of the power transformer

U_n rated phase-to-phase voltage

Example

The rated power of the transformer is 25 MVA, the ratio of the CTs on the 110 kV side is 300/1 and that on the 21 kV side is 1000/1

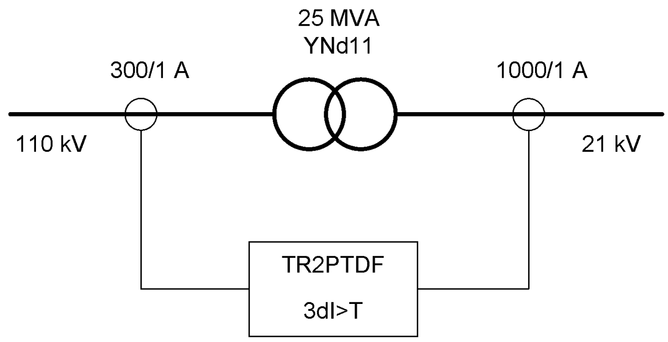


Figure 285: Example of two-winding power transformer differential protection

The rated load of the transformer is calculated on the high voltage side: I_{nT} = 25 MVA / (1.732 × 110 kV) = 131.2 A

Setting

The calculated value is set, for example, to global setting parameter: “Configuration/Analog inputs/Base values/Phase Grp1/*Current base Val Ph*” = 131 A.

Low voltage side: I_{nT} = 25 MVA / (1.732 × 21 kV) = 687.3 A

Setting

The calculated value is set, for example, to global setting parameter: “Configuration/Analog inputs/Base values/Phase Grp2/*Current base Val Ph*” = 687 A. Phase Grp1 is now selected for the high voltage side and Phase Grp2 for the low voltage side. Those selections must also be done in TR2PTDF.

Setting

Base value Sel Wnd 1 = 1

Base value Sel Wnd 2 = 2

Vector group matching and elimination of the zero-sequence component

The vector group of the power transformer is numerically matched on the high voltage and low voltage sides by means of the *Winding 1 type*, *Winding 2 type* and *Clock number* settings. Thus no interposing CTs are needed if there is only a power transformer inside the protected zone. The matching is based on phase shifting and a numerical delta connection in the IED. If the neutral of a star-connected power transformer is earthed, any earth fault in the network is perceived by the IED as a differential current. The elimination of the zero-sequence component can be selected for that winding by setting the *Zro A elimination* parameter.

Table 549: TR2PTDF settings corresponding to the power transformer vector groups and zero-sequence elimination

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
Yy0	Y	Y	Clk Num 0	Not needed
YNy0	YN	Y	Clk Num 0	HV side
YNyn0	YN	YN	Clk Num 0	HV & LV side
Yyn0	Y	YN	Clk Num 0	LV side
Yy2	Y	Y	Clk Num 2	Not needed
YNy2	YN	Y	Clk Num 2	Not needed
YNyn2	YN	YN	Clk Num 2	Not needed
Yyn2	Y	YN	Clk Num 2	Not needed
Yy4	Y	Y	Clk Num 4	Not needed
YNy4	YN	Y	Clk Num 4	Not needed
YNyn4	YN	YN	Clk Num 4	Not needed
Yyn4	Y	YN	Clk Num 4	Not needed
Yy6	Y	Y	Clk Num 6	Not needed
YNy6	YN	Y	Clk Num 6	HV side
YNyn6	YN	YN	Clk Num 6	HV & LV side
Yyn6	Y	YN	Clk Num 6	LV side
Yy8	Y	Y	Clk Num 8	Not needed
YNy8	YN	Y	Clk Num 8	Not needed
YNyn8	YN	YN	Clk Num 8	Not needed
Yyn8	Y	YN	Clk Num 8	Not needed
Yy10	Y	Y	Clk Num 10	Not needed
YNy10	YN	Y	Clk Num 10	Not needed
YNyn10	YN	YN	Clk Num 10	Not needed
Yyn10	Y	YN	Clk Num 10	Not needed
Yd1	Y	D	Clk Num 1	Not needed
YNd1	YN	D	Clk Num 1	Not needed
Yd5	Y	D	Clk Num 5	Not needed
YNd5	YN	D	Clk Num 5	Not needed
Yd7	Y	D	Clk Num 7	Not needed
YNd7	YN	D	Clk Num 7	Not needed
Yd11	Y	D	Clk Num 11	Not needed
YNd11	YN	D	Clk Num 11	Not needed
Dd0	D	D	Clk Num 0	Not needed
Dd2	D	D	Clk Num 2	Not needed
Dd4	D	D	Clk Num 4	Not needed
Dd6	D	D	Clk Num 6	Not needed
Dd8	D	D	Clk Num 8	Not needed
Table continues on next page				

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
Dd10	D	D	Clk Num 10	Not needed
Dy1	D	Y	Clk Num 1	Not needed
Dyn1	D	YN	Clk Num 1	Not needed
Dy5	D	Y	Clk Num 5	Not needed
Dyn5	D	YN	Clk Num 5	Not needed
Dy7	D	Y	Clk Num 7	Not needed
Dyn7	D	YN	Clk Num 7	Not needed
Dy11	D	Y	Clk Num 11	Not needed
Dyn11	D	YN	Clk Num 11	Not needed
Yz1	Y	Z	Clk Num 1	Not needed
YNz1	YN	Z	Clk Num 1	Not needed
YNzn1	YN	ZN	Clk Num 1	LV side
Yzn1	Y	ZN	Clk Num 1	Not needed
Yz5	Y	Z	Clk Num 5	Not needed
YNz5	YN	Z	Clk Num 5	Not needed
YNzn5	YN	ZN	Clk Num 5	LV side
Yzn5	Y	ZN	Clk Num 5	Not needed
Yz7	Y	Z	Clk Num 7	Not needed
YNz7	YN	Z	Clk Num 7	Not needed
YNzn7	YN	ZN	Clk Num 7	LV side
Yzn7	Y	ZN	Clk Num 7	Not needed
Yz11	Y	Z	Clk Num 11	Not needed
YNz11	YN	Z	Clk Num 11	Not needed
YNzn11	YN	ZN	Clk Num 11	LV side
Yzn11	Y	ZN	Clk Num 11	Not needed
Zy1	Z	Y	Clk Num 1	Not needed
Zyn1	Z	YN	Clk Num 1	Not needed
ZNyn1	ZN	YN	Clk Num 1	HV side
ZNy1	ZN	Y	Clk Num 1	Not needed
Zy5	Z	Y	Clk Num 5	Not needed
Zyn5	Z	YN	Clk Num 5	Not needed
ZNyn5	ZN	YN	Clk Num 5	HV side
ZNy5	ZN	Y	Clk Num 5	Not needed
Zy7	Z	Y	Clk Num 7	Not needed
Zyn7	Z	YN	Clk Num 7	Not needed
ZNyn7	ZN	YN	Clk Num 7	HV side
ZNy7	ZN	Y	Clk Num 7	Not needed
Zy11	Z	Y	Clk Num 11	Not needed
Zyn11	Z	YN	Clk Num 11	Not needed

Table continues on next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
ZNyn11	ZN	YN	Clk Num 11	HV side
ZNy11	ZN	Y	Clk Num 11	Not needed
Dz0	D	Z	Clk Num 0	Not needed
Dzn0	D	ZN	Clk Num 0	LV side
Dz2	D	Z	Clk Num 2	Not needed
Dzn2	D	ZN	Clk Num 2	Not needed
Dz4	D	Z	Clk Num 4	Not needed
Dzn4	D	ZN	Clk Num 4	Not needed
Dz6	D	Z	Clk Num 6	Not needed
Dzn6	D	ZN	Clk Num 6	LV side
Dz8	D	Z	Clk Num 8	Not needed
Dzn8	D	ZN	Clk Num 8	Not needed
Dz10	D	Z	Clk Num 10	Not needed
Dzn10	D	ZN	Clk Num 10	Not needed
Zd0	Z	D	Clk Num 0	Not needed
ZNd0	ZN	D	Clk Num 0	HV side
Zd2	Z	D	Clk Num 2	Not needed
ZNd2	ZN	D	Clk Num 2	Not needed
Zd4	Z	D	Clk Num 4	Not needed
ZNd4	ZN	D	Clk Num 4	Not needed
Zd6	Z	D	Clk Num 6	Not needed
ZNd6	ZN	D	Clk Num 6	HV side
Zd8	Z	D	Clk Num 8	Not needed
ZNd8	ZN	D	Clk Num 8	Not needed
Zd10	Z	D	Clk Num 10	Not needed
ZNd10	ZN	D	Clk Num 10	Not needed
Zz0	Z	Z	Clk Num 0	Not needed
ZNz0	ZN	Z	Clk Num 0	HV side
ZNzn0	ZN	ZN	Clk Num 0	HV & LV side
Zzn0	Z	ZN	Clk Num 0	LV side
Zz2	Z	Z	Clk Num 2	Not needed
ZNz2	ZN	Z	Clk Num 2	Not needed
ZNzn2	ZN	ZN	Clk Num 2	Not needed
Zzn2	Z	ZN	Clk Num 2	Not needed
Zz4	Z	Z	Clk Num 4	Not needed
ZNz4	ZN	Z	Clk Num 4	Not needed
ZNzn4	ZN	ZN	Clk Num 4	Not needed
Zzn4	Z	ZN	Clk Num 4	Not needed
Zz6	Z	Z	Clk Num 6	Not needed

Table continues on next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
ZNz6	ZN	Z	Clk Num 6	HV side
ZNzn6	ZN	ZN	Clk Num 6	HV & LV side
Zzn6	Z	ZN	Clk Num 6	LV side
Zz8	Z	Z	Clk Num 8	Not needed
ZNz8	ZN	Z	Clk Num 8	Not needed
ZNzn8	ZN	ZN	Clk Num 8	Not needed
Zzn8	Z	ZN	Clk Num 8	Not needed
Zz10	Z	Z	Clk Num 10	Not needed
ZNz10	ZN	Z	Clk Num 10	Not needed
ZNzn10	ZN	ZN	Clk Num 10	Not needed
Zzn10	Z	ZN	Clk Num 10	Not needed

Commissioning

The correct settings, which are *CT connection type*, *Winding 1 type*, *Winding 2 type* and *Clock number*, for the connection group compensation can be verified by monitoring the angle values `I_ANGL_A1_B1`, `I_ANGL_B1_C1`, `I_ANGL_C1_A1`, `I_ANGL_A2_B2`, `I_ANGL_B2_C2`, `I_ANGL_C2_A2`, `I_ANGL_A1_A2`, `I_ANGL_B1_B2` and `I_ANGL_C1_C2` while injecting the current into the transformer. These angle values are calculated from the compensated currents. See signal description in the Monitored data table.

When a station service transformer is available, it can be used to provide current to the high voltage side windings while the low voltage side windings are short-circuited. This way the current can flow in both the high voltage and low voltage windings. The commissioning signals can be provided by other means as well. The minimum current to allow for phase current and angle monitoring is 0.015 pu.

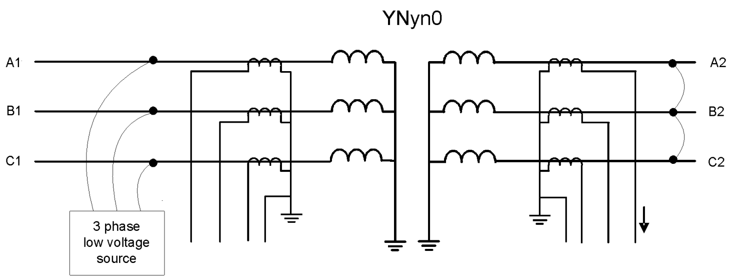


Figure 286: Low voltage test arrangement. The three-phase low voltage source can be the station service transformer.

The *Tapped winding* control setting parameter has to be set to “Not in use” to make sure that the monitored current values are not scaled by the automatic adaptation to the tap changer position. When only the angle values are required, the setting of *Tapped winding* is not needed since angle values are not affected by the tap changer position adaptation.

When injecting the currents in the high voltage winding, the angle values I_ANGL_A1_B1, I_ANGL_B1_C1, I_ANGL_C1_A1, I_ANGL_A2_B2, I_ANGL_B2_C2 and I_ANGL_C2_A2 have to show +120 deg. Otherwise the phase order can be wrong or the polarity of a current transformer differs from the polarities of the other current transformers on the same side.

If the angle values I_ANGL_A1_B1, I_ANGL_B1_C1 and I_ANGL_C1_A1 show -120 deg, the phase order is wrong on the high voltage side. If the angle values I_ANGL_A2_B2, I_ANGL_B2_C2 and I_ANGL_C2_A2 show -120 deg, the phase order is wrong on the low voltage side. If the angle values I_ANGL_A1_B1, I_ANGL_B1_C1 and I_ANGL_C1_A1 do not show the same value of +120, the polarity of one current transformer can be wrong. For instance, if the polarity of the current transformer measuring IL2 is wrong, I_ANGL_A1_B1 shows -60 deg, I_ANGL_B1_C1 shows -60 deg and I_ANGL_C1_A1 shows +120 deg.

When the phase order and the angle values are correct, the angle values I_ANGL_A1_A2, I_ANGL_B1_B2 and I_ANGL_C1_C2 usually show ±180 deg. There can be several reasons if the angle values are not ±180 deg. If the values are 0 deg, the value given for *CT connection type* is probably wrong. If the angle values are something else, the value for *Clock number* can be wrong. Another reason is that the combination of *Winding 1 type* and *Winding 2 type* does not match *Clock number*. This means that the resulting connection group is not supported.

Example

If *Winding 1 type* is set to "Y", *Winding 2 type* is set to “Y” and *Clock number* is set to "Clk num 1", the resulting connection group "Yy1" is not a supported combination. Similarly if *Winding 1 type* is set to "Y", *Winding 2 type* is set to "D" and *Clock number* is set to "Clk num 0", the resulting connection group "Yd0" is not a supported combination. All the non-supported combinations of *Winding 1 type*, *Winding 2 type* and *Clock number* settings result in the default connection group compensation that is "Yy0".

Recommendations for current transformers

The more important the object to be protected, the more attention has to be paid to the current transformers. It is not normally possible to dimension the current transformer so that they repeat the currents with high DC components without saturating when the residual flux of the current transformer is high. TR2PTDF operates reliably even though the current transformers are partially saturated.

The accuracy class recommended for current transformers to be used with TR2PTDF is 5P, in which the limit of the current error at the rated primary current is 1 percent and the limit of the phase displacement is 60 minutes. The limit of the composite error at the rated accuracy limit primary current is five percent.

The approximate value of the accuracy limit factor F_a corresponding to the actual current transformer burden can be calculated on the basis of the rated accuracy limit factor F_n at the rated burden, the rated burden S_n, the internal burden $S_{in}$and the actual burden S_a of the current transformer.

$$F_a = F_n \times \frac{S_{in} + S_n}{S_{in} + S_a}$$

(Equation 84)

F_a The approximate value of the accuracy limit factor (ALF) corresponding to the actual CT burden

F_n The rated accuracy limit factor at the rated burden of the current transformer

S_n The rated burden of the current transformer

S_{in} The internal burden of the current transformer

S_a The actual burden of the current transformer

Example 1

The rated burden S_n of the current transformer 5P20 is 10 VA, the secondary rated current is 5A, the internal resistance R_{in}= 0.07 Ω and the accuracy limit factor F_n corresponding to the rated burden is 20 (5P20). Thus the internal burden of the current transformer is S_{in}= $(5A)^2 \times 0.07$ Ω = 1.75 VA. The input impedance of the IED at a rated current of 5A is <20 mΩ. If the measurement conductors have a resistance of 0.113 Ω, the actual burden of the current transformer is $S_a = (5A)^2 \times (0.113 + 0.020)$ Ω = 3.33 VA. Thus the accuracy limit factor F_a corresponding to the actual burden is approximately 46.

The CT burden can grow considerably at the rated current 5A. The actual burden of the current transformer decreases at the rated current of 1A while the repeatability simultaneously improves.

At faults occurring in the protected area, the currents may be very high compared to the rated currents of the current transformers. Due to the instantaneous stage of the differential function block, it is sufficient that the current transformers are capable of repeating the current required for instantaneous tripping during the first cycle.

Thus the current transformers usually are able to reproduce the asymmetric fault current without saturating within the next 10 ms after the occurrence of the fault to secure that the operate times of the IED comply with the retardation time.

The accuracy limit factors corresponding to the actual burden of the phase current transformer to be used in differential protection fulfill the requirement.

$$F_a > K_r \times Ik_{\max} \times (T_{dc} \times \omega \times (1 - e^{-T_m / T_{dc}}) + 1)$$

(Equation 85)

Ik_{max} The maximum through-going fault current (in pu) at which the protection is not allowed to operate

T_{dc} The primary DC time constant related to Ik_{max}

ω	The angular frequency, that is, 2 × π × fn
T_m	The time-to-saturate, that is, the duration of the saturation free transformation
K_r	The remanence factor 1/(1-r), where r is the maximum remanence flux in pu from saturation flux

The accuracy limit factors corresponding to the actual burden of the phase current transformer is used in differential protection.

The parameter *r* is the maximum remanence flux density in the CT core in p.u. from saturation flux density. The value of the parameter *r* depends on the magnetic material used and on the construction of the CT. For instance, if the value of *r* = 0.4, the remanence flux density can be 40 percent of the saturation flux density. The manufacturer of the CT has to be contacted when an accurate value for the parameter *r* is needed. The value *r* = 0.4 is recommended to be used when an accurate value is not available.

The required minimum time-to-saturate T_m in TR2PTDF is half fundamental cycle period (10 ms when fn = 50 Hz).

Two typical cases are considered for the determination of the sufficient accuracy limit factor (F_a):

1. A fault occurring at the substation bus:
   The protection must be stable at a fault arising during a normal operating situation. Re-energizing the transformer against a bus fault leads to very high fault currents and thermal stress and therefore re-energizing is not preferred in this case. Thus, the remanence can be neglected.
   The maximum through-going fault current Ik_{max} is typically 10 pu for a substation main transformer. At a short circuit fault close to the supply transformer, the DC time constant (T_{dc}) of the fault current is almost the same as that of the transformer, the typical value being 100 ms.

Ik_{max}	10 pu
T_{dc}	100 ms
ω	100π Hz
T_m	10 ms
K_r	1

   When the values are substituted in Equation 85, the result is:

   $$F_a > K_r \times Ik_{\max} \times (T_{dc} \times \omega \times (1 - e^{-T_m / T_{dc}}) + 1) \approx 40$$

2. Re-energizing against a fault occurring further down in the network:

The protection must be stable also during re-energization against a fault on the line. In this case, the existence of remanence is very probable. It is assumed to be 40 percent here.
On the other hand, the fault current is now smaller and since the ratio of the resistance and reactance is greater in this location, having a full DC offset is not possible. Furthermore, the DC time constant (T_{dc}) of the fault current is now smaller, assumed to be 50 ms here.
Assuming a maximum fault current being 30 percent lower than in the bus fault and a DC offset 90 percent of the maximum.

Ik_{max}	0.7 × 10 = 7 (pu)
T_{dc}	50 ms
ω	100π Hz
T_m	10 ms
K_r	1/(1-0.4) = 1.6667

When the values are substituted in the equation, the result is:

$$F_a > K_r \times Ik_{\max} \times 0.9 \times (T_{dc} \times \omega \times (1 - e^{-T_m / T_{dc}}) + 1) \approx 40$$

If the actual burden of the current transformer (S_a) in Equation 84 cannot be reduced low enough to provide a sufficient value for F_a, there are two alternatives to deal with the situation:

- a CT with a higher rated burden S_n can be chosen (which also means a higher rated accuracy limit F_n)
- a CT with a higher nominal primary current I_{1n} (but the same rated burden) can be chosen

Example 2

Assuming that the actions according to alternative two above are taken in order to improve the actual accuracy limit factor:

$$F_a = \frac{IrCT}{IrTR} \times F_n$$

(Equation 86)

IrTR	1000 A (rated secondary side current of the power transformer)
IrCT	1500 A (rated primary current of the CT on the transformer secondary side)
F_n	30 (rated accuracy limit factor of the CT)
F_a	(IrCT / IrTR) × Fn (actual accuracy limit factor due to oversizing the CT) = (1500/1000) × 30 = 45

In TR2PTDF, it is important that the accuracy limit factors F_a of the phase current transformers at both sides correspond with each other, that is, the burdens of the current transformers on both sides are to be as equal as possible. If high inrush or start currents with high DC components pass through the protected object when it is connected to the network, special attention is required for the performance and the burdens of the current transformers and for the settings of the function block.

4.3.1.6 CT connections and transformation ratio correction

The connections of the primary current transformers are designated as "Type 1" and "Type 2".

- If the positive directions of the winding 1 and winding 2 IED currents are opposite, the *CT connection type* setting parameter is "Type 1". The connection examples of "Type 1" are as shown in Figure 287 and Figure 288.
- If the positive directions of the winding 1 and winding 2 IED currents equate, the *CT connection type* setting parameter is "Type 2". The connection examples of "Type 2" are as shown in Figure 289 and Figure 290.
- The default value of the *CT connection type* setting is "Type 1".

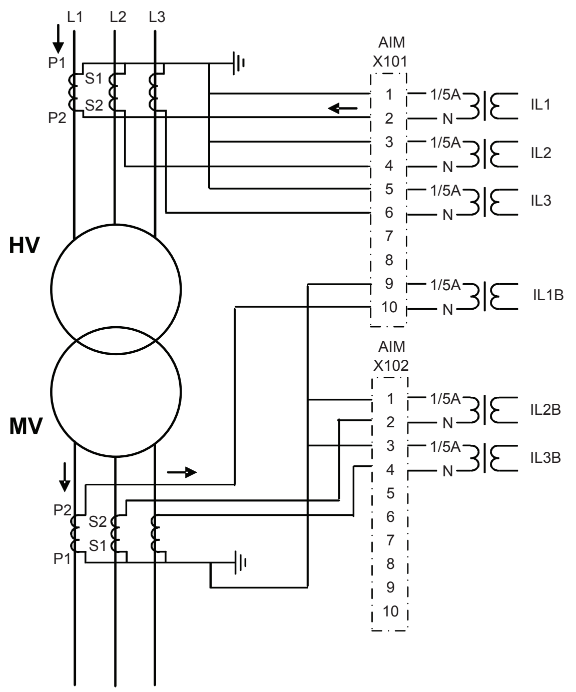


Figure 287: Connection example of current transformers of Type 1

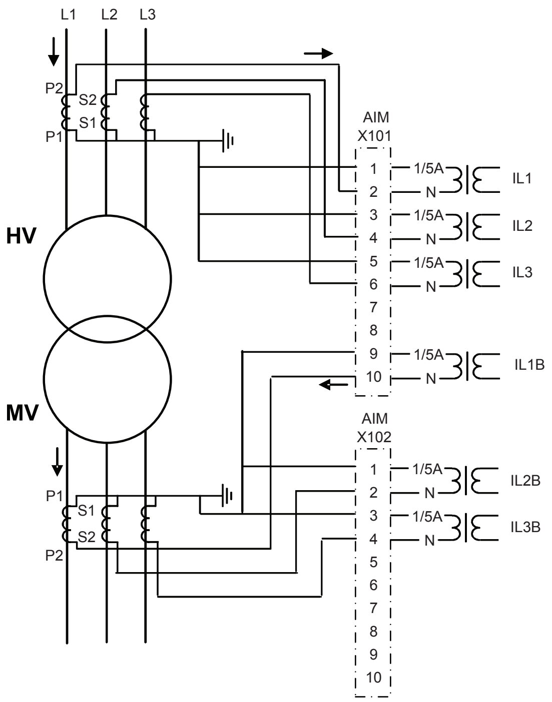


Figure 288: Alternative connection example of current transformers of Type 1

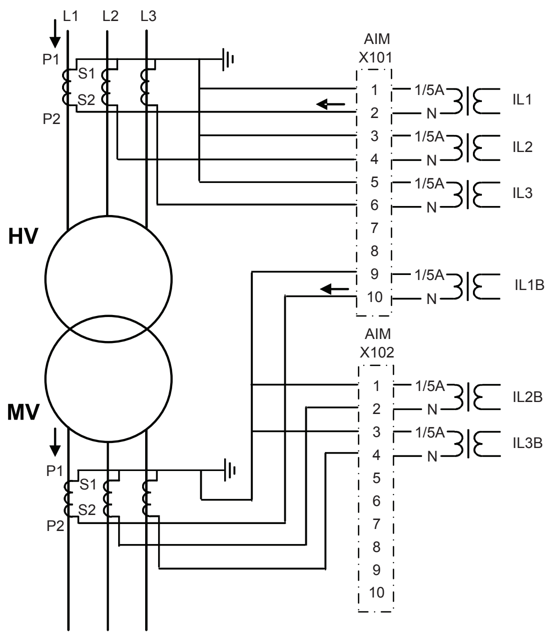


Figure 289: Connection example of current transformers of Type 2

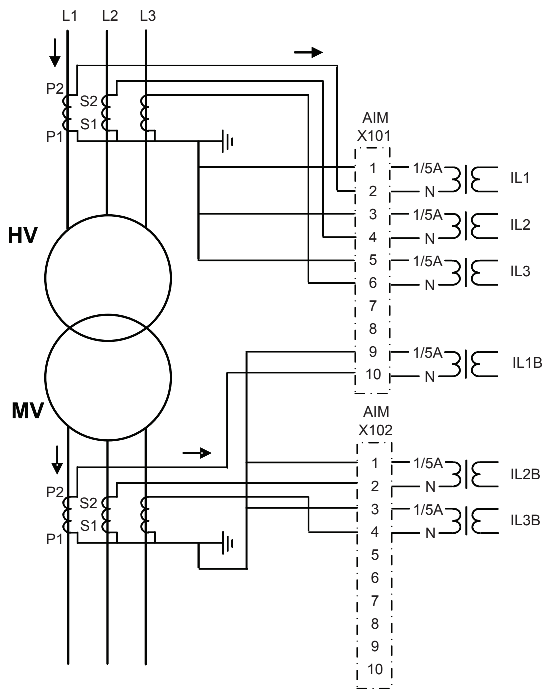


Figure 290: Alternative connection example of current transformers of Type 2

If the rated primary current of the winding 1 and winding 2 side current transformers is not equal to the rated current of the power transformer on the concerned side, the **Phase Grp1…3*Current base Val Ph*** global setting parameters can be used for correcting the transformation ratios. The general base values can be set equal to the rated primary current of the power transformer on both sides. The base values for winding 1 and winding 2 are selected with the *Base value Sel Wnd 1* and *Base value Sel Wnd 2* setting parameters.

4.3.1.7 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.3.1.8 Signals

Table 550: TR2PTDF Input signals

Name	Type	Default	Description
I3P1	GROUP SIGNAL	-	Three phase group signal for current inputs from winding 1
I3P2	GROUP SIGNAL	-	Three phase group signal for current inputs from winding 2
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR_LS	BOOLEAN	0	Blocks operate outputs from biased stage
BLK_OPR_HS	BOOLEAN	0	Blocks operate outputs from instantaneous stage
TAP_POS	INTEGER	0	Present tap position reading (integer)
TAP_POS_IV	BOOLEAN	0	Tap position invalidity

Table 551: TR2PTDF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal, combined (all phases, both stages)
OPR_A	BOOLEAN	Operate signal phase A
OPR_B	BOOLEAN	Operate signal phase B
OPR_C	BOOLEAN	Operate signal phase C
OPR_LS	BOOLEAN	Operate signal from low set (biased) stage
OPR_HS	BOOLEAN	Operate signal from high set (instantaneous) stage
BLKD2H	BOOLEAN	Status from 2nd harmonic restraint block, combined
BLKD2H_A	BOOLEAN	Status from 2nd harmonic restraint block, phase A
BLKD2H_B	BOOLEAN	Status from 2nd harmonic restraint block, phase B
BLKD2H_C	BOOLEAN	Status from 2nd harmonic restraint block, phase C
BLKD5H	BOOLEAN	Status from 5th harmonic restraint blocking, combined
BLKD5H_A	BOOLEAN	Status from 5th harmonic restraint blocking, phase A
BLKD5H_B	BOOLEAN	Status from 5th harmonic restraint blocking, phase B
BLKD5H_C	BOOLEAN	Status from 5th harmonic restraint blocking, phase C
BLKDWAV	BOOLEAN	Status from waveform blocking, combined
BLKDWAV_A	BOOLEAN	Status from waveform blocking, phase A
BLKDWAV_B	BOOLEAN	Status from waveform blocking, phase B
BLKDWAV_C	BOOLEAN	Status from waveform blocking, phase C

4.3.1.9 Settings

Table 552: TR2PTDF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Restraint mode	2.h & 5.h & wav Waveform 2.h & waveform 5.h & waveform	-	-	2.h & 5.h & wav	Selects what harmonic blocking methods are in use
High operate value	500 - 3000	%	10	1000	Instantaneous stage setting
Low operate value	5 - 50	%	1	20	Basic setting for stabilized operation
Slope section 2	10 - 50	%	1	30	Slope of the second line of the operating characteristics
End section 2	100 - 500	%	1	150	Turn-point between sections 2 and 3 of the characteristics
Start value 2.H	7 - 20	%	1	15	2. harmonic blocking ratio
Start value 5.H	10 - 50	%	1	35	5. harmonic blocking ratio

Table 553: TR2PTDF Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Stop value 5.H	10 - 50	%	1	35	5. harmonic deblocking ratio
Enable high set	No Yes	-	-	Yes	Enable instantaneous (high set) stage
Harmonic deblock 2.H	Not allowed Allowed	-	-	Allowed	2. harmonic deblocking in case of switch on to fault
Harmonic deblock 5.H	Not allowed Allowed	-	-	Not allowed	5. harmonic deblocking in case of severe overvoltage

Table 554: TR2PTDF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Clock number	Clk Num 0 Clk Num 1 Clk Num 2 Clk Num 4 Clk Num 5 Clk Num 6 Clk Num 7 Clk Num 8 Clk Num 10 Clk Num 11	-	-	Clk Num 0	Phase shift between winding1 and winding 2 (clock number)
Winding 1 type	Y YN D Z ZN	-	-	Y	Connection of the winding 1

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Winding 2 type	Y YN D Z ZN	-	-	Y	Connection of the winding 2
CT connection type	Type 1 Type 2	-	-	Type 1	CT connection type
Zro A elimination	Not eliminated Winding 1 Winding 2 Winding 1 and 2	-	-	Not eliminated	Elimination of the zero-sequence current

Table 555: TR2PTDF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Wnd 1	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector winding 1, phase
Base value Sel Wnd 2	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 2	Base value selector winding 2, phase
Step of tap	0.60 - 9.00	%	0.01	1.50	The change in voltage corresp. one step of the tap changer
Tapped winding	Not in use Winding 1 Winding 2	-	-	Not in use	The winding where the tap changer is connected to.
Max winding tap	-36 - 36	-	1	0	The tap pos resulting maximum of effective winding turns
Min winding tap	-36 - 36	-	1	36	The tap pos resulting minimnum of effective winding turns
Tap nominal	-36 - 36	-	1	18	The nominal position of the tap changer

4.3.1.10 Measured values

Table 556: TR2PTDF Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR_LS	BOOLEAN	0	Blocks operate outputs from biased stage
BLK_OPR_HS	BOOLEAN	0	Blocks operate outputs from instantaneous stage
TAP_POS	INTEGER	0	Present tap position reading (integer)
TAP_POS_IV	BOOLEAN	0	Tap position invalidity

4.3.1.11 Monitored data

Table 557: TR2PTDF Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal phase A
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal phase B
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal phase C
OPR_LS	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal from low set (biased) stage
OPR_HS	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal from high set (instantaneous) stage
BLKD2H_A	BOOLEAN	0=FALSE 1=TRUE	-	Status from 2nd harmonic restraint block, phase A
BLKD2H_B	BOOLEAN	0=FALSE 1=TRUE	-	Status from 2nd harmonic restraint block, phase B
BLKD2H_C	BOOLEAN	0=FALSE 1=TRUE	-	Status from 2nd harmonic restraint block, phase C
BLKD5H_A	BOOLEAN	0=FALSE 1=TRUE	-	Status from 5th harmonic restraint blocking, phase A
BLKD5H_B	BOOLEAN	0=FALSE 1=TRUE	-	Status from 5th harmonic restraint blocking, phase B
BLKD5H_C	BOOLEAN	0=FALSE 1=TRUE	-	Status from 5th harmonic restraint blocking, phase C
BLKDWAV_A	BOOLEAN	0=FALSE 1=TRUE	-	Status from waveform blocking, phase A
BLKDWAV_B	BOOLEAN	0=FALSE 1=TRUE	-	Status from waveform blocking, phase B
BLKDWAV_C	BOOLEAN	0=FALSE 1=TRUE	-	Status from waveform blocking, phase C
I_AMPL_A1	REAL	-	-	Compensated current amplitude phase A, winding 1
I_AMPL_B1	REAL	-	-	Compensated current amplitude phase B, winding 1
I_AMPL_C1	REAL	-	-	Compensated current amplitude phase C, winding 1
I_AMPL_A2	REAL	-	-	Compensated current amplitude phase A, winding 2
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
I_AMPL_B2	REAL	-	-	Compensated current amplitude phase B, winding 2
I_AMPL_C2	REAL	-	-	Compensated current amplitude phase C, winding 2
ID_A	REAL	-	-	Differential current phase A
ID_B	REAL	-	-	Differential current phase B
ID_C	REAL	-	-	Differential current phase C
IB_A	REAL	-	-	Bias current phase A
IB_B	REAL	-	-	Biasing current phase B
IB_C	REAL	-	-	Biasing current phase C
I_ANGL_A1_B1	REAL	-	deg	Current phase angle phase A – phase B, winding 1
I_ANGL_B1_C1	REAL	-	deg	Current phase angle phase B – phase C, winding 1
I_ANGL_C1_A1	REAL	-	deg	Current phase angle phase C – phase A, winding 1
I_ANGL_A2_B2	REAL	-	deg	Current phase angle phase A – phase B, winding 2
I_ANGL_B2_C2	REAL	-	deg	Current phase angle phase B – phase C, winding 2
I_ANGL_C2_A2	REAL	-	deg	Current phase angle phase C – phase A, winding 2
I_ANGL_A1_A2	REAL	-	deg	Current phase angle diff between winding 1 and 2, phase A
I_ANGL_B1_B2	REAL	-	deg	Current phase angle diff between winding 1 and 2, phase B
I_ANGL_C1_C2	REAL	-	deg	Current phase angle diff between winding 1 and 2, phase C
I_2H_RAT_A	REAL	-	-	Differential current second harmonic ratio, phase A
I_2H_RAT_B	REAL	-	-	Differential current second harmonic ratio, phase B
I_2H_RAT_C	REAL	-	-	Differential current second harmonic ratio, phase C

4.3.1.12 Technical data

Table 558: TR2PTDF Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × I_n
Operate time[1)2)]	Biased low stage Instantaneous high stage	Typically 35 ms (±5 ms) Typically 17 ms (±5 ms)
Reset time		<30 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Suppression of harmonics		DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

1) Differential current before fault = 0.0 × I_n, f_n = 50 Hz. Injected differential current = 2.0 × set operate value
2) Includes the delay of the output contact value and f_n = 50 Hz

4.3.1.13 Technical revision history

Table 559: TR2PTDF technical revision history

Technical revision	Change
B	Internal improvements

4.3.2 Low impedance restricted earth-fault protection LREFPNDF

4.3.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Low impedance restricted earth-fault protection	LREFPNDF	dIoLo>	87NL

4.3.2.2 Function block

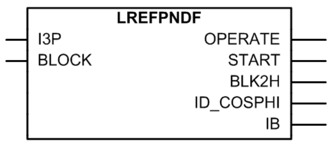


Figure 291: Function block

4.3.2.3 Functionality

The stabilized restricted low-impedance earth-fault protection LREFPNDF for a two-winding transformer is based on the numerically stabilized differential current principle. No external stabilizing resistor or non-linear resistor are required.

The fundamental components of the currents are used for calculating the residual current of the phase currents, the neutral current, differential currents and stabilizing currents. The operating characteristics are according to the definite time.

LREFPNDF contains a blocking functionality. The neutral current second harmonic is used for blocking during the transformer inrush situation. Blocking deactivates all outputs and resets timers.

4.3.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the stabilized restricted low-impedance earth-fault protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

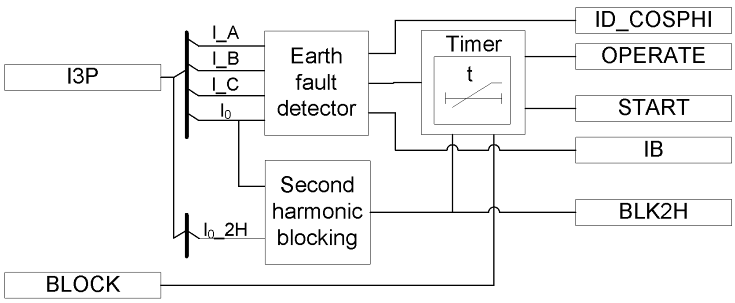


Figure 292: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Earth-fault detector

The operation is based on comparing the amplitude and the phase difference between the sum of the fundamental frequency component of the phase currents (ΣI, residual current) and the fundamental frequency component of the neutral current (Io) flowing in the conductor between the transformer or generator's neutral point and earth. The differential current is calculated as the absolute value of the difference between the residual current, that is, the sum of the fundamental frequency components of the phase currents I_A, I_B and I_C, and the neutral current. The directional differential current ID_COSPHI is the product of the differential current and cosφ. The value is available in the monitored data view.

$$ID\_COSPHI = (|\overline{\Sigma I} - \overline{Io}|) \times \cos\varphi$$

(Equation 87)

$\overline{\Sigma I}$	Residual current
φ	Phase difference between the residual and neutral currents
$\overline{Io}$	Neutral current

An earth fault occurring in the protected area, that is, between the phase CTs and the neutral connection CT, causes a differential current. The directions, that is, the phase difference of the residual current and the neutral current, are considered in the operation criteria to maintain selectivity. A correct value for *CT connection type* is determined by the connection polarities of the current transformer.

The current transformer ratio mismatch between the phase current transformer and neutral current transformer (residual current in the analog input settings) is taken into account by the function with the properly set analog input setting values.

During an earth fault in the protected area, the currents ΣI and Io are directed towards the protected area. The factor cosφ is 1 when the phase difference of the residual current and the neutral current is 180 degrees, that is, when the currents are in opposite direction at the earth faults within the protected area. Similarly, ID_COSPHI is specified to be 0 when the phase difference between the residual current and the neutral current is less than 90 degrees in situations where there is no earth fault in the protected area. Thus tripping is possible only when the phase difference between the residual current and the neutral current is above 90 degrees.

The stabilizing current IB used by the stabilizing current principle is calculated as an average of the phase currents in the windings to be protected. The value is available in the monitored data view.

$$IB = \frac{|\overline{I\_A}| + |\overline{I\_B}| + |\overline{I\_C}|}{3}$$

(Equation 88)

The *Operate value* setting is used for defining the characteristics of the function. The differential current value required for tripping is constant at the stabilizing current values 0.0 < IB/In < 1.0, where In is the nominal current and refers to the nominal of the phase current inputs in this function. When the stabilizing current is higher than 1.0, the slope of the operation characteristic (ID/IB) is constant at 50 percent.

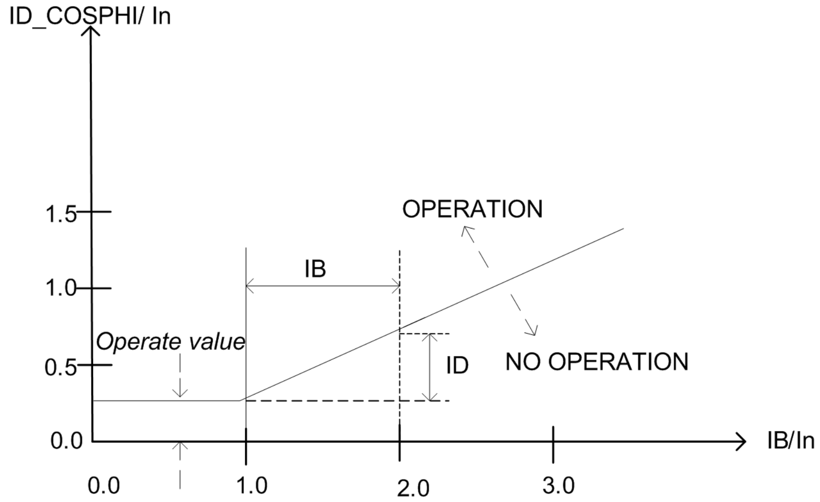


Figure 293: Operating characteristics of the stabilized earth-fault protection function

Different operating characteristics are possible based on the set *Operate value*.

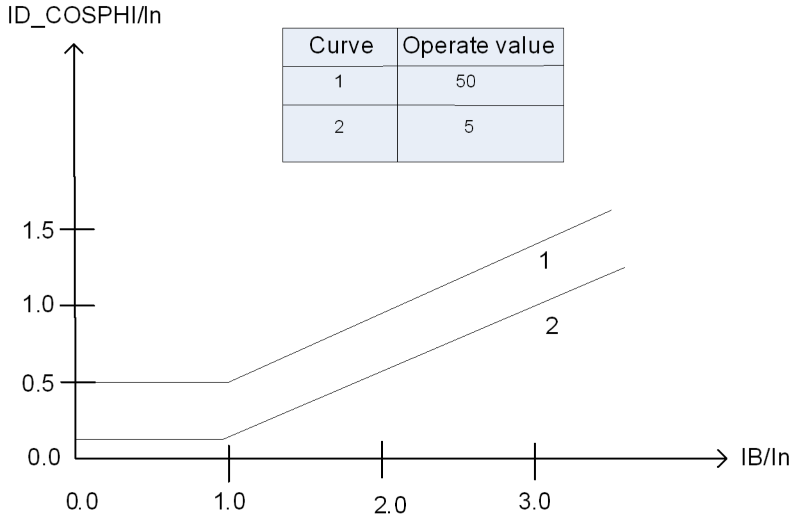


Figure 294: Setting range of the operating characteristics for the stabilized differential current principle of the earth-fault protection function

To calculate the directional differential current ID_COSPHI, the fundamental frequency amplitude of both the residual and neutral currents has to be above 4 percent of In. If neither or only one condition is fulfilled at a time, the cosφ term is forced to 1. After the conditions are fulfilled, both currents must stay above 2 percent of In to allow the continuous calculation of the cosφ term.

Second harmonic blocking

This module compares the ratio of the current second harmonic (I_0_2H) and I_0 to the set value *Start value 2.H*. If the ratio (I_0_2H / I_0) value exceeds the set value, the BLK2H output is activated.

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of a transformer running in parallel with the protected transformer connected to the network.

The second harmonic blocking is disabled when *Restraint mode* is set to "None" and enabled when set to "Harmonic2".

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Minimum operate time*, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the reset timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The activation of the BLOCK signal resets the timer and deactivates the START and OPERATE outputs. The activation of the output of the second harmonic blocking signal BLK2H deactivates the OPERATE output.

4.3.2.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.3.2.6 Application

An earth-fault protection using an overcurrent element does not adequately protect the transformer winding in general and the star-connected winding in particular.

The restricted earth-fault protection is mainly used as a unit protection for the transformer windings. LREFPNDF is a sensitive protection applied to protect the star-connected winding of a transformer. This protection system remains stable for all the faults outside the protected zone.

LREFPNDF provides higher sensitivity for the detection of earth faults than the overall transformer differential protection. This is a high-speed unit protection scheme applied to the star-connected winding of the transformer. LREFPNDF is normally applied when the transformer is earthed solidly or through low-impedance resistor (NER). LREFPNDF can be also applied on the delta side of the transformer if an earthing transformer (zig-zag transformer) is used there. In LREFPNDF, the difference of the fundamental component of all three phase currents and the neutral current is provided to the differential element to detect the earth fault in the transformer winding based on the numerical stabilized differential current principle.

Connection of current transformers

The connections of the main CTs are designated as "Type 1" and "Type 2". In case the earthings of the current transformers on the phase side and the neutral side are both either inside or outside the area to be protected, the setting parameter *CT connection type* is "Type 1".

If the earthing of the current transformers on the phase side is inside the area to be protected and the neutral side is outside the area to be protected or if the earthing on the phase side is outside the area and on the neutral side inside the area, the setting parameter CT connection type is "Type 2".

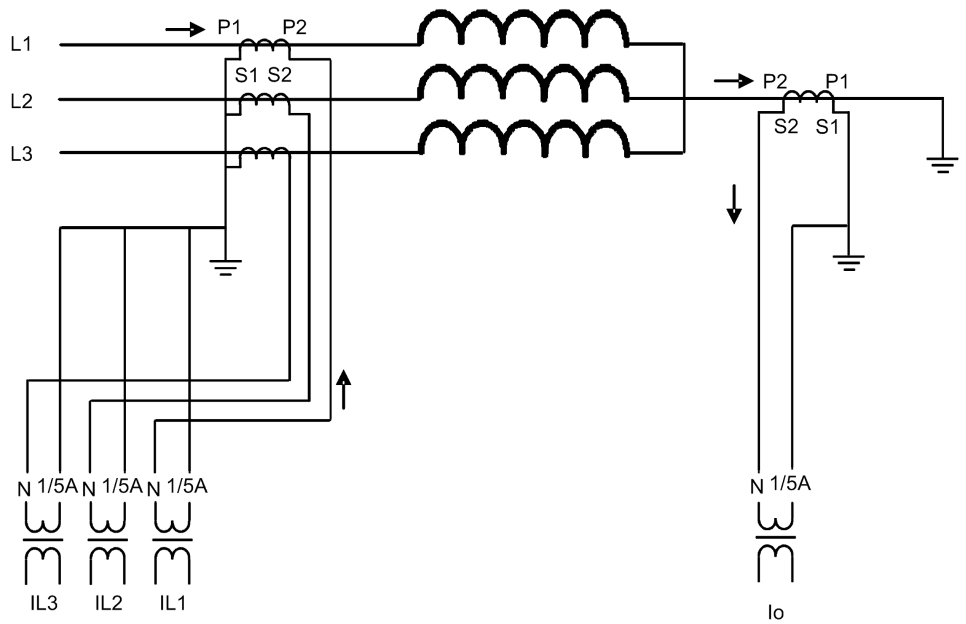


Figure 295: Connection of the current transformers of Type 1. The connected phase currents and the neutral current have opposite directions at an external earth-fault situation.

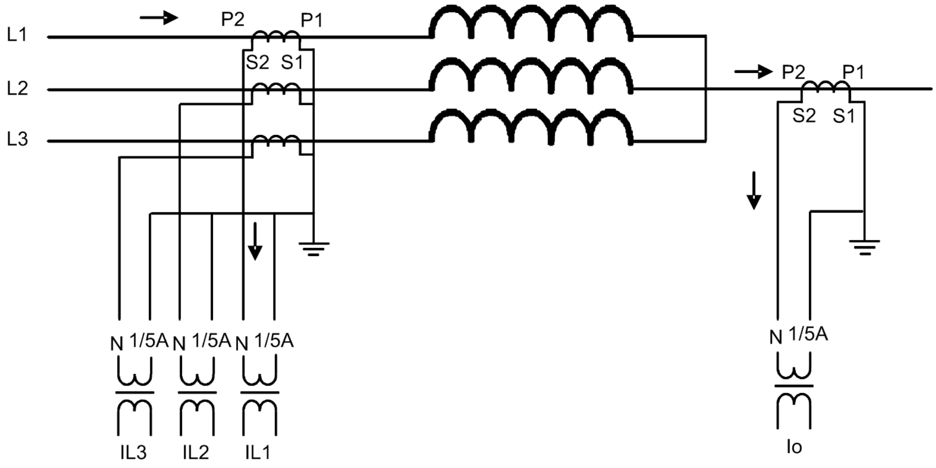


Figure 296: Connection of the current transformers of Type 2. The phase currents and the neutral current have equal directions at an external earth-fault situation.

Internal and external faults

LREFPNDF does not respond to any faults outside the protected zone. An external fault is detected by checking the phase angle difference of the neutral current and the sum of the phase currents. When the difference is less than 90 degrees, the operation is internally restrained or blocked. Hence the protection is not sensitive to an external fault.

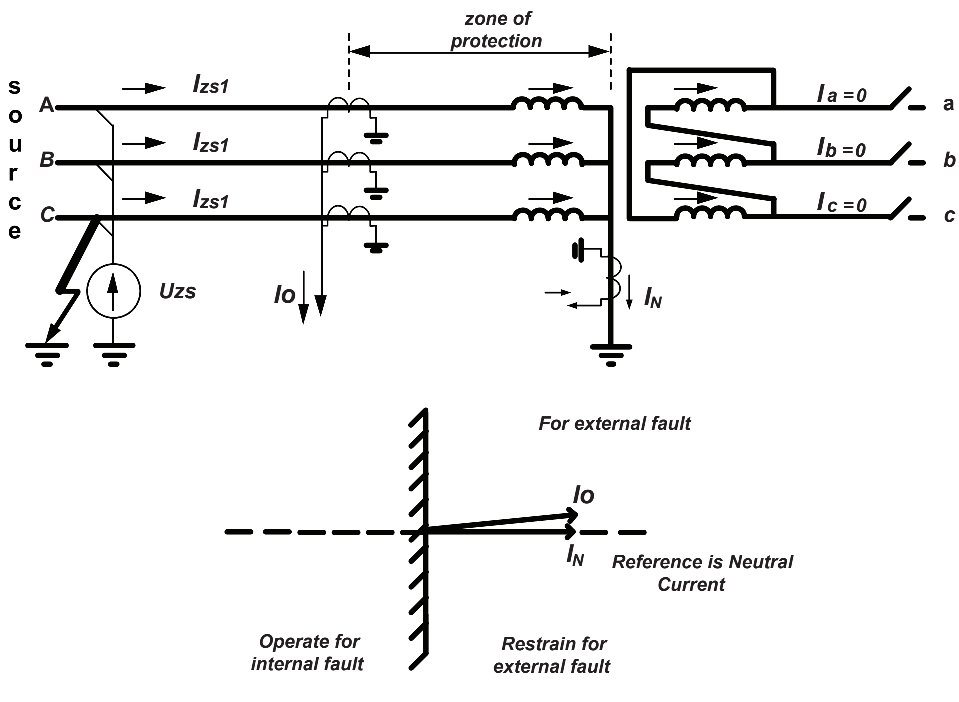


Figure 297: Current flow in all the CTs for an external fault

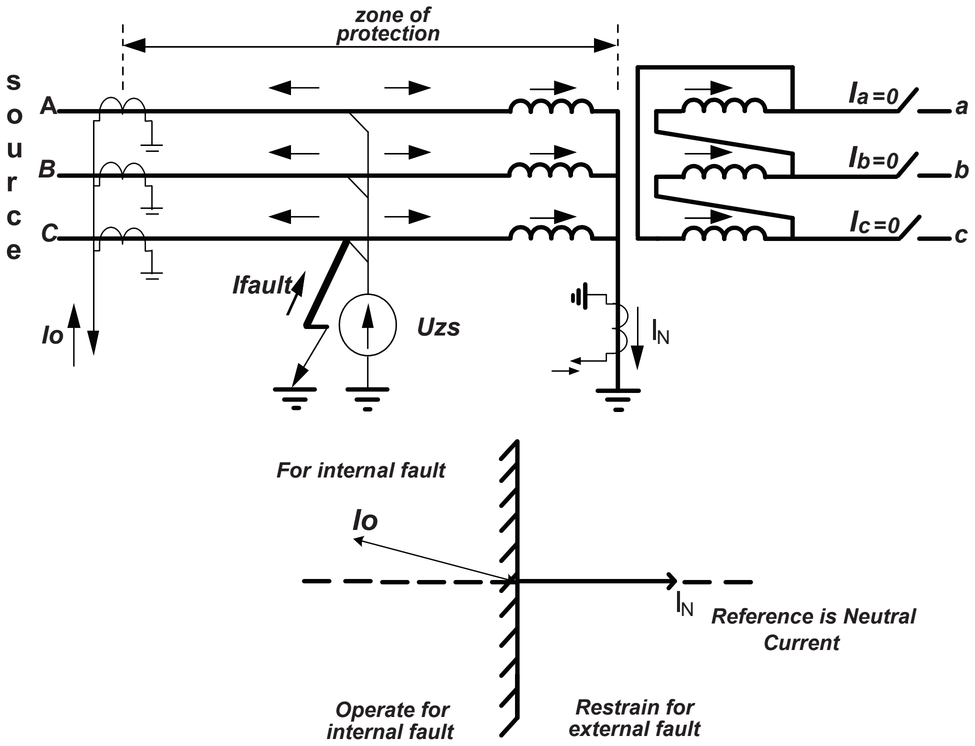


Figure 298: Current flow in all the CTs for an internal fault

LREFPNDF does not respond to phase-to-phase faults either, as in this case the fault current flows between the two line CTs and so the neutral CT does not experience this fault current.

Blocking based on the second harmonic of the neutral current

The transformer magnetizing inrush currents occur when the transformer is energized after a period of de-energization. The inrush current can be many times the rated current, and the halving time can be up to several seconds. For the differential IED, the inrush current represents the differential current, which causes the IED to operate almost always when the transformer is connected to the network. Typically, the inrush current contains a large amount of second harmonics.

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of a transformer running in parallel with the protected transformer already connected to the network.

Blocking the starting of the restricted earth-fault protection at the magnetizing inrush is based on the ratio of the second harmonic and the fundamental frequency amplitudes of the neutral current Io_2H / Io. Typically, the second harmonic content of the neutral current at the magnetizing inrush is higher than that of the phase currents.

4.3.2.7 Signals

Table 560: LREFPNDF Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase currents
BLOCK	BOOLEAN	0	Blocks all the output signals

Table 561: LREFPNDF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Low impedance restricted earthfault protection operate
START	BOOLEAN	Low impedance restricted earthfault protection start
BLK2H	BOOLEAN	Signal to indicate second harmonic blocking when the second harmonic has been enabled
ID_COSPHI	REAL	Directional differential current Id cosphi
IB	REAL	Bias current

4.3.2.8 Settings

Table 562: LREFPNDF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operate value	5 - 50	%	1	5	Min ratio of differential and nominal current for a trip

Table 563: LREFPNDF Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Restraint mode	None 2nd harmonic	-	-	2nd harmonic	Setting to allow for second harmonic blocking
Start value 2.H	10 - 50	%	1	30	Ratio to cause the second harmonic blocking
Minimum operate time	0.040 - 300.000	s	0.001	0.040	Minimum operate time

Table 564: LREFPNDF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
CT connection type	Type 1 Type 2	-	-	Type 2	Signal to compensate for the reverse polarity connections

Table 565: LREFPNDF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.3.2.9 Measured values

Table 566: LREFPNDF Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0.0	current amplitude (DFT) phase 1
I_AMPL_B	REAL	0.0	current amplitude (DFT) phase 2
I_AMPL_C	REAL	0.0	current amplitude (DFT) phase 3
I0_AMPL	REAL	0.0	Current amplitude (DFT) Neutral
I0_ANG	REAL	0.0	Angle of the current in neutral
I0_2H_AMPL	REAL	0.0	Amplitude of second harmonic component of neutral current
BLOCK	BOOLEAN	0	Blocks all the output signals

4.3.2.10 Monitored data

Table 567: LREFPNDF Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Low impedance restricted earthfault protection operate
START	BOOLEAN	0=FALSE 1=TRUE	-	Low impedance restricted earthfault protection start
BLK2H	BOOLEAN	0=FALSE 1=TRUE	-	Signal to indicate second harmonic blocking when the second harmonic has been enabled
ID_COSPHI	REAL	-	A	Directional differential current Id cosphi
IB	REAL	-	A	Bias current
START_DUR	REAL	-	%	Start duration in percentage of the total operating time

4.3.2.11 Technical data

Table 568: LREFPNDF Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × I_n
Start time[1)2)]	I_{Fault} = 2.0 × set *Operate value* I_{Fault} = 10.0 × set *Operate value*	Typically 18 ms (±5 ms) Typically 12 ms (±5 ms)
Reset time		<50 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5, …

1) Current before fault = 0.0 × I_n, f_n = 50 Hz
2) Includes the delay of the signal output contact

4.3.2.12 Technical revision history

Table 569: LREFPNDF technical revision history

Technical revision	Change
B	*Base value Sel Res* setting is removed.

4.3.3 High impedance restricted earth-fault protection HREFPDIF

4.3.3.1 Identification

Functional description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High impedance restricted earth-fault protection	HREFPDIF	dIoHi>	87NH

4.3.3.2 Function block

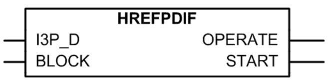


Figure 299: Function block

4.3.3.3 Functionality

The high-impedance restricted earth-fault protection HREFPDIF is used for the restricted earth-fault protection of generators and power transformers based on the high-impedance principle.

HREFPDIF starts when the ID_N, the differential neutral current, exceeds the set limit. HREFPDIF operates with the DT characteristic.

HREFPDIF contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.3.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the high impedance restricted earth-fault protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

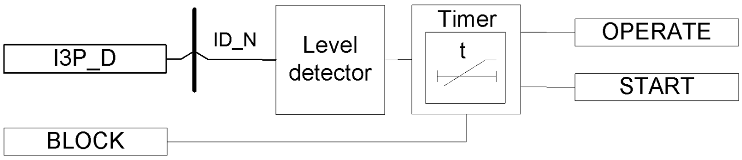


Figure 300: Functional module diagram. Group signal I3P_D is used for feeding the necessary analog signals to the function.

Level detector

The level detector compares the differential neutral current to the *Operate value* setting. If the ID_N value exceeds the set *Operate value*, the level detector sends an enable signal to the timer module to start the definite timer.

Timer

Once activated, the timer activates the `START` output. The timer characteristic is according to DT. When the operation timer has reached the value set by *Minimum operate time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The activation of the BLOCK signal resets the timer and deactivates the START and OPERATE outputs.

4.3.3.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the residual current or voltage-related settings, for example, "*Residual Grp 1*", "*Residual Grp 2*" and "*Residual Grp 3*". One of the groups to be used with the "Base value Sel Res" setting must be selected.

4.3.3.6 Application

In solidly earthed systems, the restricted earth-fault protection is always deployed as a complement to the normal transformer differential protection. The advantage of the restricted earth-fault protection is its high sensitivity. Sensitivities of close to 1.0 percent can be achieved, whereas normal differential IEDs have their minimum sensitivity in the range of 5 to 10 percent. The level for HREFPDIF is dependent on the current transformers' magnetizing currents. The restricted earth-fault protection is also very fast due to the simple measuring principle as it is a unit type of protection.

The differences in measuring principle limit the biased differential IED's possibility to detect the earth faults. Such faults are then only detected by the restricted earth-fault function.

The restricted earth-fault IED is connected across each directly or to low-ohmic earthed transformer winding. If the same CTs are connected to other IEDs, separate cores are to be used.

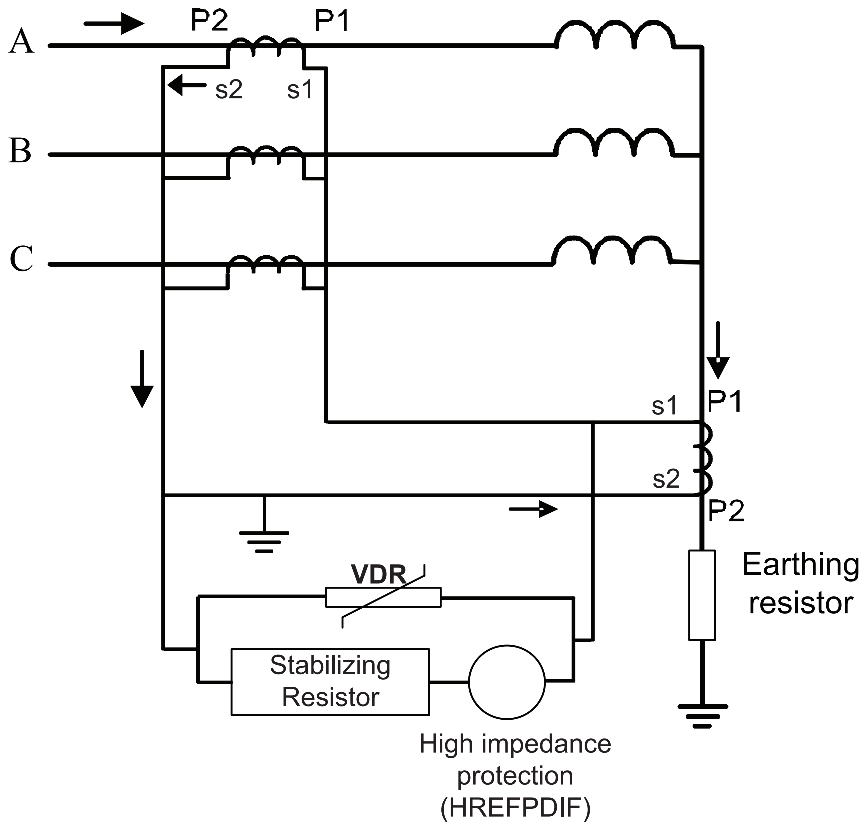


Figure 301: Connection scheme for the restricted earth-fault protection according to the high-impedance principle

High-impedance principle

High-impedance principle is stable for all types of faults outside the zone of protection. The stabilization is obtained by a stabilizing resistor in the differential circuit. This method requires that all the CTs used have a similar magnetizing characteristic, same ratio and relatively high knee point voltage. CTs on each sides are connected in parallel along with a relay-measuring branch as shown in Figure 302. The measuring branch is a series connection of stabilizing resistor and IED.

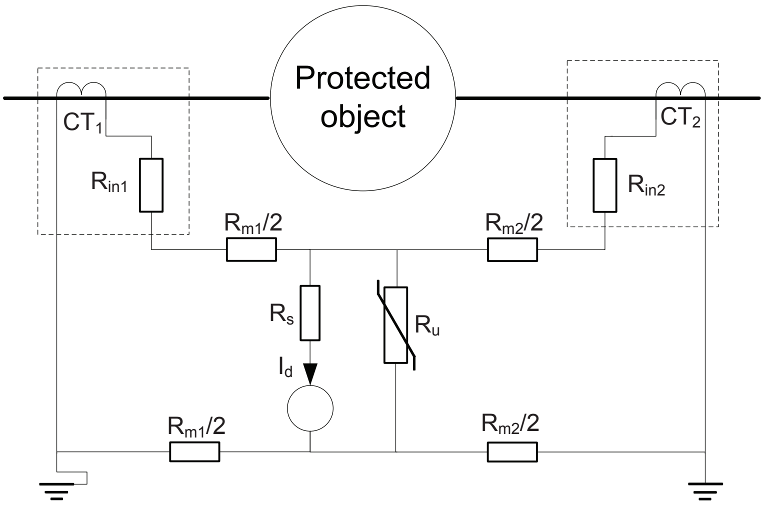


Figure 302: High-impedance principle

The stability of the protection is based on the use of the stabilizing resistor (Rs) and the fact that the impedance of the CT secondary quickly decreases as the CT saturates. The magnetization reactance of a fully saturated CT goes to zero and the impedance is formed only by the resistance of the winding (R_{in}) and lead resistance (R_m).

The CT saturation causes a differential current which now has two paths to flow: through the saturated CT because of the near-zero magnetizing reactance and through the measuring branch. The stabilizing resistor is selected as such that the current in the measuring branch is below the relay operating current during out-of-zone faults. As a result, the operation is stable during the saturation and can still be sensitive at the non-saturated parts of the current waveform as shown in Figure 303.

In case of an internal fault, the fault current cannot circulate through the CTs but it flows through the measuring branch and the protection operates. Partial CT saturation can occur in case of an internal fault, but the non-saturated part of the current waveform causes the protection to operate.

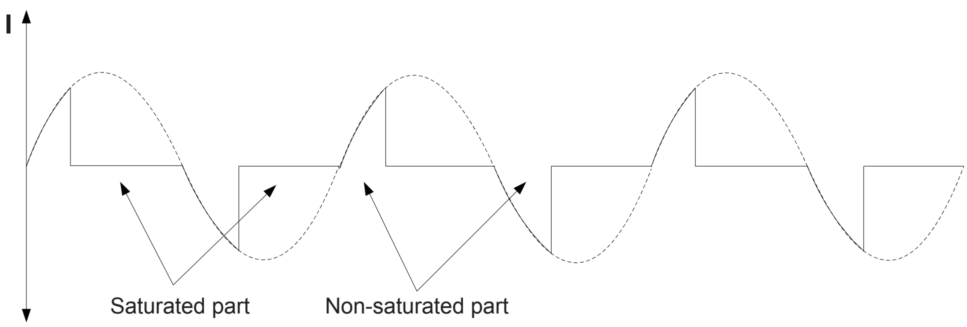


Figure 303: Secondary waveform of a saturated CT

At internal fault, the secondary circuit voltage can easily exceed the isolation voltage of the CTs, connection wires and IED. To limit this voltage, a voltage-dependent resistor VDR is used as shown in Figure 302.

The whole scheme, that is, the stabilizing resistor, voltage-dependent resistor and wiring, must be adequately maintained (operation- and insulation-tested regularly) to be able to withstand the high-voltage pulses which appear during an internal fault throughout the lifetime of the equipment. Otherwise, during a fault within the zone of protection, any flashover in the CT secondary circuits or in any other part of the scheme may prevent a correct operation of the high-impedance differential function.

4.3.3.7 The measuring configuration

The external measuring configuration is composed of four current transformers measuring the currents and a stabilizing resistor. A varistor is needed if high overvoltages are expected.

The value of the stabilizing resistor is calculated with the formula:

$$R_s = \frac{U_s}{I_{rs}}$$

(Equation 89)

R_s the resistance of the stabilizing resistor

U_s the stabilizing voltage of the IED

I_{rs} the value of the *Low operate value* setting

The stabilizing voltage is calculated with the formula:

$$U_s = \frac{I_{k\max}}{n}(R_{in} + R_m)$$

(Equation 90)

I_{kmax} the highest through-fault current

n the turns ratio of the CT

R_{in} the secondary internal resistance of the CT

R_m the resistance of the longest loop of secondary circuit

Additionally, it is required that the current transformers' knee-point voltages U_k are at least twice the stabilizing voltage value U_s.

4.3.3.8 Recommendations for current transformers

The sensitivity and reliability of the protection depends a lot on the characteristics of the current transformers. The CTs must have an identical transformation ratio. It is recommended that all current transformers have an equal burden and characteristics and are of same type, preferably from the same manufacturing batch, that is, an identical construction should be used. If the CT characteristics and burden values are not equal, calculation for each branch in the scheme should be done separately and the worst-case result is then used.

First, the stabilizing voltage, that is, the voltage appearing across the measuring branch during the out-of-zone fault, is calculated assuming that one of the parallel connected CT is fully saturated. The stabilizing voltage can be calculated with the formula

$$U_s = \frac{I_{k\max}}{n}(R_{in} + R_m)$$

(Equation 91)

I_{kmax}	the highest through-fault current in primary amps. The highest earth-fault or short circuit current during the out-of-zone fault.
n	the turns ratio of the CT
R_{in}	the secondary internal resistance of the CT in ohms
R_m	the resistance (maximum of R_{in} + R_m) of the CT secondary circuit in ohms

The current transformers must be able to force enough current to operate the IED through the differential circuit during a fault condition inside the zone of protection. To ensure this, the knee point voltage U_{kn} should be at least two times higher than the stabilizing voltage U_s.

The required knee point voltage U_{kn} of the current transformer is calculated using the formula

$$U_{kn} \geq 2 \times U_s$$

(Equation 92)

U_{kn}	the knee point voltage
U_s	the stabilizing voltage

The factor two is used when no delay in the operating time of the protection in any situation is acceptable. To prevent the knee point voltage from growing too high, it is advisable to use current transformers, the secondary winding resistance of which is of the same size as the resistance of the measuring loop.

As the impedance of the IED alone is low, a stabilizing resistor is needed. The value of the stabilizing resistor is calculated with the formula

$$R_s = \frac{U_s}{I_{rs}}$$

(Equation 93)

R_s the resistance of the stabilizing resistor

U_s the stabilizing voltage of the IED

I_{rs} the value of the *Operate value* setting in secondary amps.

The stabilizing resistor should be capable to dissipate high energy within a very short time; therefore, the wire wound-type resistor should be used. Because of the possible CT inaccuracy, which might cause some current through the stabilizing resistor in a normal load situation, the rated power should be 25 W minimum.

If U_{kn} is high or the stabilizing voltage is low, a resistor with a higher power rating is needed. Often resistor manufacturers allow 10 times rated power for 5 seconds. Thus the power of the resistor can be calculated with the equation

$$\frac{U_{kn}^2}{R_s \times 10}$$

(Equation 94)

The actual sensitivity of the protection is affected by the IED setting, the magnetizing currents of the parallel connected CTs and the shunting effect of the voltage-dependent resistor (VDR). The value of the primary current I_{prim} at which the IED operates at a certain setting can be calculated with the formula

$$I_{prim} = n \times (I_{rs} + I_u + m \times I_m)$$

(Equation 95)

I_{prim} the primary current at which the protection is to start

n the turn ratio of the current transformer

I_{rs} the value of the *Operate value* setting

I_u the leakage current flowing through the VDR at the U_s voltage

m the number of current transformers included in the protection per phase (=4)

I_m the magnetizing current per current transformer at the U_s voltage

The I_e value given in many catalogs is the excitation current at the knee point voltage. Assuming $U_{kn} \approx 2 \text{ x } U_s$, the value of $I_m \approx \frac{I_e}{2}$ gives an approximate value for Equation 95.

The selection of current transformers can be divided into procedures:

1. In principle, the highest through-fault should be known. However, when the necessary data are not available, approximates can be used:
   - Small power transformers: I_{kmax} = 16 x I_n (corresponds to z_k = 6% and infinite grid)
   - Large power transformers: I_{kmax} = 12 x I_n (corresponds to z_k = 8% and infinite grid)
   - Generators and motors: I_{kmax} = 6 x I_n

   Where I_n = rated current and z_k = short circuit impedance of the protected object
2. The rated primary current I_{1n} of the CT has to be higher than the rated current of the machine.
   The choice of the CT also specifies R_{in}.
3. The required U_{kn} is calculated with Equation 92. If the U_{kn} of the CT is not high enough, another CT has to be chosen. The value of the U_{kn} is given by the manufacturer in the case of Class X current transformers or it can be estimated with Equation 96.
4. The sensitivity I_{prim} is calculated with Equation 95. If the achieved sensitivity is sufficient, the present CT is chosen. If a better sensitivity is needed, a CT with a bigger core is chosen.

If other than Class X CTs are used, an estimate for U_{kn} is calculated with the equation

$$U_{kn} = 0.8 \times F_n \times I_{2n} \times \left(R_{in} + \frac{S_n}{I_{2n}^2} \right)$$

(Equation 96)

F_n	the rated accuracy limit factor corresponding to the rated burden S_n
I_{2n}	the rated secondary current of the CT
R_{in}	the secondary internal resistance of the CT
S_n	the volt-amp rating of the CT

The formulas are based on choosing the CTs according to Equation 92, which results an absolutely stable scheme. In some cases, it is possible to achieve stability with knee point voltages lower than stated in the formulas. The conditions in the network, however, have to be known well enough to ensure the stability.

1. If $U_k \geq 2$ x U_s, fast IED operation is secure.
2. If $U_k \geq 1.5$ x U_s and < 2 x U_s, IED operation can be slightly prolonged and should be studied case by case.
   If $U_k < 1.5$ x U_s, the IED operation is jeopardized. Another CT has to be chosen.

The need for the VDR depends on certain conditions.

First, voltage U_{max}, ignoring the CT saturation during the fault, is calculated with the equation

$$U_{max} = \frac{I_{k\,max\,in}}{n} \times \left(R_{in} + R_m + R_s\right) \approx \frac{I_{k\,max\,in}}{n} \times R_s$$

(Equation 97)

I_{kmaxin}	the maximum fault current inside the zone, in primary amps
n	the turns ration of the CT
R_{in}	the internal resistance of the CT in ohms
R_m	the resistance of the longest loop of the CT secondary circuit, in ohms
R_s	the resistance of the stabilized resistor, in ohms

Next, the peak voltage û, which includes the CT saturation, is estimated with the formula (given by P.Mathews, 1955)

$$\hat{u} = 2\sqrt{2U_{kn}\left(U_{max} - U_{kn}\right)}$$

(Equation 98)

U_{kn} the knee point voltage of the CT

The VDR is recommended when the peak voltage û ≥ 2kV, which is the insulation level for which the IED is tested.

If R_s was smaller, the VDR could be avoided. However, the value of R_s depends on the IED operation current and stabilizing voltage. Thus, either a higher setting must be used in the IED or the stabilizing voltage must be lowered.

4.3.3.9 Signals

Table 570: HREFPDIF Input signals

Name	Type	Default	Description
I3P_D	GROUP SIGNAL	-	Three phase group signal for differential current inputs
BLOCK	BOOLEAN	0	Block overall function

Table 571: HREFPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	High impedance restricted earthfault protection operate
START	BOOLEAN	High impedance restricted earthfault protection start

4.3.3.10 Settings

Table 572: HREFPDIF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operate value	0.5 - 50.0	%	0.1	0.5	Low operate value, percentage of the nominal current
Minimum operate time	0.020 - 300.000	s	0.001	0.020	Minimum operate time

Table 573: HREFPDIF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

Table 574: HREFPDIF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.3.3.11 Measured values

Table 575: HREFPDIF Measured values

Name	Type	Default	Description
ID_N	REAL	0.0	Differential neutral current
BLOCK	BOOLEAN	0	Block overall function

4.3.3.12 Monitored data

Table 576: HREFPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	High impedance restricted earthfault protection operate
START	BOOLEAN	0=FALSE 1=TRUE	-	High impedance restricted earthfault protection start
START_DUR	REAL	-	%	Start duration in percentage of the total operating time

4.3.3.13 Technical data

Table 577: HREFPDIF Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × I_n
Start time[1)2)]	I_{Fault} = 2.0 × set *Operate value* I_{Fault} = 10.0 × set *Operate value*	Typically 22 ms (±5 ms) Typically 15 ms (±5 ms)
Reset time		<60 ms
Reset ratio		Typically 0.96
Retardation time		<60 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms

1) Current before fault = 0.0 × I_n, f_n = 50 Hz
2) Includes the delay of the signal output contact

4.3.3.14 Technical revision history - HREFPDIF

Table 578: HREFPDIF technical revision history

Technical revision	Change
B	Internal improvements

4.3.4 Stabilized differential protection for machines MPDIF

4.3.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Stabilized differential protection for machines	MPDIF	3dI>G/M	87G/87M

4.3.4.2 Function block

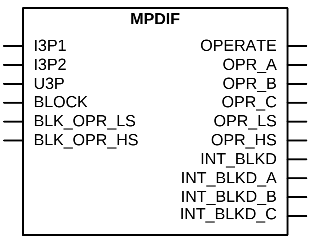


Figure 304: Function block

4.3.4.3 Functionality

Stabilized differential protection for machines MPDIF is a unit protection function. The possibility of internal failures of the machines is relatively low. However, the consequences in terms of cost and production loss are often serious, which makes the differential protection an important protection function.

The stability of the differential protection is enhanced by a DC restraint feature. This feature decreases the sensitivity of the differential protection optionally for a temporary time period to avoid an unnecessary disconnection of the machine during the external faults that have a fault current with high DC currents. MPDIF also includes a CT saturation-based blocking which prevents unnecessary tripping in case of the detection of the magnetizing inrush currents which can be present at the switching operations, overvoltages or external faults.

4.3.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the stabilized differential protection for motors can be described using a module diagram. All the modules in the diagram are explained in the next sections.

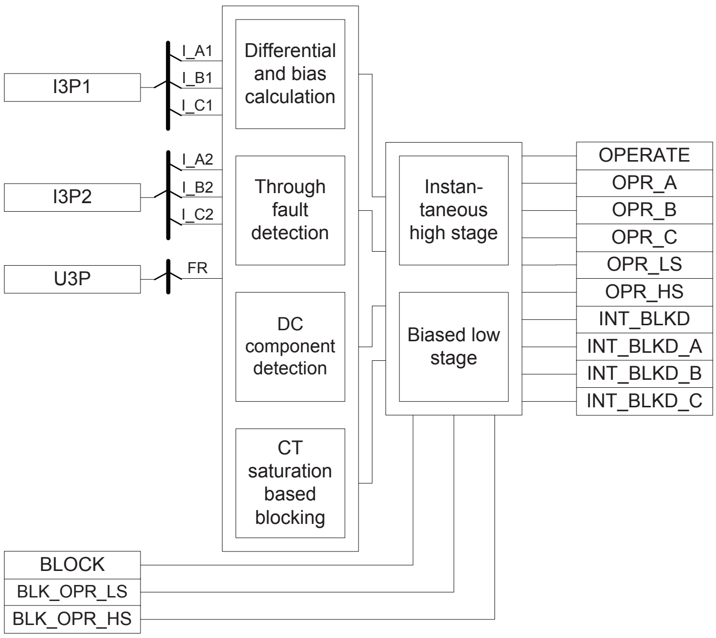


Figure 305: Functional module diagram

Differential and bias calculation

Differential calculation module calculates the differential current. The differential current is the difference in current between the phase and neutral sides of the machine. The phase currents $\bar{I}_1$ and $\bar{I}_2$ denote the fundamental frequency components on the phase and neutral sides of the current. The amplitude of the differential current I_d is obtained using the equation (assuming that the positive direction of the current is towards the machine):

$$I_d = \left|\bar{I}_1 + \bar{I}_2\right|$$

(Equation 99)

During normal conditions, there is no fault in the area protected by the function block, so the currents $\bar{I}_1$ and $\bar{I}_2$ are equal and the differential current $I_d = 0$. However, in practice some differential current exists due to inaccuracies in the current transformer on the phase and neutral sides, but it is very small during normal conditions.

The module calculates the differential current for all three phases.

The low-stage differential protection is stabilized with a bias current. The bias current is also known as the stabilizing current. Stabilization means that the differential current required for tripping increases according to the bias current and the operation characteristics. When an internal fault occurs, the currents on both sides of the protected object are flowing into it. This causes the biasing current to be considerably smaller, which makes the operation more sensitive during internal faults.

The traditional way for calculating the stabilized current is:

$$I_b = \left|\frac{\bar{I}_1 - \bar{I}_2}{2}\right|$$

(Equation 100)

The module calculates the bias current for all three phases.

Generator differential protection should be available already during the starting (acceleration) phase of the generator, so it is recommended to use an adaptive DFT preprocessing block to provide analog input to this function.

Through-fault detection

Through-fault (TF) detection module is for detecting whether the fault is external, that is, going through, or internal. This information is essential for ensuring the correct operation of the protection in case of the CT saturation:

- In a through-fault situation, CTs can saturate because of a high fault current magnitude. Such AC saturation does not happen immediately when the fault begins. Thus, the TF module sees the fault as external because the bias current

is high but the differential current remains low. If the AC saturation then occurs, a CT saturation-based blocking is allowed to work to prevent tripping.
- Normally, the phase angle between the machine neutral and line side CTs is 180 degrees. If an internal fault occurs during a through fault, an angle less than 50 degrees clearly indicates an internal fault and the TF module overrules, that is, deblocks the presence of any blocking due to CT saturation.

CT saturation-based blocking

Higher currents during the motor startup or abnormally high magnetizing currents at an overvoltage (transformer-fed motor) or an external fault may saturate the current transformers. The uneven saturation of the star and line side CTs (for example, due to burden differences) may lead to a differential current which can cause a differential protection to operate. This module blocks the operation of MPDIF biased low stage internally in case of the CT saturation. Once the blocking is activated, it is held for a certain time after the blocking conditions have ceased to be fulfilled.

DC component detection

On detection of a DC component, the function temporarily desensitizes the differential protection. The functioning of this module depends on the *DC restrain Enable* setting. The DC components are continuously extracted from the three instantaneous differential currents. The highest DC component of all three is taken as a kind of DC restraint in a sense that the highest effective, temporary sensitivity of the protection is temporarily decreased as a function of this highest DC offset. The calculated DC restraint current is not allowed to decay (from its highest ever measured value) faster than with a time constant of one second. The value of the temporarily effective sensitivity limit is limited upwards to the rated current of the machine or 3.3 times that of *Low operate value*, whichever is smaller. The temporary extra limit decays exponentially from its maximum value with a time constant of one second.

This feature should be used in case of networks where very long time constants are expected. The temporary sensitivity limit is higher to the set operating characteristics. In other words, the temporary limit has superposed the unchanged operating characteristics and temporarily determines the highest sensitivity of the protection. The temporary sensitivity is less than the sensitivity in section 1 of the operating characteristic and is supposed to prevent an unwanted trip during the external faults with lower currents.

MPDIF uses three-phase voltage U3P for obtaining the actual network frequency. The actual frequency information is needed to calculate the accurate DC component in the current signal.

Biased low stage

The current differential protection needs to be biased because of the possible appearance of a differential current which can be due to something else than an actual fault in the machine. In case of differential protection, a false differential current can be caused by:

- CT errors
- CT saturation at high currents passing through the machine

The differential current caused by CT errors increases at the same percent ratio as the load current.

The high currents passing through the protected object can be caused by the through fault. Therefore, the operation of the differential protection is biased with respect to the load current. In the biased differential protection, the higher the differential current required for the protection of operation, the higher the load current.

Based on the conditions checked from the through-fault module, the DC (component) detection module and the CT saturation-based blocking modules, the biased low-stage module decides whether the differential current is due to the internal faults or some false reason. In case of detection of the TF, DC or CT saturation, the internal differential blocking signal is generated, which in turn blocks the operate signal. In case of internal faults, the operation of the differential protection is affected by the bias current .

The *Low operate value* setting for the stabilized stage of the function block is determined with the equation:

$$Low\,operate\,value = \frac{I_{d1}}{I_n} \cdot 100\%$$

(Equation 101)

The *Slope section 2* is determined correspondingly:

$$Slope\,section\,2 = \frac{I_{d2}}{I_{b2}} \cdot 100\%$$

(Equation 102)

The end of the first section *End section 1* can be set at a desired point within the range of 0 to 100 percent (or % I_n). Accordingly, the end of the second section *End section 2* can be set within the range of 100 percent to 300 percent (or % I_n).

The slope of the operating characteristic for the function block varies in different parts of the range.

In section 1, where $0.0 < I_b/I_n <$ *End section 1*, the differential current required for tripping is constant. The value of the differential current is the same as the *Low operate value* setting selected for the function block. The *Low operate value* setting allows for small inaccuracies of the current transformers but it can also be used to influence the overall level of the operating characteristic.

In section 2, where *End section 1* < I_b/I_n < *End section 2*, is called the influence area of the setting *Slope section 2*. In this section, variations in *End section 2* affect the slope of the characteristic, that is, how big the change in the differential current required for tripping is in comparison to the change in the load current. The *End section 2* setting allows for the CT errors.

In section 3, where I_b/I_n > *End section 2*, the slope of the characteristic is constant. The slope is 100 percent, which means that an increase in the differential current is equal to the corresponding increase in the stabilizing current.

The required differential current for tripping at a certain stabilizing current level can be calculated using the formulae:

For a stabilizing current lower than *End section 1*

$$I_{doperate}[\% I_r] = Set\,Low\,operate\,value$$

(Equation 103)

For a stabilizing current higher than *End section 1* but lower than *End section 2*

$$I_{doperate}[\% I_r] = Low\,operate\,value + (I_b[\% Ir] - End\ section\,1) \cdot Slope\,section\,2$$

(Equation 104)

For higher stabilizing current values exceeding *End section 2*

$$I_{d\,operate}[\% I_r] = Low\,operate\,value + (End\ section\,2 - End\ section\,1) \cdot Slope\,section\,2 + (I_b\,[\% I_r] - End\ section\,2) \cdot Slope\,section\,3$$

(Equation 105)

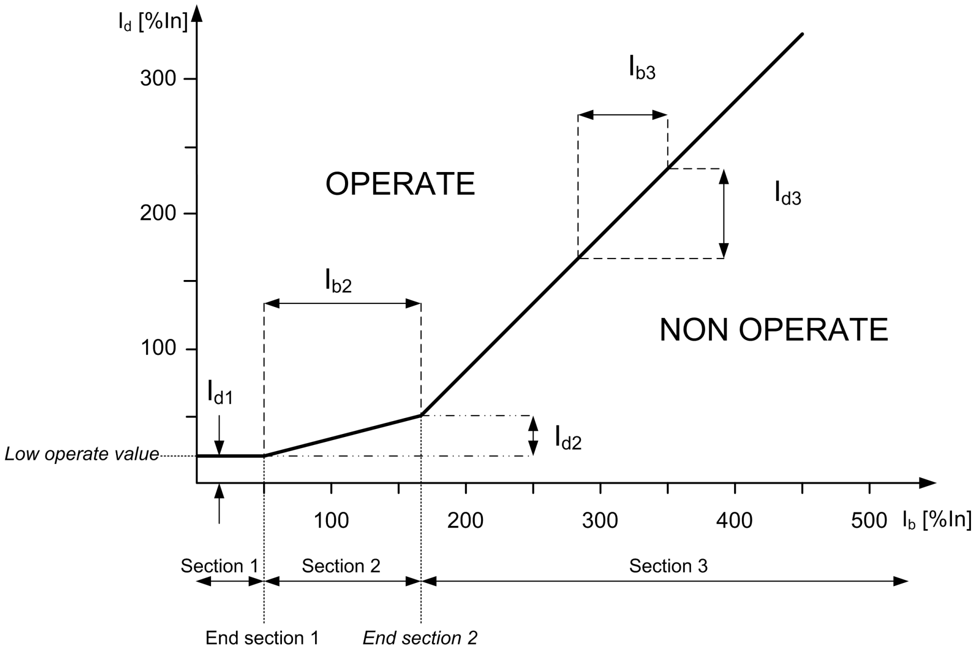


Figure 306: Operating characteristic for the stabilized stage of the differential protection function

When the differential current exceeds the operating value determined by the operating characteristics, the OPR_LS output is activated. The OPERATE output is always activated when the OPR_LS output activates, and the outputs OPR_A, OPR_B and OPR_C are activated according to the faulted phase detected by the biased low stage.

The operate signal due to the biased stage can be blocked by the activation of the BLK_OPR_LS or BLOCK input. Also, when the operation of the biased low stage is blocked by the waveform blocking functionality, the outputs INT_BLKD_A, INT_BLKD_B, INT_BLKD_C and the combined output INT_BLKD are activated according to the phase information.

The phase angle difference between the two currents I_A1 and I_A2 is theoretically 180 electrical degrees for the external fault and 0 electrical degrees for the internal fault conditions. If the phase angle difference is less than 50 electrical degrees or if the biasing current drops below 30 percent of the differential current, a fault has most likely occurred in the area protected by MPDIF. Then the internal blocking signals (CT saturation and DC blocking) of the biased stage are inhibited.

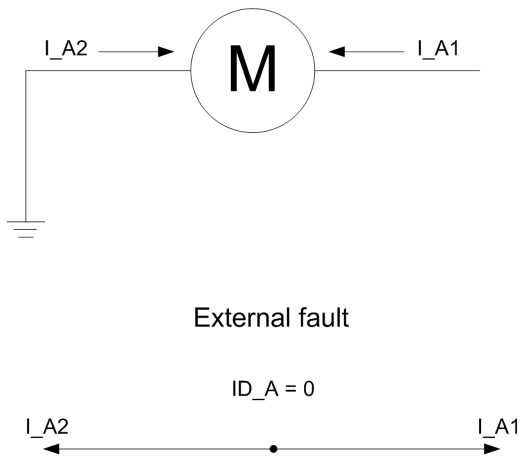


Figure 307: Positive direction of current

Instantaneous high stage

The differential protection includes an unbiased instantaneous high stage. The instantaneous stage operates and the OPR_HS output is activated when the amplitude of the fundamental frequency component of the differential current exceeds the set *High operate value* or when the instantaneous peak values of the differential current exceed 2.5 · *High operate value*. The factor 2.5 (= 1.8 · √2) is due to the maximum asymmetric short circuit current.

The OPERATE output is always activated when the OPR_HS output activates, and the outputs OPR_A, OPR_B and OPR_C are activated according to the faulted phase detected by the instantaneous high stage.

The internal blocking signals of the function block do not prevent the operation of the instantaneous stage. When required, the operate signal due to instantaneous operation can be blocked by the binary inputs `BLK_OPR_HS` or `BLOCK`.

4.3.4.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.3.4.6 Application

The differential protection works on the principle of calculating the differential current at two ends of the winding, that is, the current entering the winding is compared to the current exiting the winding. In case of any internal fault, the currents entering and exiting the winding are different, which results in a differential current, which is then used as a base for generating the operating signal. Due to this principle, the differential protection does not trip during external faults. However, it should be noted that interturn faults in the same phase are usually not detected unless they developed into some other kind of fault.

The short circuit between the phases of the stator windings normally causes large fault currents. The short circuit creates a risk of damages to the insulation, windings and stator core. The large short circuit currents cause large current forces which can damage other components in the machine. The short circuit can also initiate explosion and fire. When a short circuit occurs in a machine, there is a damage that has to be repaired. The severity and the repair time depend on the degree of damage, which is highly dependent on the fault time. The fast fault clearance of this fault type is of greatest importance to limit the damages and the economic loss.

To limit the damages in connection to the stator winding short circuits, the fault clearance time must be as short as possible (instantaneous). The fault current contributions from both the external power system (via the machine or the block circuit breaker) and from the machine itself must be disconnected as fast as possible.

The DC restraint feature should be used in case of an application with a long DC time constant in the fault currents are present. This fault current may be of a lesser magnitude (less than rated current) but is unpleasant and tends to saturate the CT and operate the differential protection for external faults. This feature is effective at moderate through-currents and ineffective at higher through-currents.

Although the short circuit fault current is normally very large, that is, significantly larger than the rated current of the machine, it is possible that a short circuit can occur between phases close to the neutral point of the machine, causing a relatively small fault current. The fault current fed from the synchronous machine can also be limited due to a low excitation of the synchronous generator. This is normally the case at the run-up of the synchronous machine, before synchronization to the network. Therefore, it is desired that the detection of the machine phase-to-phase short circuits shall be relatively sensitive, thus detecting the small fault currents.

It is also important that the machine short circuit protection does not trip for external faults when a large fault current is fed from the machine. To combine fast fault clearance, sensitivity and selectivity, the machine current differential protection is normally the best alternative for the phase-to-phase short circuits.

The risk of an unwanted differential protection operation caused by the current transformer saturation is a universal differential protection problem. If a big synchronous machine is tripped in connection to an external short circuit, it gives an increased risk of a power system collapse. Besides, there is a production loss for every unwanted trip of the machine. Therefore, preventing the unwanted disconnection of machines has a great economical value.

Recommendations for current transformers

The more important the object to be protected is, the more attention is paid to the current transformers. It is not normally possible to dimension the current transformers so that they repeat the currents with high DC components without saturating when the residual flux of the current transformer is high. The differential protection function block operates reliably even though the current transformers are partially saturated.

The accuracy class recommended for current transformers to be used with the differential function block is 5P, in which the limit of the current error at the rated primary current is 1 percent and the limit of the phase displacement is 60 minutes. The limit of the composite error at the rated accuracy limit primary current is 5 percent.

The approximate value of the actual accuracy limit factor F_a corresponding to the actual CT burden can be calculated on the basis of the rated accuracy limit factor F_n (ALF) at the rated burden, the rated burden S_n, the internal burden S_{in} and the actual burden S_a of the current transformer as:

$$F_a = F_n \times \frac{S_{in} + S_n}{S_{in} + S_a}$$

(Equation 106)

Example 1

The rated burden S_n of the current transformer 5P20 is 10 VA, the secondary rated current 5A, the internal resistance $R_{in} = 0.07\ \Omega$ and the rated accuracy limit factor F_n corresponding to the rated burden is 20 (5P20). The internal burden of the current transformer is $S_{in} = (5A)^2 \cdot 0.07\ \Omega = 1.75$ VA. The input impedance of the IED at a rated current of 5A is < 20 mΩ. If the measurement conductors have a resistance of 0.113 Ω, the actual burden of the current transformer is $S_a = (5A)^2 \cdot (0.113 + 0.020)\ \Omega = 3.33$ VA. Thus, the accuracy limit factor F_a corresponding to the actual burden is about 46.

The CT burden can grow considerably at the rated current 5A. The actual burden of the current transformer decreases at the rated current of 1 A while the repeatability simultaneously improves.

At faults occurring in the protected area, the fault currents can be very high compared to the rated currents of the current transformers. Due to the instantaneous stage of the differential function block, it is sufficient that the current transformers are capable of repeating the current required for an instantaneous tripping during the first cycle.

Thus the current transformers usually are able to reproduce the asymmetric fault current without saturating within the next 10 ms after the occurrence of the fault to secure that the operate times of the IED comply with the retardation time.

The accuracy limit factors corresponding to the actual burden of the phase current transformer to be used in differential protection must fulfill the requirement:

$$F_a > K_r \times Ik_{\max} \times (T_{dc} \times \omega \times (1 - e^{\frac{-T_m}{T_{dc}}}) + 1)$$

(Equation 107)

Ik_{max}	The maximum through-going fault current (in I_R) at which the protection is not allowed to operate
T_{dc}	The primary DC time constant related to Ik_{max}
ω	The angular frequency, that is, 2 x π x f_n
T_m	The time to saturate, that is, the duration of the saturation-free transformation
K_r	The remanence factor 1/(1-r), where r is the maximum remanence flux in p.u. from the saturation flux

The parameter r is the maximum remanence flux density in the CT core in pu from the saturation flux density. The value of the parameter r depends on the magnetic material used and also on the construction of the CT. For instance, if the value r = 0.4, the remanence flux density can be 40 percent of the saturation flux density. The manufacturer of the CT has to be contacted when an accurate value for the parameter r is needed. The value r = 0.4 is recommended to be used when an accurate value is not available.

The required minimum time-to-saturate T_m in MPDIF is half-fundamental cycle period (10 ms when f_n = 50 Hz).

Two typical cases are considered for the determination of the sufficient actual accuracy limit factor F_a:

1. A fault occurring at the substation bus.

The protection must be stable at a fault arising during a normal operating situation. The reenergizing of the transformer against a bus fault leads to very high fault currents and thermal stress. Therefore, reenergizing is not preferred in this case. The remanence can be neglected.
The maximum through-going fault current Ik_{max} is typically 6 I_R for a motor. At a short circuit fault close to the supply transformer, the DC time constant T_{dc} of the fault current is almost the same as that of the transformer, the typical value being 100 ms.

Ik_{max}	6 I_R
T_{dc}	100 ms
ω	100π Hz
T_m	10 ms
K_r	1

Equation 107 with these values gives the result:

$$F_a > K_r \times Ik_{\max} \times (T_{dc} \times \omega \times (1 - e^{\frac{-T_m}{T_{dc}}}) + 1) \approx 24$$

2. Reenergizing against a fault occurring further down in the network.

The protection must be stable also during reenergization against a fault on the line. In this case, the existence of remanence is very probable. It is assumed to be 40 percent here.
On the other hand the fault current is now smaller and since the ratio of the resistance and reactance is greater in this location, having a full DC offset is not possible. Furthermore, the DC time constant (T_{dc}) of the fault current is now smaller, assumed to be 50 ms here.
Assuming the maximum fault current is 30 percent lower than in the bus fault and a DC offset 90 percent of the maximum.

Ik_{max}	0.7 · 6 = 4.2 (I_R)
T_{dc}	50 ms
ω	100π Hz
T_m	10 ms
K_r	1/(1-0.4) = 1.6667

Equation 107 with these values gives the result:

$$F_a > K_r \times Ik_{\max} \times 0.9 \times (T_{dc} \times \omega \times (1 - e^{\frac{-T_m}{T_{dc}}}) + 1) \approx 24$$

If the actual burden of the current transformer S_a in the accuracy limit factor equation cannot be reduced low enough to provide a sufficient value for F_a, there are two alternatives to deal with the situation.

1. A current transformer with a higher rated burden S_n can be chosen (which also means a higher rated accurate limit F_n).
2. A current transformer with a higher nominal primary current I_{1n} (but the same rated burden) can be chosen.

Alternative 2 is more cost-effective and therefore often better, although the sensitivity of the scheme is slightly reduced.

Example 2

Here the actions according to alternative 2 are taken to improve the actual accuracy limit factor.

$$F_a = \left(\frac{I_R CT}{I_R Motor} \right) \times F_n$$

(Equation 108)

I_RCT	rated primary current of the CT, for example, 1500A
I_RMotor	rated current of the motor under protection, for example, 1000A
F_n	rated accuracy limit factor of the CT, for example, 30
F_a	actual accuracy limit factor due to oversizing the CT, substituting the values in the equation, F_a = 45

In differential protection it is important that the accuracy limit factors F_a of the phase current transformers at both sides correspond with each other, that is, the burdens of the current transformers on both sides are to be as close to each other as possible. If high inrush or start currents with high DC components pass through the protected object when it is connected to the network, special attention is required for the performance and the burdens of the current transformers and the settings of the function block.

Connection of current transformers

The connections of the main current transformers are designated as Type 1 and Type 2. If the earthings of the current transformers are either inside or outside the area to be protected, the setting *CT connection type* is of "Type 1" as shown in Figure 308. If the earthing of the current transformers are both inside and outside the area to be protected, the setting *CT connection type* is of "Type 2" as shown in Figure 309.

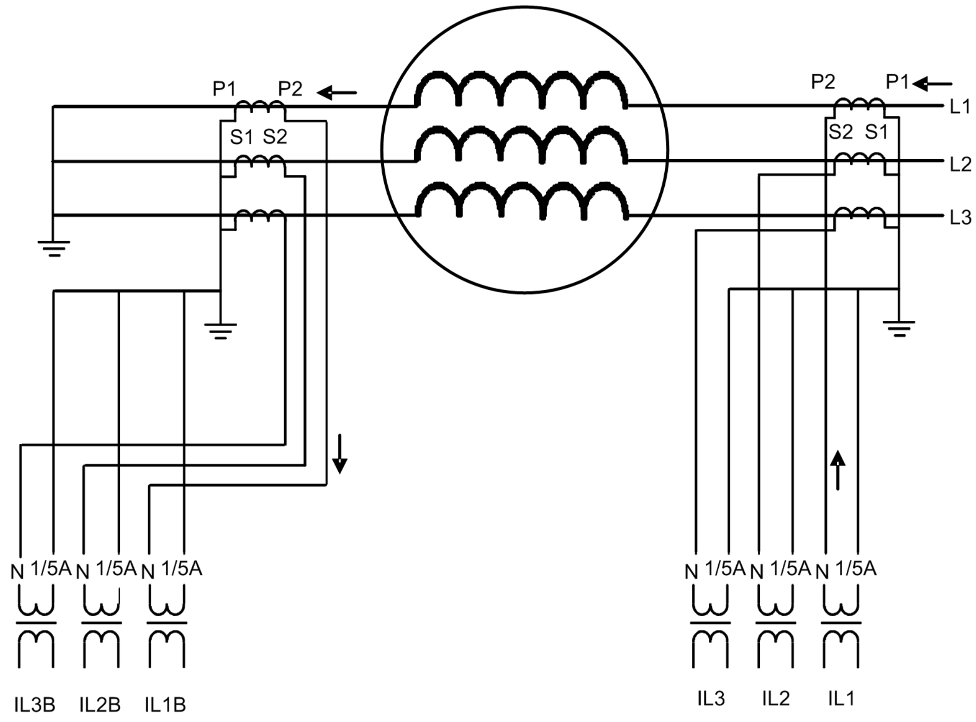


Figure 308: Connection of current transformer of Type 1

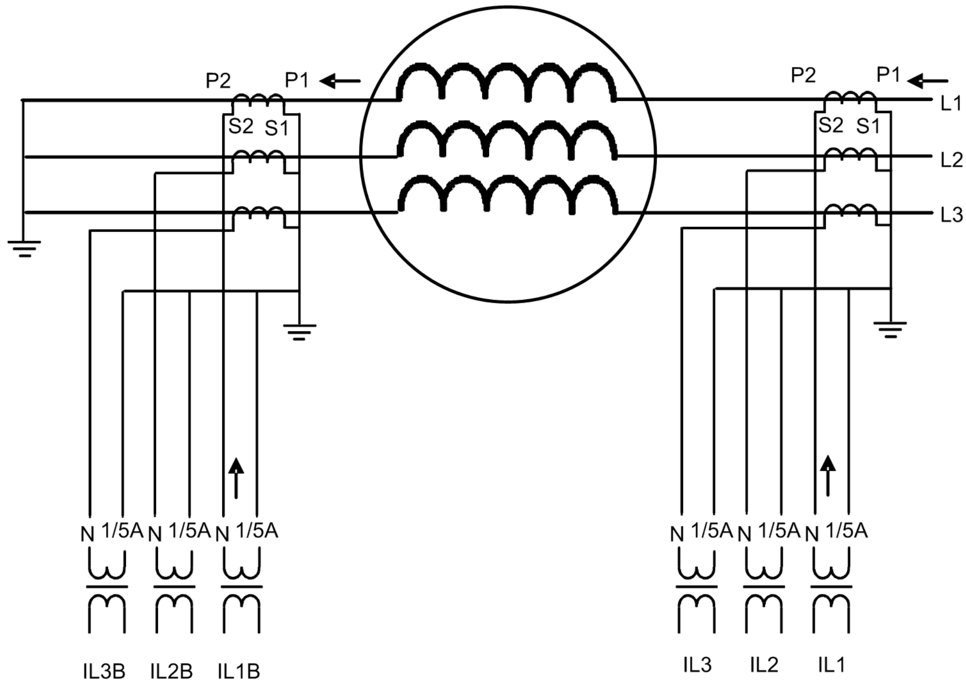


Figure 309: Connection of current transformer of Type 2

Saturation of current transformers

There are basically two types of saturation phenomena that have to be detected: the AC saturation and the DC saturation. The AC saturation is caused by a high fault current where the CT magnetic flux exceeds its maximum value. As a result, the secondary current is distorted as shown in Figure 310. A DC component in the current also causes the flux to increase until the CT saturates. This is known as DC saturation.

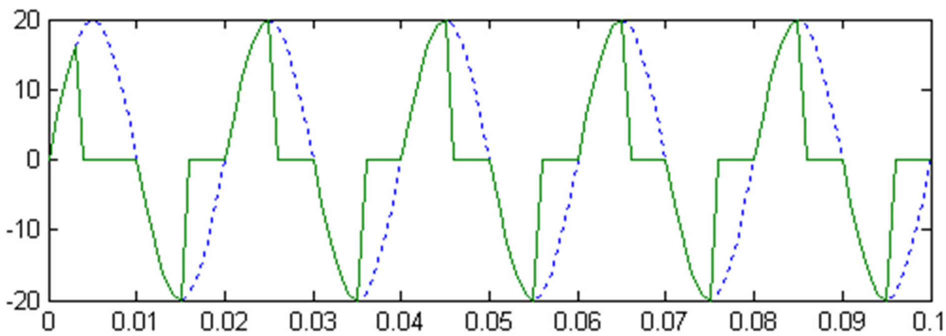


Figure 310: AC saturation

When having a short circuit in a power line, the short circuit current contains a DC component. The magnitude of the DC component depends on the phase angle when the short circuit occurs. Figure 311 shows the secondary current of the CT in the fault situation. Because of the DC component, the flux reaches its maximum value at 0.07 second causing saturation. As the DC component decays, the CT recovers gradually from the saturation.

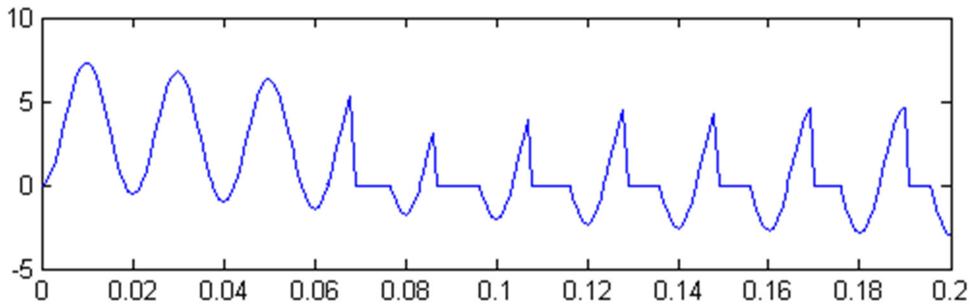


Figure 311: DC saturation

4.3.4.7 Signals

Table 579: MPDIF Input signals

Name	Type	Default	Description
I3P1	GROUP SIGNAL	-	Three phase group signal for current inputs, line side
I3P2	GROUP SIGNAL	-	Three phase group signal for current inputs, neutral side
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR_LS	BOOLEAN	0	Blocks operate outputs from biased stage
BLK_OPR_HS	BOOLEAN	0	Blocks operate outputs from instantaneous stage

Table 580: MPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal, combined (all phases, both stages)
OPR_A	BOOLEAN	Operate signal, Phase A
OPR_B	BOOLEAN	Operate signal, Phase B
OPR_C	BOOLEAN	Operate signal, Phase C
OPR_LS	BOOLEAN	Operate signal from low set (biased) stage
OPR_HS	BOOLEAN	Operate signal from high set (instantaneous) stage
INT_BLKD	BOOLEAN	Protection internally blocked, combined

Table continues on next page

Name	Type	Description
INT_BLKD_A	BOOLEAN	Protection internally blocked, Phase A
INT_BLKD_B	BOOLEAN	Protection internally blocked, Phase B
INT_BLKD_C	BOOLEAN	Protection internally blocked, Phase C

4.3.4.8 Settings

Table 581: MPDIF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
High operate value	100 - 1000	%	1	500	Instantaneous stage setting
Low operate value	5 - 30	%	1	5	Basic setting for stabilized operation
Slope section 2	10.0 - 50.0	%	0.1	20.0	Slope of the second line of the operation characteristics
End section 1	0 - 100	%	1	50	Turn-point between sections 1 and 2 of the characteristics
End section 2	100 - 300	%	1	150	Turn-point between sections 2 and 3 of the characteristics

Table 582: MPDIF Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
DC restrain enable	No Yes	-	-	No	Setting for enabling DC restrain feature

Table 583: MPDIF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
CT connection type	Type 1 Type 2	-	-	Type 1	CT connection type

Table 584: MPDIF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase

4.3.4.9 Measured values

Table 585: MPDIF Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR_LS	BOOLEAN	0	Blocks operate outputs from biased stage
BLK_OPR_HS	BOOLEAN	0	Blocks operate outputs from instantaneous stage

4.3.4.10 Monitored data

Table 586: MPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal, Phase A
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal, Phase B
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal, Phase C
OPR_LS	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal from low set (biased) stage
OPR_HS	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal from high set (instantaneous) stage
INT_BLKD_A	BOOLEAN	0=FALSE 1=TRUE	-	Protection internally blocked, Phase A
INT_BLKD_B	BOOLEAN	0=FALSE 1=TRUE	-	Protection internally blocked, Phase B
INT_BLKD_C	BOOLEAN	0=FALSE 1=TRUE	-	Protection internally blocked, Phase C
ID_A	REAL	-	A	Differential current, Phase A
ID_B	REAL	-	A	Differential current, Phase B
ID_C	REAL	-	A	Differential current, Phase C
IB_A	REAL	-	A	Bias current, phase A
IB_B	REAL	-	A	Bias current, phase B
IB_C	REAL	-	A	Bias current, phase C
I_ANGL_A1_B1	REAL	-	deg	Current phase angle Phase A – Phase B, line side
I_ANGL_B1_C1	REAL	-	deg	Current phase angle Phase B – Phase C, line side
I_ANGL_C1_A1	REAL	-	deg	Current phase angle Phase C – Phase A, line side
I_ANGL_A2_B2	REAL	-	deg	Current phase angle Phase A – Phase B, neutral side
I_ANGL_B2_C2	REAL	-	deg	Current phase angle Phase B – Phase C, neutral side
I_ANGL_C2_A2	REAL	-	deg	Current phase angle Phase C – Phase A, neutral side

Table continues on next page

Name	Type	Values (Range)	Unit	Description
I_ANGL_A1_A2	REAL	-	deg	Current phase angle diff between line and neutral side, Phase A
I_ANGL_B1_B2	REAL	-	deg	Current phase angle diff between line and neutral side, Phase B
I_ANGL_C1_C2	REAL	-	deg	Current phase angle diff between line and neutral side, Phase C

4.3.4.11 Technical data

Table 587: MPDIF Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±3% of the set value or $\pm 0.002 \times I_n$
Operate time 1)2)	Biased low stage Instantaneous high stage3)	Typically 40 ms (±10 ms) Typically 15 ms (±10 ms)
Reset time		<40 ms
Reset ratio		Typically 0.96
Retardation time		<20 ms

1) Fn = 50 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the high speed power output contact
3) Ifault = 2 × *High operate value*

4.3.4.12 Technical revision history

Table 588: MPDIF technical revision history

Technical revision	Change
B	• Change in function description and IEC 60617 and ANSI symbol • Added support for frequency adaptivity

4.3.5 High-impedance or flux-balance based differential protection for machines MHZPDIF

4.3.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance or flux-balance based differential protection for machines	MHZPDIF	3dIHi>G/M	87GH/87MH

4.3.5.2 Function block

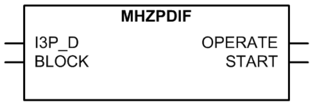


Figure 312: Function block

4.3.5.3 Functionality

The high-impedance or flux-balance based differential protection for machines MHZPDIF provides winding short circuit protection for generators and motors.

MHZPDIF starts and operates when any of the three-phase differential currents, ID_A, ID_B and ID_C, exceeds the set limit. The operation time characteristic is according to the definite time (DT).

This function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

4.3.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the high-impedance or flux-balance based differential protection for machines can be described using a module diagram. All the modules in the diagram are explained in the next sections.

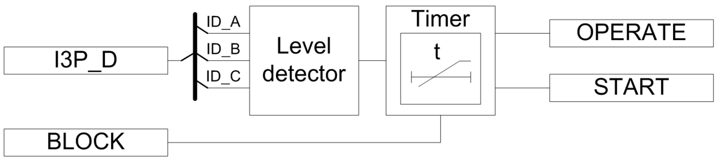


Figure 313: Functional module diagram

Level detector

This module compares the three-phase differential currents to the set *Operate value*. If any of the differential currents ID_A, ID_B and ID_C exceeds the set *Operate value*, the level detector module sends an enable signal to the timer module to start the definite timer (DT).

Timer

Once activated, the timer activates the START output. The timer characteristic is according to DT. When the operation timer has reached the value set by *Minimum operate time*, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The activation of the BLOCK signal resets the timer and deactivates the START and OPERATE outputs.

It is recommended to use the adaptive DFT preprocessing block to provide the analog input to this function.

4.3.5.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.3.5.6 Application

MHZPDIF provides the winding short circuit and earth-fault protection for generators and motors. The high-impedance or flux-balance principle has been used through many years for differential protection due to the capability to manage through-faults with a heavy current transformer (CT) saturation.

High-impedance principle

The high-impedance principle is stable for all types of faults outside the protection zone. The stabilization is obtained by a stabilizing resistor in the differential circuit. This method requires all the CTs to have a similar magnetizing characteristic, same ratio and a relatively high knee point voltage. The CTs in each phase are connected in parallel with a relay-measuring branch. The measuring branch is a series connection of the stabilizing resistor and the IED.

The stability of the protection is based on the use of the stabilizing resistor (R_S) and the fact that the impedance of the CT secondary quickly decreases as the CT saturates. The magnetization reactance of a fully saturated CT drops to zero and the impedance is formed only by the resistance of the winding (R_{in}) and lead resistance (R_m).

The CT saturation causes a differential current which can flow through the saturated CT (because of the near-zero magnetizing reactance) or through the measuring branch. The stabilizing resistor is selected so that the current in the measuring branch is below the IED operating current during out-of-zone faults. As a result, the operation is stable during the saturation and can still be sensitive at the undistorted parts of the current waveform.

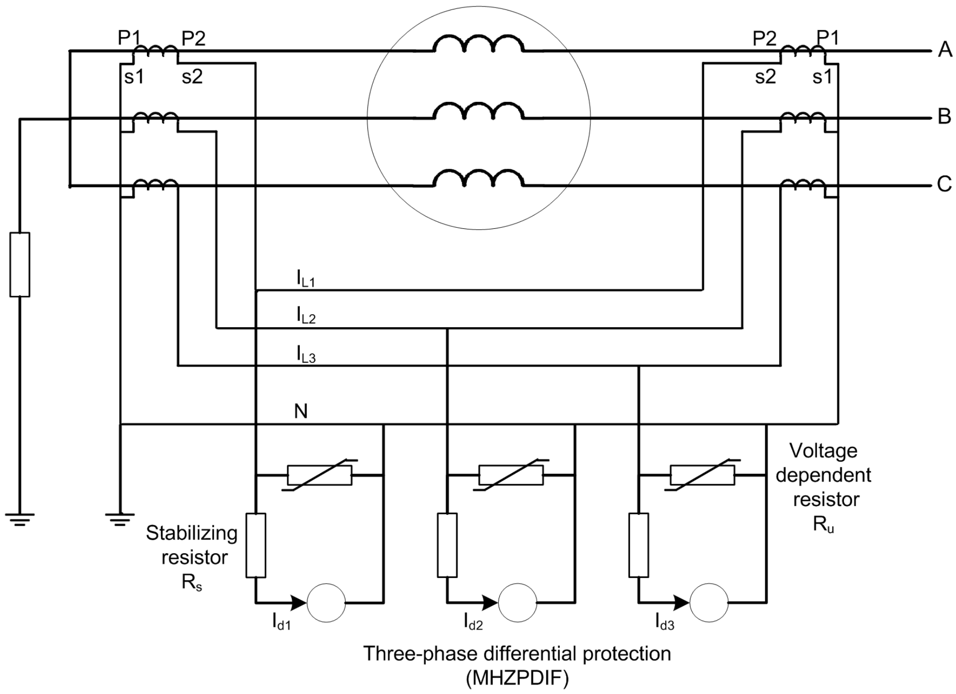


Figure 314: Three-phase differential protection for generators and motors based on high-impedance principle

In case of an internal fault, the fault current cannot circulate through the CTs. It flows through the measuring branch, and the protection operates. A partial CT saturation can occur in case of an internal fault, but the undistorted part of the current waveform causes the protection to operate.

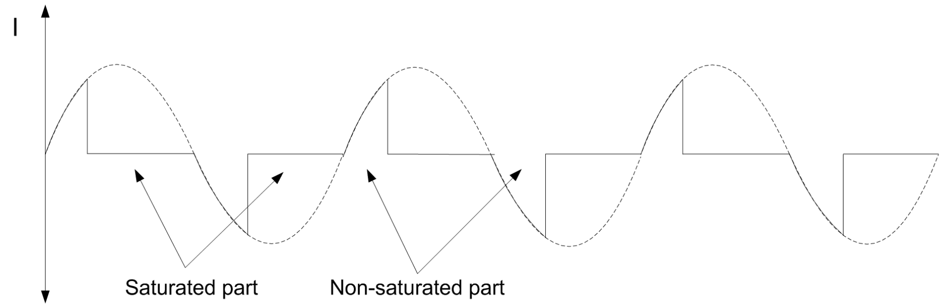


Figure 315: Secondary waveform of a saturated CT

At an internal fault, the secondary circuit voltage can easily exceed the isolation voltage of the CTs, connection wires and the IED. To limit this voltage, a voltage-dependent resistor (VDR) is used.

The whole scheme, that is, the stabilizing resistor, voltage-dependent resistor and wiring, must be adequately maintained (operation and insulation tested regularly) to be able to withstand the high-voltage pulses that appear during an internal fault throughout the lifetime of the equipment. Otherwise, during a fault within the zone of protection, any flashover in the CT secondary circuits or any other part of the scheme can prevent the correct operation of MHZPDIF.

Flux-balancing principle

In a measuring configuration for the three-phase differential currents according to the flux-balancing principle, no stabilizing resistors are needed. The configuration, however, requires the use of core balance current transformers. The compared currents, the one at the line end and the other at the neutral end, are both measured by the same core balance current transformer.

In this scheme, the currents flowing through one core balance transformer cancel each other out when there is no fault within the protected zone. When a fault occurs within the protected zone, the currents flowing through the core balance transformer amplify each other and the differential protection operates.

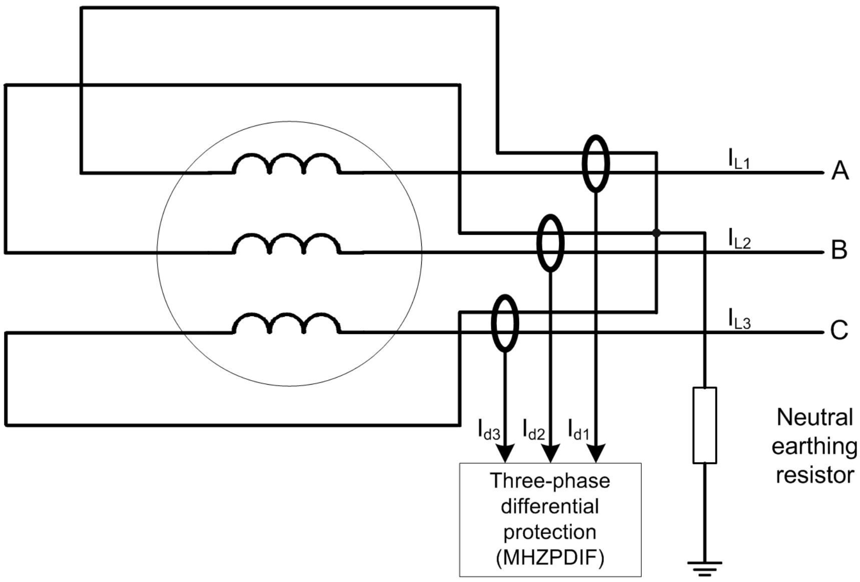


Figure 316: Three-phase differential protection for generators and motors based on flux-balancing principle

The advantage of this scheme is that the CT rated primary current can be selected smaller than the rated current of the machine.

If six current transformers are used, the flux-balancing principle (that is, summing two CTs in each phase) cannot be used. Instead, the high-impedance principle or stabilized three-phase differential protection must be used.

4.3.5.7 Recommendations for current transformers

High-impedance principle

The sensitivity and reliability of the protection depend on the characteristics of the current transformers. The CTs must have an identical transformation ratio. It is recommended that all current transformers have an equal burden and characteristics and that they are of the same type, preferably from the same manufacturing batch, that is, an identical construction used. If the CT characteristics and the burden values are not equal, the calculation for each branch in the scheme should be done separately and the worst-case result is used. In the case where the CT winding resistance and the burden of the branches are not equal, the maximum burden equal to 3.2 Ω should be used for calculating the stabilized voltage.

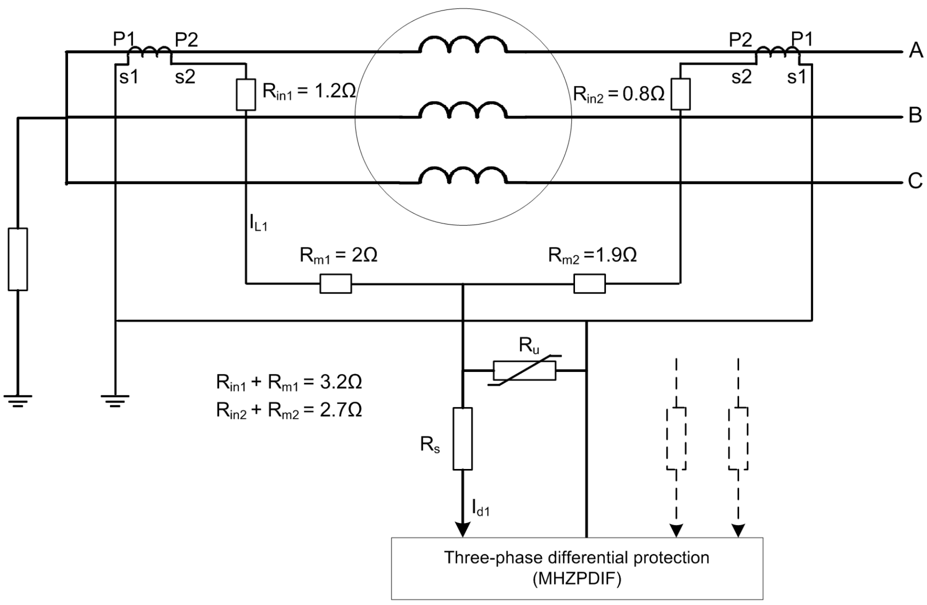


Figure 317: High-impedance differential protection with different CT burden value on each branch

First, the stabilizing voltage, that is, the voltage appearing across the measuring branch during an out-of-zone fault, is calculated assuming that one of the CTs connected in parallel is fully saturated. The stabilizing voltage can be calculated using the formula:

$$U_S = \frac{I_{kmax}}{n}(R_{in} + R_m)$$

(Equation 109)

I_{kmax}	The highest through-fault current in primary amps. The highest earth fault or short circuit current during out-of-zone fault.
n	Turns ratio of the CT
R_{in}	Secondary winding resistance of CT in ohms
R_m	Resistance (maximum of R_{in} + R_m) of the CT secondary circuit in ohms

The current transformers must be able to force enough current to operate the IED through the differential circuit during a fault condition inside the protection zone. To ensure this, the knee point voltage U_{kn} should be at least twice higher than the stabilizing voltage U_s.

The required knee point voltage U_{kn} of the current transformer is calculated using the formula:

$$U_{kn} \geq 2 \times U_S$$

(Equation 110)

U_{kn} Knee point voltage

U_s Stabilizing voltage

The factor two is used when no delay in the operating time of the protection in any situation is acceptable. It is advisable to use the current transformers whose secondary winding resistance is of the same size as the resistance of the measuring loop to prevent the knee point voltage from growing too high.

As the impedance of the IED is low, a stabilizing resistor is needed. The value of the stabilizing resistor is calculated using the formula:

$$R_S = \frac{U_S}{I_{rs}}$$

(Equation 111)

R_S Resistance of the stabilizing resistor

U_S Stabilizing voltage of the IED

I_{rs} Value of the *Operate value* setting in secondary amps

The stabilizing resistor should be capable of dissipating high energy within a very short time. Therefore, a wire-wound-type resistor should be used. The rated power should be in class of a few tens of watts in minimum because of the possible CT inaccuracy, which might cause some current through the stabilizing resistor in a normal load situation.

If U_{kn} is high or the stabilizing voltage is low, a resistor with a higher power rating is needed. Often the resistor manufacturers allow 10 times rated power for five seconds. Thus the power of the resistor can be calculated from the equation:

$$\frac{U_{kn}^2}{Rs \times 10}$$

(Equation 112)

The actual sensitivity of the protection is affected by the IED setting, the magnetizing currents of the CTs connected in parallel and the shunting effect of the voltage-dependent resistor. The value of the primary current I_{prim} at which the IED operates at a certain setting can be calculated using the formula:

$$I_{prim} = n \times (I_{rs} + I_u + m \times I_m)$$

(Equation 113)

I_m	Magnetizing current per current transformer at the U_s voltage
I_{prim}	Primary current level at which the protection is to start
I_{rs}	Value of the *Operate value* setting
I_u	Leakage current through VDR at the U_s voltage
n	turn ratio of the current transformer
m	number of current transformers included in the protection per phase (=2)

The I_e value given in many catalogs is the excitation current at the knee point voltage.

Assuming $U_{KN} \approx 2 \times U_s$, the value of $I_m \approx I_e/2$ gives an approximate value for Equation 113.

The selection of the current transformers is based on the following procedures:

1. The rated current I_n of the protected machine should be known. The value of I_n also affects how high I_{kmax} is. Normally the I_{kmax} value for generators and motors is $6 \times I_n$.
2. The rated primary current I_{1n} of the CT has to be higher than the rated current of the machine. The choice of the CT also specifies R_{in}.
3. The required U_{kn} is calculated using Equation 110. If U_{kn} of the CT is not high enough, another CT has to be chosen. The value of U_{kn} is given by the manufacturer in the case of the Class X current transformer or it can be estimated using Equation 114.
4. The sensitivity I_{prim} is calculated using Equation 113. If the achieved sensitivity is sufficient, the present CT is chosen. A CT with a bigger core is chosen if a better sensitivity is needed.

If a CT other than Class X CTs is used, an estimate for U_{kn} is calculated using:

$$U_{kn} = 0.8 \times F_n \times I_{2n} \times (R_{in} + \frac{Sn}{I_{2n}^2})$$

(Equation 114)

F_n	Rated accuracy limit factor corresponding to the rated burden S_n
I_{2n}	Rated secondary current of the current transformer
R_{in}	Secondary internal resistance of the CT
S_n	Volt-amp rating of the CT

The formulas are based on choosing the CTs according to Equation 110, which results in an absolute stable scheme. In some cases, it is possible to achieve stability with the knee point voltages lower than the voltage stated in the formulas. However, the network conditions have to be known well enough to ensure the stability.

- If $U_k >= 2 \times U_s$, the fast IED operation is secure.
- If $U_k >= 1.5 \times U_s$ and $< 2 \times U_s$, the IED operation can be slightly prolonged and it should be studied case by case.
- If $U_k < 1.5 \times U_s$, the IED operation is jeopardized. Another CT has to be chosen.

The need for a voltage-dependent resistor (VDR) depends on the insulation level for which the IEDs are tested.

First, the voltage U_{max} ignoring the CT saturation during the fault is calculated as:

$$U_{max} = \frac{I_{kmax\,in}}{n} \times (R_{in} + R_m + R_s) \approx \frac{I_{kmax\,in}}{n} \times R_s$$

(Equation 115)

$I_{kmax\,in}$	Maximum fault current inside the zone in primary amps
n	Turns ratio of CT
R_{in}	Internal resistance of CT in ohms
R_m	Resistance of the longest loop of the CT secondary circuit in ohms
R_s	Resistance of the stabilized resistor in ohms

Next the peak voltage û, which includes the CT saturation, is estimated using the formula given by P.Mathews in 1955.

$$\hat{u} = 2\sqrt{2U_{kn}\left(U_{max} - U_{kn}\right)}$$

(Equation 116)

U_{kn}	Knee point voltage of CT

The VDR is recommended when the peak voltage û ≥ 2 kV (it is the insulation level for which the IEDs are tested).

For example, the maximum fault current in case of fault inside the zone is 12.6 kA in primary, CT is of 1250/5 A (that is, ratio n = 240) and knee point voltage is 81 V. Stabilizing resistor is 330 Ω.

$$U_{max} = \frac{12600A}{240} \times 330\ \Omega = 17325\ V$$

$$\hat{u} = 2\sqrt{2 \times 81 \times (17325 - 81)} \approx 3.34\,kV$$

As the peak voltage û is 3.2 kV, VDR must be used. Sometimes if R_s is smaller, VDR can be avoided. But the value of R_s depends on the IED operation current and stabilizing voltage. Thus a higher setting in the IED must be used or the stabilizing voltage lowered.

Flux-balancing principle

When the function block is used with the flux-balancing principle, there are no extra requirements for the measuring devices but the core balance transformers used in the ordinary overcurrent protection are adequate here as well.

4.3.5.8 Example calculations for high-impedance differential protection

The example shows the calculation for the *Operate value* setting, stabilizing resistor value (R_s) and required knee point voltage (U_{kn}) of the CTs.

Table 589: Protected generator values

Quantities	Values
S_n	8 MVA
U_n	6 kV
I_n	770 A
I_{kmax}	4620 A, (6 x I_n) out of zone fault
$I_{kmax\ in}$	9.24 kA, (12 x I_n) in zone fault

Table 590: Assumed CT data

Quantities	Values
CT	1000/1 A
R_{in}	15.3 Ω
U_{kn}	323 V
I_e	35 mA (at U_{kn})

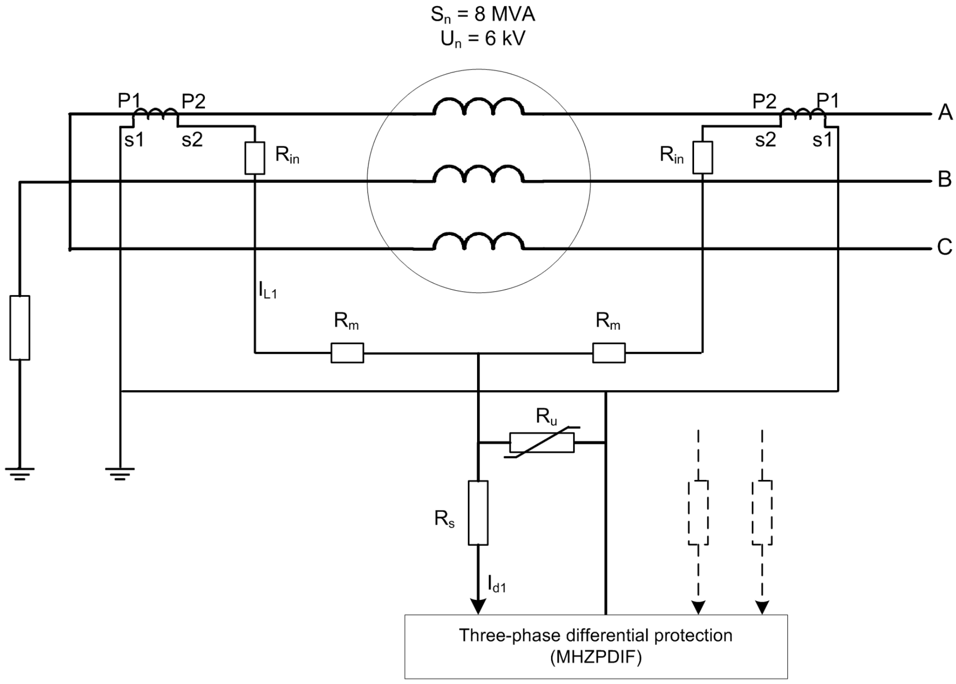


Figure 318: Example calculation for high-impedance differential protection (only one phase is presented in detail)

The length of the secondary circuit loop is 200 m and the area of the cross-section is 2.5 mm2 (resistance at 75 °C is 0.00865 Ω/m)

$$R_m = 0.00865\,\Omega / m \times 200\,m \approx 1.73\,\Omega$$

First, the stabilizing voltage is calculated based on Equation 109:

$$U_s = \frac{6 \times 770\,A}{1000}\left(15.3\,\Omega + 1.73\,\Omega\right) \approx 78.7\ V$$

In this case, the requirement for the current transformer knee point voltage is fulfilled because $U_{kn} > 2U_s$.

The magnetizing curve of the CT is assumed to be linear. The magnetizing current at the stabilizing voltage can be estimated:

$$I_m = \frac{U_s}{U_{kn}} \times I_e$$

$$I_m = \frac{78.7\,V}{323\ V} \times 35\,mA \approx 8.5\,mA$$

The setting current I_{rs} should be at the minimum of the sum of the magnetizing currents of all the connected CTs to obtain adequate protection stability.

$$I_{rs} = 2 \times 8.5\,mA \approx 17\,mA$$

The resistance of the stabilizing resistor is calculated based on Equation 111.

$$R_S = \frac{78.7\,V}{0.017\,A} \approx 4629\,\Omega$$

The calculated value 4629 Ω is the maximum value for the stabilizing resistor. If this value is not available, the next available value downwards should be chosen and the IED setting current is to be tuned according to the selected resistor. For example, the resistance value 3900 Ω is used in this case.

$$I_{rs} = \frac{78.7\,V}{3900\,\Omega} \approx 20\,mA$$

The sensitivity of the protection is obtained as per Equation 112, assuming I_u to be zero;

$$I_{prim} = 1000 \times (0.020\,A + 2 \times 0.0085\,A + 0\,A) \approx 37\,A$$

The power of the stabilizing resistor is calculated as:

$$P \geq \frac{(323\,V)^2}{3900\,\Omega} \approx 27\,W$$

Based on Equation 114 and Equation 115, the need for a voltage-dependent resistor is checked.

$$U_{max} = \frac{12 \times 770A}{1000}(3900\,\Omega + 15.3\Omega + 1.73\,\Omega + 0.10\,\Omega) \approx 36.2\,kV$$

$$\breve{u} = 2\sqrt{2 \times 323V \times (36200V - 323V)} \approx 9.6\,kV$$

The voltage-dependent resistor (one for each phase) is needed in this case because the voltage during the fault is much higher than 2 kV.

The leakage current through the varistor at the stabilizing voltage can be available from the varistor manual, assuming that to be approximately 2 mA at the stabilizing voltage.

$$I_u \approx 0.002\,A$$

The sensitivity of the protection can be recalculated taking into account the leakage current through the varistor as per Equation 112.

$$I_{prim} = 1000 \times (0.020\,A + 2 \times 0.0085\,A + 0.002\,A) \approx 39\,A$$

4.3.5.9 Signals

Table 591: MHZPDIF Input signals

Name	Type	Default	Description
I3P_D	GROUP SIGNAL	-	Three phase group signal for differential current inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs

Table 592: MHZPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
OPR_A	BOOLEAN	Operated phase A
OPR_B	BOOLEAN	Operated phase B
OPR_C	BOOLEAN	Operated phase C
START	BOOLEAN	Started
ST_A	BOOLEAN	Started phase A
ST_B	BOOLEAN	Started phase B
ST_C	BOOLEAN	Started phase C

4.3.5.10 Settings

Table 593: MHZPDIF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operate value	0.5 - 50.0	%	0.1	0.5	Operate value, percentage of the nominal current
Minimum operate time	0.02 - 300.00	s	0.01	0.02	Minimum operate time

Table 594: MHZPDIF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 595: MHZPDIF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Reset delay time	0.00 - 60.00	s	0.01	0.02	Reset delay time

4.3.5.11 Measured values

Table 596: MHZPDIF Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block signal for all binary outputs

4.3.5.12 Monitored data

Table 597: MHZPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase A
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase B
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operated phase C
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Started phase A
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Started phase B
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Started phase C
ID_A	REAL	-	A	Analog output value phase A
ID_B	REAL	-	A	Analog output value phase B
ID_C	REAL	-	A	Analog output value phase C
START_DUR	REAL	-	%	Ratio of start time / operate time

4.3.5.13 Technical data

Table 598: MHZPDIF Technical data

Characteristic	Value
Operation accuracy	±1.5% of the set value or 0.002 × I_n
Start time [1)2)]	Typically 15 ms (±10 ms)
Reset time	<65 ms
Reset ratio	Typically 0.96
Retardation time	<50 ms
Operate time accuracy in definite time mode	±1.0% of the set value of ±20 ms

1) F_n = 50 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.4 Unbalance protection

4.4.1 Negative sequence current protection NSPTOC

4.4.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative sequence current protection	NSPTOC	I2>	46

4.4.1.2 Function block

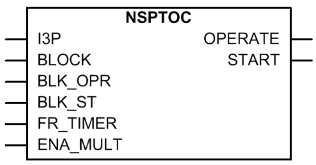


Figure 319: Function block

4.4.1.3 Functionality

The negative-sequence current protection NSPTOC is used for increasing sensitivity to detect single-phase and phase-to-phase faults or unbalanced loads due to, for example, broken conductors or unsymmetrical feeder voltages.

NSPTOC can also be used for detecting broken conductors.

The function is based on the measurement of the negative sequence current. In a fault situation, the function starts when the negative sequence current exceeds the set limit. The operate time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.4.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the negative sequence current protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

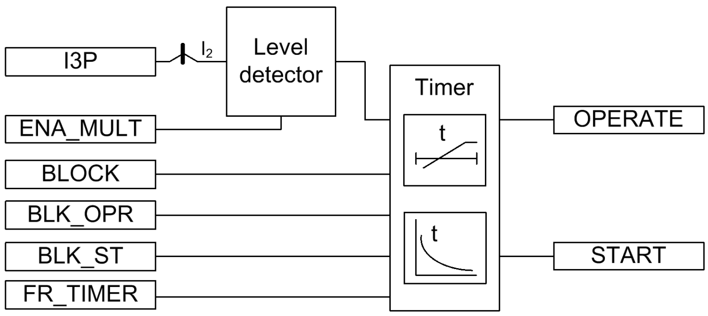


Figure 320: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Level detector

The measured negative-sequence current is compared to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector activates the timer module. If the ENA_MULT input is active, the set *Start value* is multiplied by the set *Start value Mult*.

The IED does not accept the *Start value* or *Start value Mult* setting if the product of the settings exceeds the *Start value* setting range.

Do not set the multiplier setting *Start value Mult* higher than necessary. If the value is too high, the function may not operate at all during an inrush followed by a fault, no matter how severe the fault is.

Timer

Once activated, the timer activates the START output. The ST_A, ST_B and ST_C outputs are used to indicate which phases are started. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated. The OPR_A, OPR_B and OPR_C outputs are used to indicate which phases are operated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the `FR_TIMER` input.

4.4.1.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.4.1.6 Application

Since the negative sequence current quantities are not present during normal, balanced load conditions, the negative sequence overcurrent protection elements can be set for faster and more sensitive operation than the normal phase-overcurrent protection for fault conditions occurring between two phases. The negative sequence overcurrent protection also provides a back-up protection functionality for the feeder earth-fault protection in solid and low resistance earthed networks.

The negative sequence overcurrent protection provides the back-up earth-fault protection on the high voltage side of a delta-wye connected power transformer for earth faults taking place on the wye-connected low voltage side. If an earth fault occurs on the wye-connected side of the power transformer, negative sequence current quantities appear on the delta-connected side of the power transformer.

Multiple time curves and time multiplier settings are also available for coordinating with other devices in the system.

4.4.1.7 Signals

Table 599: NSPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
BLOCK	BOOLEAN	0	Blocks all binary outputs by resetting timers
BLK_OPR	BOOLEAN	0	Blocks operate outputs.
BLK_ST	BOOLEAN	0	Blocks start outputs.
FR_TIMER	BOOLEAN	0	Freeze internal operate timer counts.
ENA_MULT	BOOLEAN	0	Enables current multiplier.

Table 600: NSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate Signal
START	BOOLEAN	Start Signal

4.4.1.8 Settings

Table 601: NSPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.01 - 5.00	pu	0.01	0.30	Start value
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier/ Time Dial in IEC/ANSI curves
Operating curve type	ANSI Ext. inv. ANSI Very inv. ANSI Norm. inv. ANSI Mod. inv. ANSI Def. Time L.T.E. inv. L.T.V. inv. L.T. inv. IEC Norm. inv. IEC Very inv. IEC inv. IEC Ext. inv. IEC S.T. inv. IEC L.T. inv. IEC Def. Time Programmable RI type RD type	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.04 - 200.00	s	0.01	0.04	Operate Delay Time

Table 602: NSPTOC Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type
Minimum operate time	0.040 - 60.000	s	0.001	0.040	Minimum operate time for IDMT curves

Table 603: NSPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 604: NSPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.4.1.9 Measured values

Table 605: NSPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.01 - 5.00	pu	0.01	0.30	Start value
Start value Mult	0.8 - 10.0	-	0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier/ Time Dial in IEC/ANSI curves
Operating curve type	ANSI Ext. inv. ANSI Very inv. ANSI Norm. inv. ANSI Mod. inv. ANSI Def. Time L.T.E. inv. L.T.V. inv. L.T. inv. IEC Norm. inv. IEC Very inv. IEC inv. IEC Ext. inv. IEC S.T. inv. IEC L.T. inv. IEC Def. Time Programmable RI type RD type	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.04 - 200.00	s	0.01	0.04	Operate Delay Time

Table 606: NSPTOC Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Type of reset curve	Immediate Def time reset Inverse reset	-	-	Immediate	Selection of reset curve type
Minimum operate time	0.040 - 60.000	s	0.001	0.040	Minimum operate time for IDMT curves

Table 607: NSPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 608: NSPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Curve parameter A	0.0086 - 120.0000	-	0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000 - 0.7120	-	0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02 - 2.00	-	0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46 - 30.00	-	0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0 - 1.0	-	0.1	1.0	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.4.1.10 Monitored data

Table 609: NSPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate Signal
START	BOOLEAN	0=FALSE 1=TRUE	-	Start Signal
START_DUR	REAL	-	%	Start Duration
INVAL_CRV	BOOLEAN	0=FALSE 1=TRUE	-	Invalid curve parameters

4.4.1.11 Technical data

Table 610: NSPTOC Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × I_n
Start time [1)2)]	I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	Typically 23 ms (±15 ms) Typically 16 ms (±15 ms)
Reset time		<40 ms
Table continues on next page		

Characteristic	Value
Reset ratio	Typically 0.96
Retardation time	<35 ms
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode	±5.0% of the theoretical value or ±20 ms 3)
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) *Operate curve type* = IEC definite time, negative sequence current before fault = 0.0, f_n = 50 Hz
2) Includes the delay of the signal output contact
3) Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5 to 20

4.4.1.12 Technical revision history

Table 611: NSPTOC technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

4.4.2 Phase discontinuity protection PDNSPTOC

4.4.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase discontinuity protection	PDNSPTOC	I2/I1>	46PD

4.4.2.2 Function block

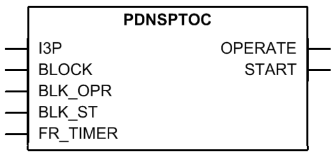


Figure 321: Function block

4.4.2.3 Functionality

The phase discontinuity protection PDNSPTOC is used for detecting unbalance situations caused by broken conductors.

The function starts and operates when the unbalance current I_2/I_1 exceeds the set limit. To prevent faulty operation at least one phase current needs to be above the minimum level. PDNSPTOC operates with DT characteristic.

The function contains a blocking functionality. It is possible to block the function output, timer or the function itself, if desired.

4.4.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of phase discontinuity protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

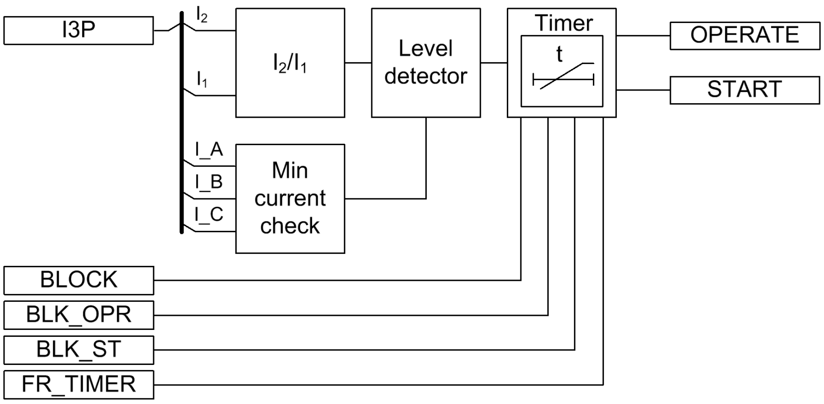


Figure 322: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

I_2/I_1

The I_2/I_1 module calculates the ratio of the negative and positive sequence current. It reports the calculated value to the level detector.

Level detector

The level detector compares the calculated ratio of the negative- and positive-sequence currents to the set *Start value*. If the calculated value exceeds the set *Start value* and the min current check module has exceeded the value of *Min phase current*, the level detector reports the exceeding of the value to the timer.

Min current check

The min current check module checks whether the measured phase currents are above the set *Min phase current*. At least one of the phase currents needs to be above the set limit to enable the level detector module.

Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets internal timers. The binary input `BLK_ST` can be used to block the start signals. The binary input `BLK_OPR` can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the `FR_TIMER` input.

4.4.2.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.4.2.6 Application

In three-phase distribution and subtransmission network applications the phase discontinuity in one phase can cause increase of zero sequence voltage and short overvoltage peaks and also oscillation in the corresponding phase.

PDNSPTOC is a three-phase protection with DT characteristic, designed for detecting broken conductors in distribution and subtransmission networks. The function is applicable for both overhead lines and underground cables.

The operation of PDNSPTOC is based on the ratio of positive and negative sequence currents. This gives better sensitivity and stability compared to plain negative sequence current protection since the calculated ratio of positive and negative sequence currents is relatively constant during load variations.

The unbalance of the network is detected by monitoring the negative and positive sequence current ratio, where the negative sequence current value is I_2 and I_1 is the positive sequence current value. The unbalance is calculated:

$$Iratio = \frac{I_2}{I_1}$$

(Equation 117)

Broken conductor fault situation can occur in phase A in a feeder.

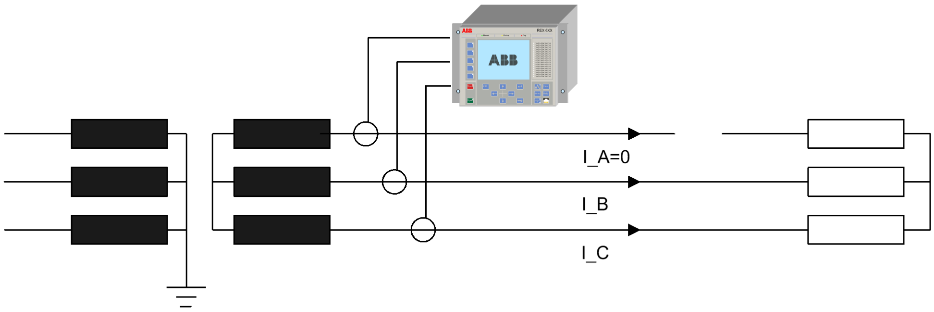


Figure 323: Broken conductor fault situation in phase A in a distribution or subtransmission feeder

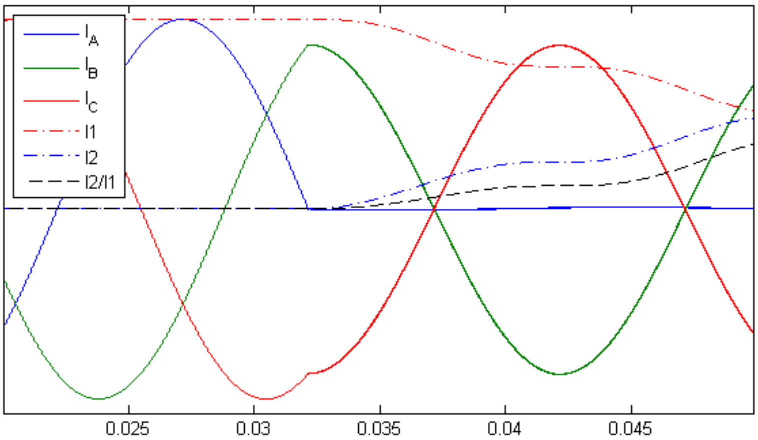


Figure 324: Three-phase current quantities during the broken conductor fault in phase A with the ratio of negative and positive sequence currents

4.4.2.7 Signals

Table 612: PDNSPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
BLOCK	BOOLEAN	0	Block all binary outputs by resetting timers.
BLK_OPR	BOOLEAN	0	Block operate outputs.
BLK_ST	BOOLEAN	0	Block start outputs
FR_TIMER	BOOLEAN	0	Freeze internal operate time counts

Table 613: *PDNSPTOC Output signals*

Name	Type	Description
OPERATE	BOOLEAN	Phase discontinuity protection operated.
START	BOOLEAN	Phase discontinuity protection started

4.4.2.8 Settings

Table 614: PDNSPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	10 - 100	%	1	20	Current ratio setting I2 / I1
Operate delay time	0.100 - 30.000	s	0.001	0.100	Operate time delay

Table 615: PDNSPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 616: PDNSPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset time delay
Min phase current	0.05 - 0.30	pu	0.01	0.10	Minimum phase current

4.4.2.9 Measured values

Table 617: PDNSPTOC Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0.0	Current value of phase A
I_AMPL_B	REAL	0.0	Current value of phase B
I_AMPL_C	REAL	0.0	Current value of phase C
I1_AMPL	REAL	0.0	Positive phase sequence current value
I2_AMPL	REAL	0.0	Negative phase sequence current value
BLOCK	BOOLEAN	0	Block all binary outputs by resetting timers.
BLK_OPR	BOOLEAN	0	Block operate outputs.
BLK_ST	BOOLEAN	0	Block start outputs
FR_TIMER	BOOLEAN	0	Freeze internal operate time counts

4.4.2.10 Monitored data

Table 618: PDNSPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Phase discontinuity protection operated.
START	BOOLEAN	0=FALSE 1=TRUE	-	Phase discontinuity protection started
START_DUR	REAL	-	%	Ratio of start time / operate time
RATIO_I2_I1	REAL	-	%	Measured current ratio I2 / I1

4.4.2.11 Technical data

Table 619: PDNSPTOC Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±2% of the set value
Start time	Typically 15 ms
Reset time	<40 ms
Reset ratio	Typically 0.96
Retardation time	<35 ms
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

4.4.2.12 Technical revision history

Table 620: PDNSPTOC technical revision history

Technical revision	Change
B	Internal improvements

4.4.3 Phase reversal protection PREVPTOC

4.4.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase reversal protection	PREVPTOC	I2>>	46R

4.4.3.2 Function block

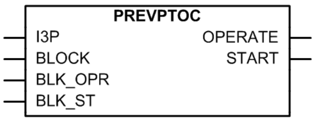


Figure 325: Function block

4.4.3.3 Functionality

The phase-reversal protection PREVPTOC is used to detect the reversed connection of the phases to a three-phase motor by monitoring the negative phase-sequence current I_2 of the motor.

PREVPTOC starts and operates when I_2 exceeds the set limit. PREVPTOC operates on definite time (DT) characteristics. PREVPTOC is based on the calculated I_2, and the function detects too high I_2 values during the motor startup. The excessive I_2 values are caused by incorrectly connected phases, which in turn makes the motor rotate in the opposite direction.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.4.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the phase reversal protection can be described with a module diagram. All the modules in the diagram are explained in the next sections.

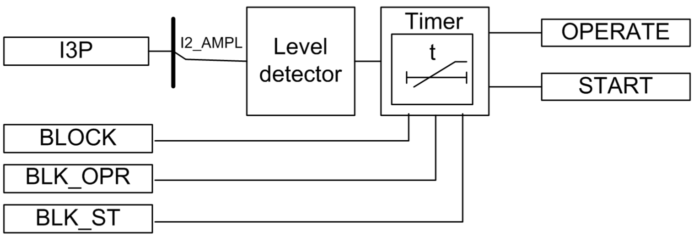


Figure 326: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Level detector

The level detector compares the negative-sequence current to the set *Start value*. If the I_2 value exceeds the set *Start value*, the level detector sends an enabling signal to the timer module.

Timer

Once activated, the timer activates the START output. When the operation timer has reached the set *Operate delay time* value, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value of 200 ms, the operation timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The activation of the BLOCK signal resets the timer and deactivates the START and OPERATE outputs. It is possible to block individual START and OPERATE outputs by the activation of the BLK_ST and BLK_OPR inputs respectively.

4.4.3.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.4.3.6 Application

The rotation of a motor in the reverse direction is not a desirable operating condition. When the motor drives fans and pumps, for example, and the rotation direction is reversed due to a wrong phase sequence, the driven process can be disturbed and the flow of the cooling air of the motor can become reversed too. With a motor designed only for a particular rotation direction, the reversed rotation direction can lead to an inefficient cooling of the motor due to the fan design.

In a motor, the value of the negative sequence component of the phase currents is very negligible when compared to the positive-sequence component of the current during a healthy operating condition of the motor. But when the motor is started with the phase connections in the reverse order, the magnitude of I_2 is very high. So whenever the value of I_2 exceeds the start value, the function detects the reverse rotation direction and provides an operate signal that disconnects the motor from the supply.

4.4.3.7 Signals

Table 621: PREVPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output

Table 622: PREVPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated signal
START	BOOLEAN	Started signal

4.4.3.8 Settings

Table 623: PREVPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.05 - 1.00	pu	0.01	0.75	Start value
Operate delay time	0.100 - 30.000	s	0.001	0.100	Operate delay time

Table 624: PREVPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

Table 625: PREVPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase

4.4.3.9 Measured Values

Table 626: PREVPTOC Measured values

Name	Type	Default	Description
I2_AMPL	REAL	0.0	Negative phase sequence current value
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output

4.4.3.10 Monitored data

Table 627: PREVPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated signal
START	BOOLEAN	0=FALSE 1=TRUE	-	Started signal
START_DUR	REAL	-	%	Start duration in percentage of the total operating time

4.4.3.11 Technical data

Table 628: PREVPTOC Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × I_n
Start time1)2)	I_{Fault} = 2.0 × set *Start value*	Typically 25 ms (±15 ms)
Reset time		<40 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Negative-sequence current before = 0.0 × I_n, f_n = 50 Hz
2) Includes the delay of the signal output contact

4.4.4 Negative-sequence overcurrent protection for machines MNSPTOC

4.4.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overcurrent protection for machines	MNSPTOC	I2>G/M	46G/46M

4.4.4.2 Function block

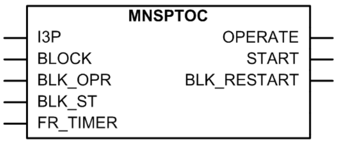


Figure 327: Function block

4.4.4.3 Functionality

The negative-sequence overcurrent protection for machines function MNSPTOC protects electric motors from phase unbalance. A small voltage unbalance can produce a large negative-sequence current flow in the motor. For example, a 5 percent voltage unbalance produces a stator negative-sequence current of 30 percent of the full load current, which can severely heat the motor. MNSPTOC detects the large negative-sequence current and disconnects the motor.

4.4.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of unbalance protection based on negative sequence current can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

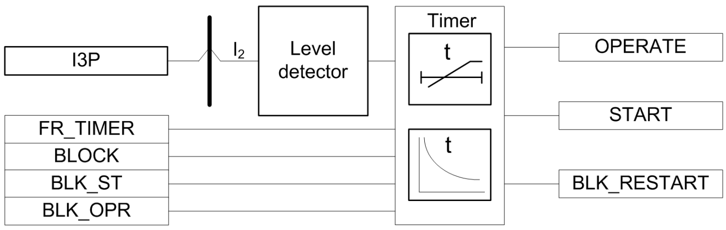


Figure 328: Functional module diagram

Level detector

The calculated negative-sequence current is compared to the *Start value* setting. If the measured value exceeds the *Start value* setting, the function activates the timer module.

Timer

Once activated, the timer activates the `START` output. Depending on the value of the set *Operating curve type*, the time characteristics are according to DT or IDMT. When the operation timer has reached the value set by *Operate delay time* in the

DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

In a drop-off situation, that is, when the value of the negative-sequence current drops below the *Start value* setting, the reset timer is activated and the START output resets after the time delay of *Reset delay time* for the DT characteristics. For IDMT, the reset time depends on the curve type selected.

For the IDMT curves, it is possible to define minimum and maximum operate times with the *Minimum operate time* and *Maximum operate time* settings. The *Machine time Mult* setting parameter corresponds to the machine constant, equal to the I_2^2t constant of the machine, as stated by the machine manufacturer.

The activation of the OPERATE output activates the BLK_RESTART output. The deactivation of the OPERATE output activates the cooling timer. The timer is set to the value entered in the *Cooling time* setting. The BLK_RESTART output is kept active until the cooling timer is exceeded. If the negative-sequence current increases above the set value during this period, the OPERATE output is activated immediately.

The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

The T_ENARESTART output indicates the duration for which the BLK_RESTART output remains active, that is, it indicates the remaining time of the cooling timer. The value is available in the monitored data view.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The BLOCK binary input can be used for blocking the function. Activating the BLOCK input deactivates all the binary outputs and resets the internal timers. It is possible to block individual START and OPERATE outputs with the activation of the BLK_ST and BLK_OPR inputs.

4.4.4.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.4.4.6 Timer characteristics

MNSPTOC supports both DT and IDMT characteristics. The DT timer characteristics can be selected with "ANSI Def. Time" or "IEC Def. Time" in the

Operating curve type setting. The functionality is identical in both cases. When the DT characteristics are selected, the functionality is only affected by the *Operate delay time* and *Reset delay time* settings.

The IED provides two user-programmable IDMT characteristics curves, "Inv. curve A" and "Inv. curve B".

Current-based inverse definite minimum time curve (IDMT)

In inverse-time modes, the operate time depends on the momentary value of the current: the higher the current, the shorter the operate time. The operate time calculation or integration starts immediately when the current exceeds the set *Start value* and the START output is activated.

The OPERATE output of the component is activated when the cumulative sum of the integrator calculating the overcurrent situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used.

The *Minimum operate time* and *Maximum operate time* settings define the minimum operate time and maximum operate time possible for the IDMT mode. For setting these parameters, a careful study of the particular IDMT curves is recommended.

Inv. curve A

The inverse time equation for curve type A is:

$$t[s] = \frac{k}{\left(\frac{I_2}{I_r}\right)^2}$$

(Equation 118)

t[s]	Operate time in seconds
k	Set *Machine time Mult*
I_2	Negative-sequence current
I_r	Set *Rated current*

If the negative-sequence current drops below the *Start value* setting, the reset time is defined as:

$$t[s] = a \times \left(\frac{b}{100}\right)$$

(Equation 119)

t[s]	Reset time in seconds
a	set *Cooling time*
b	percentage of start time elapse (START_DUR)

When the reset period is initiated, the time for which START has been active is saved. Now, if the fault reoccurs, that is, the negative-sequence current rises above the set value during the reset period, the operate calculations are continued using the saved values. However, if the reset period elapses without a fault being detected, the operate timer is reset and the saved values of start time and integration are cleared.

Inv. curve B

The inverse time equation for curve type B is:

$$t[s] = \frac{k}{\left(\frac{I_2}{I_r}\right)^2 - \left(\frac{I_S}{I_r}\right)^2}$$

(Equation 120)

t[s]	Operate time in seconds
k	*Machine time Mult*
I_2	Negative-sequence current
I_S	Set *Start value*
I_r	Set *Rated current*

If the fault disappears, the negative-sequence current drops below the *Start value* setting and the START output is deactivated. However, the function does not reset instantaneously, but instead it depends on the equation or the *Cooling time* setting.

The timer can be reset in two ways:

- With a drop in the negative-sequence current below start value, the subtraction in the denominator becomes negative and the cumulative sum starts to decrease. The decrease in the sum indicates the cooling of the machine and the cooling speed depends on the value of the negative-sequence current. If the sum reaches zero without a fault being detected, the accumulation stops and the timer is reset.
- If the reset time set through the *Cooling time* setting elapses without a fault being detected, the timer is reset.

The reset period thus continues for a time equal to the *Cooling time* setting or until the operate time decreases to zero, whichever is less.

4.4.4.7 Application

In a three-phase motor, the conditions that can lead to unbalance are single phasing, voltage unbalance from the supply and single-phase fault. The negative sequence current damages the motor during the unbalanced voltage condition, and therefore the negative sequence current is monitored to check the unbalance condition.

When the voltages supplied to an operating motor become unbalanced, the positive-sequence current remains substantially unchanged, but the negative-sequence current flows due to the unbalance. For example, if the unbalance is caused by an open circuit in any phase, a negative-sequence current flows and it is equal and opposite to the previous load current in a healthy phase. The combination of positive and negative-sequence currents produces phase currents approximately 1.7 times the previous load in each healthy phase and zero current in the open phase.

The negative-sequence currents flow through the stator windings inducing negative-sequence voltage in the rotor windings. This can result in a high rotor current that damages the rotor winding. The frequency of the induced current is approximately twice the supply frequency. Due to skin effect, the induced current with a frequency double the supply frequency encounters high rotor resistance which leads to excessive heating even with phase currents with value less than the rated current of the motor.

The negative-sequence impedance of induction or a synchronous motor is approximately equal to the locked rotor impedance, which is approximately one-sixth of the normal motor impedance, considering that the motor has a locked-rotor current of six times the rated current. Therefore, even a three percent voltage unbalance can lead to 18 percent stator negative sequence current in windings. The severity of this is indicated by a 30-40 percent increase in the motor temperature due to the extra current.

4.4.4.8 Signals

Table 629: MNSPTOC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
BLOCK	BOOLEAN	0	Blocks all the binary output signals of the function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers

Table 630: MNSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started
BLK_RESTART	BOOLEAN	Signal for blocking reconnection of an overheated machine

4.4.4.9 Settings

Table 631: MNSPTOC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.01 - 0.50	pu	0.01	0.20	Start value of negative-sequence current
Operating curve type	ANSI Def. Time IEC Def. Time Inv. Curve A Inv. Curve B	-	-	IEC Def. Time	Selection of time delay curve type
Machine time Mult	5.0 - 100.0	-	0.1	5.0	Machine time multiplier
Operate delay time	0.10 - 120.00	s	0.01	1.00	Operate time in definite-time mode
Maximum operate time	500 - 7200	s	1	1000	Max operate time regardless of the inverse characteristic
Minimum operate time	0.10 - 120.00	s	0.01	0.10	Definite minimum operate time
Cooling time	5 - 7200	s	1	50	Time required to cool the machine

Table 632: MNSPTOC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 633: MNSPTOC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Reset delay time	0.00 - 60.00	s	0.01	0.02	Resetting time of the operate time counter in DT mode

4.4.4.10 Measured values

Table 634: MNSPTOC Measured values

Name	Type	Default	Description
I2_AMPL	REAL	0.0	Negative phase sequence current value
BLOCK	BOOLEAN	0	Blocks all the binary output signals of the function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze signal for timers

4.4.4.11 Monitored data

Table 635: MNSPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
BLK_RESTART	BOOLEAN	0=FALSE 1=TRUE	-	Signal for blocking reconnection of an overheated machine
T_ENARESTART	INTEGER	-	s	Estimated time to reset of block restart
START_DUR	REAL	-	%	Ratio of start time / operate time

4.4.4.12 Technical data

Table 636: MNSPTOC Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or $\pm 0.002 \times I_n$
Start time[1)2)]	$I_{Fault} = 5.0 \times$ set *Start value*	Typically 43 ms (±15 ms)
Reset time		<70 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±35 ms
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±30 ms [3)]
Suppression of harmonics		DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

1) Negative-sequence current before = $0.0 \times I_n$, f_n = 50 Hz
2) Includes the delay of the signal output contact
3) *Start value* multiples in range of 1.10...5.00

4.4.4.13 Technical revision history

Table 637: MNSPTOC technical revision history

Technical revision	Change
B	Correction in IEC 61850 mapping
C	Change in the function IEC 60617 and ANSI symbol
D	Change in the function description available in PCM600

4.5 Voltage protection

4.5.1 Three-phase overvoltage protection PHPTOV

4.5.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase overvoltage protection	PHPTOV	3U>	59

4.5.1.2 Function block

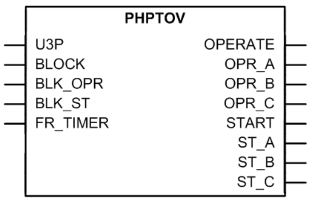


Figure 329: Function block

4.5.1.3 Functionality

The three-phase overvoltage protection PHPTOV is applied on power system elements, such as generators, transformers, motors and power lines, to protect the system from excessive voltages that could damage the insulation and cause insulation breakdown. The three-phase overvoltage function includes a settable value for the detection of overvoltage either in a single phase, two phases or three phases.

Correspondingly, the function gives an operate signal in the respective phases.

PHPTOV includes both definite time (DT) and inverse definite minimum time (IDMT) characteristics for the delay of the trip.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.5.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the three-phase overvoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

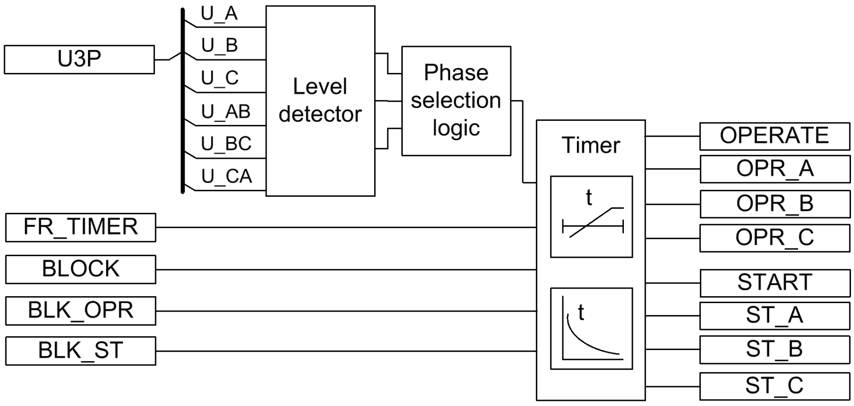


Figure 330: Functional module diagram

Level detector

The fundamental frequency component of the measured three phase voltages are compared phase-wise to the set value of the *Start value* setting. If the measured value is higher than the set value of the *Start value* setting, the level detector enables the phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies above/below the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

The *Voltage selection* setting is used for selecting phase-to-earth or phase-to-phase voltages for protection.

For the voltage IDMT operation mode, the used IDMT curve equations contain discontinuity characteristics (denominator in the equation becomes zero with a certain value of the measured voltage). The *Curve Sat relative* setting is used to compensate for an undesired operation.

For a more detailed description of the IDMT curves and the use of the *Curve Sat Relative* setting, see the General function block features section in this manual.

U_MAX gives the maximum value of the phase-to-earth or phase-to-phase voltages, and U_RATIO is the ratio between U_MAX and the *Start value* setting. The values are available in the monitored data view.

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases matches the set *Num of start phases*, the phase selection logic activates the timer.

Timer

Once activated, the timer activates the `START` output and the corresponding output of the respective phases (ST A, ST B, ST C). Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT. PHPTOV supports the following IDMT operating curve types:

- (5) ANSI Def. Time
- (15) IEC Def. Time
- (17) Inv. Curve A
- (18) Inv. Curve B
- (19) Inv. Curve C
- (20) Programmable.

For a detailed description of the voltage IDMT curves, see the General function block features section in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value set by the IDMT operate time curve, the `OPERATE` output is activated. The corresponding output for the respective phases (OPR A, OPR B, OPR C) is also activated.

When the user programmable IDMT operate time curve is selected, the operate time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation occurs, that is, a fault suddenly disappears before the operation delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected operation time characteristics. If the DT characteristics are selected, the reset timer runs until the set *Reset delay time* value is exceeded. If the drop-off situation exceeds the set *Reset delay time*, the timer is reset and the `START` output is deactivated.

When the IDMT operation time curve is selected, the functionality of the timer in the drop-off state depends on the combination of the *Type of reset curve*, *Type of time reset* and *Reset delay time* settings.

Table 638: Reset time functionality when IDMT operation time curve selected

Reset functionality		Value/effect of settings		
		"Type of reset curve"	*Type of time reset*	*Reset delay time*
Instantaneous reset	Operation timer is reset instantaneously when drop-off occurs	“Immediate”	Setting has no effect	Setting has no effect
Frozen timer	Operation timer is frozen during drop-off	“Def time reset”	“Freeze Op Timer”	Defines the freezing time for operation timer during drop-off. After the set delay, the operate timer is reset.
Linear decrease	Operation timer value linearly decreases during the drop-off situation	“Def time reset”	“Decr. Op timer”	Operation timer is reset after the set value is exceeded.

Example

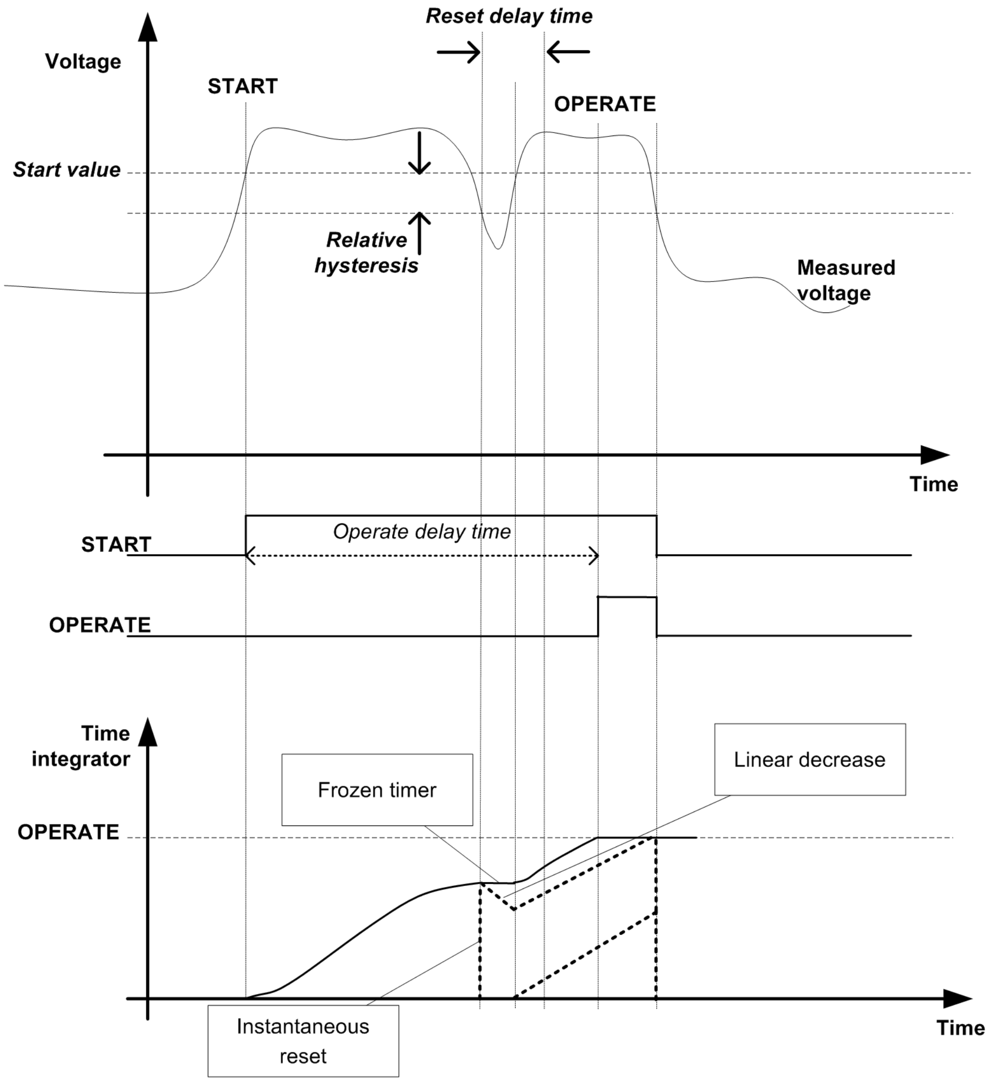


Figure 331: Behavior of different IDMT reset modes.

The *Time multiplier* setting is used for scaling the IDMT operating times.

The *Minimum operate time* setting defines the minimum operate time for IDMT. The setting is only applicable when the IDMT curves are used.

The *Minimum operate time* setting should be used with care because the operation time is according to the IDMT curve but always at least the value of the *Minimum operate time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets the internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operating signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

Note that the FR_TIMER input has no effect during definite time linearly decreasing reset.

4.5.1.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.5.1.6 Application

Overvoltage in a network occurs either due to the transient surges on the network or due to prolonged power frequency overvoltages. Surge arresters are used to protect the network against the transient overvoltages, but the IED protection function is used to protect against power frequency overvoltages.

The power frequency overvoltage may occur in the network due to contingencies such as:

- Defective operation of the automatic voltage regulator when the generator is in isolated operation.
- Operation under manual control with the voltage regulator out of service. A sudden variation of load, in particular the reactive power component, gives rise to a substantial change in voltage because of the large voltage regulation inherent in a typical alternator.
- Sudden loss of load due to the tripping of outgoing feeders, leaving the generator isolated or feeding a very small load, can cause a sudden rise in the terminal voltage due to the trapped field flux and overspeed.

PHPTOV is not usually applied to the attended generators but can be required for the unattended automatic hydro-stations. If a load sensitive to overvoltages remains connected, it leads to equipment damage.

Therefore, it is essential to provide power frequency overvoltage protection in the form of time delayed element, either IDMT or DT.

4.5.1.7 Signals

Table 639: PHPTOV Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Voltage magnitude in all the three phases
BLOCK	BOOLEAN	0	Blocks all the binary output signals of the function
BLK_OPR	BOOLEAN	0	Blocks all the trip signals of the function
BLK_ST	BOOLEAN	0	Blocks all the start outputs of the function
FR_TIMER	BOOLEAN	0	Freezes all the operate timer counts

Table 640: PHPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal, combined
OPR_A	BOOLEAN	Operate signal, phase 1
OPR_B	BOOLEAN	Operate signal, phase 2
OPR_C	BOOLEAN	Operate signal, phase 3
START	BOOLEAN	Start signal, combined
ST_A	BOOLEAN	Start signal, phase 1
ST_B	BOOLEAN	Start signal, phase 2
ST_C	BOOLEAN	Start signal, phase 3

4.5.1.8 Settings

Table 641: PHPTOV Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.05 - 1.60	pu	0.01	1.10	Preset value to check for the voltage violation
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC curves
Operating curve type	ANSI Def. Time IEC Def. Time Inv. Curve A Inv. Curve B Inv. Curve C Programmable	-	-	IEC Def. Time	Selection of the type of time delay curve
Operate delay time	0.040 - 300.000	s	0.010	0.040	Operating time delay for definite time curve

Table 642: PHPTOV Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Type of reset curve	Immediate Def time reset	-	-	Immediate	Selection of reset curve type
Type of time reset	Freeze Op timer Decr. Op timer	-	-	Freeze Op timer	Type of time reset (1=Freeze Op timer, 2= Decrease Op timer)

Table 643: PHPTOV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
Voltage selection	phase-to-earth phase-to-phase	-	-	phase-to-phase	Parameter to select phase or phase-to-phase voltages
Num of start phases	1 out of 3 2 out of 3 3 out of 3	-	-	1 out of 3	Number of phases required for operate activation

Table 644: PHPTOV Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Relative hysteresis	1.0 - 5.0	%	0.1	4.0	Relative Hysteresis to compensate for oscillations
Curve Sat Relative	0.0 - 10.0	%	0.1	2.0	Tuning parameter to avoid curve discontinuities
Curve parameter A	0.005 - 200.000	-	0.001	1.000	Parameter A for customer programmable curve
Curve parameter B	0.50 - 100.00	-	0.01	1.00	Parameter B for customer programmable curve
Curve parameter C	0.0 - 1.0	-	0.1	0.0	Parameter C for customer programmable curve
Curve parameter D	0.000 - 60.000	-	0.001	0.000	Parameter D for customer programmable curve
Curve parameter E	0.000 - 3.000	-	0.001	1.000	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Delay time provided to reset the timers
Minimum operate time	0.040 - 60.000	s	0.001	0.040	Minimum operate time delay for IDMT curves

4.5.1.9 Measured values

Table 645: PHPTOV Measured values

Name	Type	Default	Description
U_AMPL_A	REAL	0.000	Phase to ground voltage phase A
U_AMPL_B	REAL	0.000	Phase to ground voltage phase B
U_AMPL_C	REAL	0.000	Phase to ground voltage phase C
U_AMPL_AB	REAL	0.000	Phase-to-phase voltage AB
U_AMPL_BC	REAL	0.000	Phase-to-phase voltage BC
U_AMPL_CA	REAL	0.000	Phase-to-phase voltage CA
BLOCK	BOOLEAN	0	Blocks all the binary output signals of the function
BLK_OPR	BOOLEAN	0	Blocks all the trip signals of the function
BLK_ST	BOOLEAN	0	Blocks all the start outputs of the function
FR_TIMER	BOOLEAN	0	Freezes all the operate timer counts

4.5.1.10 Monitored data

Table 646: PHPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal, phase 1
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal, phase 2
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal, phase 3
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Start signal, phase 1
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Start signal, phase 2
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Start signal, phase 3
U_MAX	REAL	-	V	Maximum of the phase or phase-to-phase voltages
U_RATIO	REAL	-	-	Maximum voltage ratio to the Start value
START_DUR	REAL	-	%	Ratio of Start time to Operate time

4.5.1.11 Technical data

Table 647: PHPTOV Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × U_n
Start time[1)2)]	U_{Fault} = 2.0 × set *Start value*	Typically 17 ms (±15 ms)
Reset time		<40 ms
Reset ratio		Depends of the set *Relative hysteresis*
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms[3)]
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) *Start value* = 1.0 × U_n, Voltage before fault = 0.9 × U_n, f_n = 50 Hz, overvoltage in one phase-to-phase with nominal frequency injected from random phase angle
2) Includes the delay of the signal output contact
3) Maximum *Start value* = 1.20 × U_n, *Start value* multiples in range of 1.10...2.00

4.5.1.12 Technical revision history

Table 648: PHPTOV technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

4.5.2 Three-phase undervoltage protection PHPTUV

4.5.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase undervoltage protection	PHPTUV	3U<	27

4.5.2.2 Function block

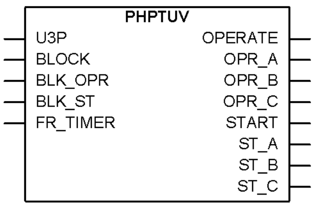


Figure 332: Function block

4.5.2.3 Functionality

The three-phase undervoltage protection PHPTUV is used to disconnect from the network devices, for example electric motors, which are damaged when subjected to service under low voltage conditions. PHPTUV includes a settable value for the detection of undervoltage either in a single phase, two phases or three phases.Correspondingly, the function gives an operate signal in the respective phases.

PHPTUV includes both definite time (DT) and inverse definite minimum time (IDMT) characteristics for the delay of the trip.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.5.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the three-phase undervoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

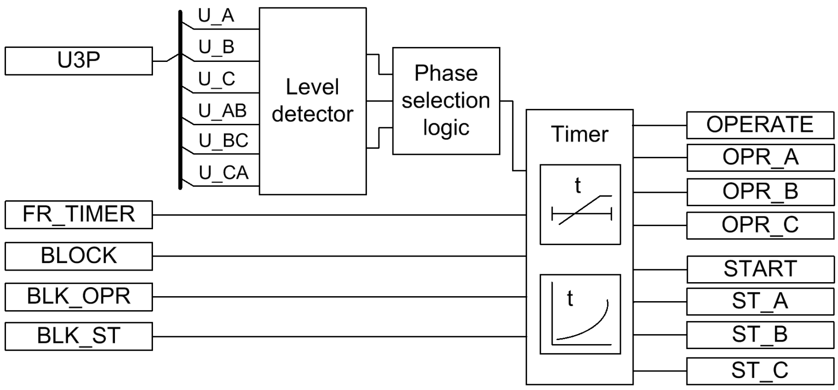


Figure 333: Functional module diagram

Level detector

The fundamental frequency component of the measured three phase voltages are compared phase-wise to the set value of the *Start value* setting. If the measured value is lower than the set value of the *Start value* setting, the level detector enables the phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies above/below the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

Blocking for low voltage levels is activated by default (*Enable block value* is set to "Yes"). The desired blocking level can be adjusted by the *Voltage block value* setting.

The *Voltage selection* setting is used for selecting phase-to-earth or phase-to-phase voltages for protection.

For the voltage IDMT operation mode, the used IDMT curve equations contain discontinuity characteristics (denominator in the equation becomes zero with a certain value of the measured voltage). The *Curve Sat relative* setting is used to compensate for an undesired operation.

For a more detailed description of the IDMT curves and the use of the *Curve Sat Relative* setting, see the General function block features section in this manual.

U_MIN gives the maximum value of the phase-to-earth or phase-to-phase voltages, and U_RATIO is the ratio between U_MIN and the *Start value* setting. The values are available in the monitored data view.

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases matches the set *Num of start phases*, the phase selection logic activates the timer.

Timer

Once activated, the timer activates the `START` output and the corresponding output of the respective phases (ST A, ST B, ST C). Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT. PHPTUV supports the following IDMT operating curve types:

- (5) ANSI Def. Time
- (15) IEC Def. Time
- (21) Inv. Curve A
- (22) Inv. Curve B
- (23) Programmable

For a detailed description of the voltage IDMT curves, see the General function block features section in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value set by the IDMT operate time curve, the `OPERATE` output is activated. The corresponding output for the respective phases (OPR A, OPR B, OPR C) is also activated.

When the user programmable IDMT operate time curve is selected, the operate time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation occurs, that is, a fault suddenly disappears before the operation delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected operation time characteristics. If the DT characteristics are selected, the reset timer runs until the set *Reset delay time* value is exceeded. If the drop-off situation exceeds the set *Reset delay time*, the timer is reset and the `START` output is deactivated.

When the IDMT operation time curve is selected, the functionality of the timer in the drop-off state depends on the combination of the *Type of reset curve*, *Type of time reset* and *Reset delay time* settings.

Table 649: Reset time functionality when IDMT operation time curve selected

Reset functionality		Value/effect of settings		
		"Type of reset curve"	*Type of time reset*	*Reset delay time*
Instantaneous reset	Operation timer is reset instantaneously when drop-off occurs	“Immediate”	Setting has no effect	Setting has no effect
Frozen timer	Operation timer is frozen during drop-off	“Def time reset”	“Freeze Op Timer”	Defines the freezing time for operation timer during drop-off. After the set delay, the operate timer is reset.
Linear decrease	Operation timer value linearly decreases during the drop-off situation	“Def time reset”	“Decr. Op timer”	Operation timer is reset after the set value is exceeded.

Example

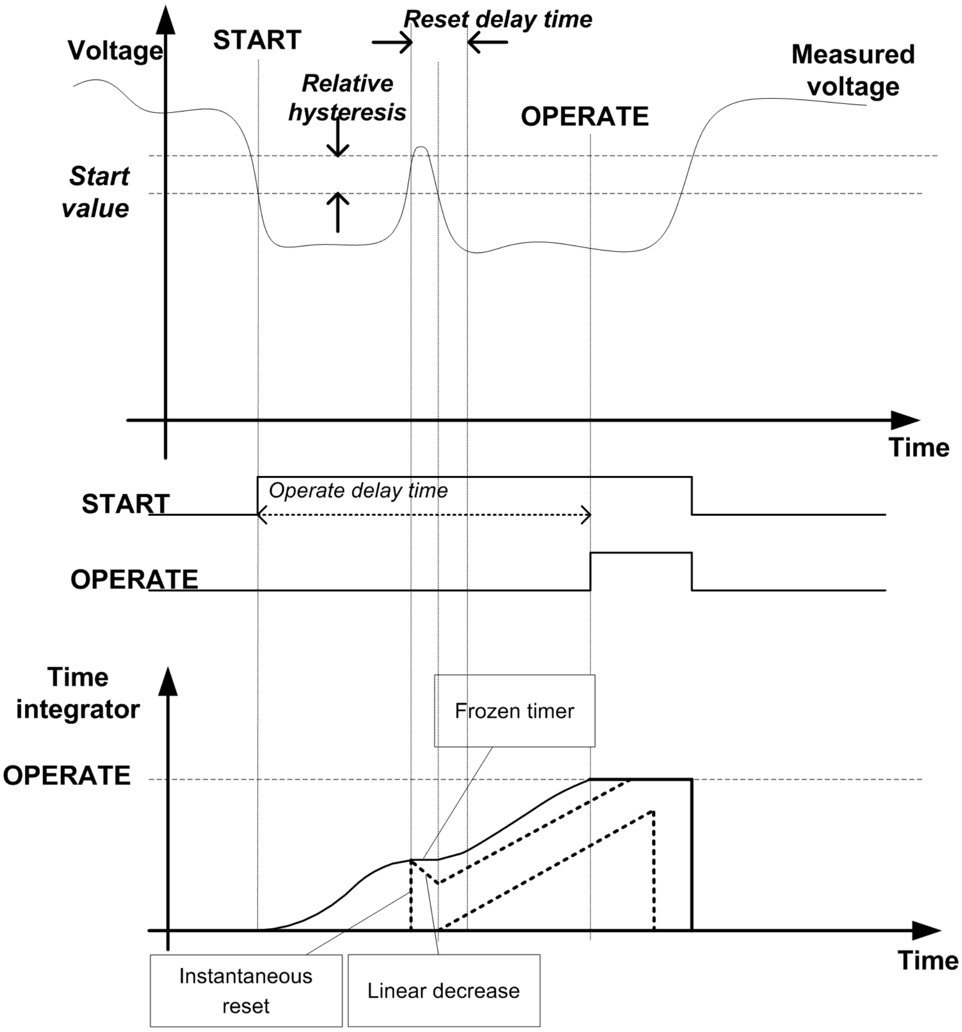


Figure 334: Behavior of different IDMT reset modes

The *Time multiplier* setting is used for scaling the IDMT operating times.

The *Minimum operate time* setting defines the minimum operate time for IDMT. The setting is only applicable when the IDMT curves are used.

The *Minimum operate time* setting should be used with care because the operation time is according to the IDMT curve but always at least the value of the *Minimum operate time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets the internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operating signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

Note that the FR_TIMER input has no effect during definite time linearly decreasing reset.

4.5.2.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.5.2.6 Application

PHPTUV is applied to power system elements, such as generators, transformers, motors and power lines, to detect low voltage conditions. Low voltage conditions are caused by abnormal operation or a fault in the power system. PHPTUV can be used in combination with overcurrent protections. Other applications are the detection of a no-voltage condition, for example before the energization of a high voltage line, or an automatic breaker trip in case of a blackout. PHPTUV is also used to initiate voltage correction measures, such as insertion of shunt capacitor banks, to compensate for a reactive load and thereby to increase the voltage.

PHPTUV can be used to disconnect from the network devices, such as electric motors, which are damaged when subjected to service under low voltage conditions. PHPTUV deals with low voltage conditions at power system frequency. Low voltage conditions can be caused by:

1. Malfunctioning of a voltage regulator or wrong settings under manual control (symmetrical voltage decrease).
2. Overload (symmetrical voltage decrease).
3. Short circuits, often as phase-to-earth faults (unsymmetrical voltage decrease).

PHPTUV prevents sensitive equipment from running under conditions that could cause overheating and thus shorten their life time expectancy. In many cases, PHPTUV is a useful function in circuits for local or remote automation processes in the power system.

4.5.2.7 Signals

Table 650: PHPTUV Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Voltage magnitude in all the three phases
BLOCK	BOOLEAN	0	Blocks all the binary output signals of the function
BLK_OPR	BOOLEAN	0	Blocks all the trip signals of the function
BLK_ST	BOOLEAN	0	Blocks all the start outputs of the function
FR_TIMER	BOOLEAN	0	Freezes all the operate timer counts

Table 651: PHPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal, combined
OPR_A	BOOLEAN	Operate signal, phase 1
OPR_B	BOOLEAN	Operate signal, phase 2
OPR_C	BOOLEAN	Operate signal, phase 3
START	BOOLEAN	Start signal, combined
ST_A	BOOLEAN	Start signal, phase 1
ST_B	BOOLEAN	Start signal, phase 2
ST_C	BOOLEAN	Start signal, phase 3

4.5.2.8 Settings

Table 652: PHPTUV Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.05 - 1.20	pu	0.01	0.90	Preset value to check for the voltage violation
Time multiplier	0.05 - 15.00	-	0.01	1.00	Time multiplier in IEC curves
Operating curve type	ANSI Def. Time IEC Def. Time Inv. Curve A Inv. Curve B Programmable	-	-	IEC Def. Time	Selection of the type of time delay curve
Operate delay time	0.040 - 300.000	s	0.010	0.040	Operating time delay for definite time curve

Table 653: PHPTUV Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Type of reset curve	Immediate Def time reset	-	-	Immediate	Selection of reset curve type
Type of time reset	Freeze Op timer Decr. Op timer	-	-	Freeze Op timer	Type of time reset (1=Freeze Op timer, 2= Decrease Op timer)

Table 654: PHPTUV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
Voltage selection	phase-to-earth phase-to-phase	-	-	phase-to-phase	Parameter to select phase or phase-to-phase voltages
Phase supervision	A or AB B or BC A&B or AB&BC C or CA A&C or AB&CA B&C or BC&CA All	-	-	All	Parameter for phase selection in undervoltage protection
Num of start phases	1 out of 3 2 out of 3 3 out of 3	-	-	1 out of 3	Number of phases required for operate activation

Table 655: PHPTUV Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Voltage block value	0.05 - 1.00	pu	0.01	0.20	Low level blocking for undervoltage mode
Relative hysteresis	1.0 - 5.0	%	0.1	4.0	Relative Hysteresis to compensate for oscillations
Curve Sat Relative	0.0 - 10.0	%	0.1	2.0	Tuning parameter to avoid curve discontinuities
Curve parameter A	0.005 - 200.000	-	0.001	1.000	Parameter A for customer programmable curve
Curve parameter B	0.50 - 100.00	-	0.01	1.00	Parameter B for customer programmable curve
Curve parameter C	0.0 - 1.0	-	0.1	0.0	Parameter C for customer programmable curve
Curve parameter D	0.000 - 60.000	-	0.001	0.000	Parameter D for customer programmable curve
Curve parameter E	0.000 - 3.000	-	0.001	1.000	Parameter E for customer programmable curve
Reset delay time	0.000 - 60.000	s	0.001	0.020	Delay time provided to reset the timers
Minimum operate time	0.040 - 60.000	s	0.001	0.040	Minimum operate time delay for IDMT curves
Enable block value	No Yes	-	-	Yes	Enable internal blocking

4.5.2.9 Measured values

Table 656: PHPTUV Measured values

Name	Type	Default	Description
U_AMPL_A	REAL	0.000	Phase to ground voltage phase A
U_AMPL_B	REAL	0.000	Phase to ground voltage phase B
U_AMPL_C	REAL	0.000	Phase to ground voltage phase C
U_AMPL_AB	REAL	0.000	Phase-to-phase voltage AB
U_AMPL_BC	REAL	0.000	Phase-to-phase voltage BC
U_AMPL_CA	REAL	0.000	Phase-to-phase voltage CA
BLOCK	BOOLEAN	0	Blocks all the binary output signals of the function
BLK_OPR	BOOLEAN	0	Blocks all the trip signals of the function
BLK_ST	BOOLEAN	0	Blocks all the start outputs of the function
FR_TIMER	BOOLEAN	0	Freezes all the operate timer counts

4.5.2.10 Monitored data

Table 657: PHPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal, phase 1
OPR_B	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal, phase 2
OPR_C	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal, phase 3
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Start signal, phase 1
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Start signal, phase 2
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Start signal, phase 3
U_MIN	REAL	-	V	Minimum of the phase or phase-to-phase voltages
U_RATIO	REAL	-	-	Minimum voltage ratio to the Start value
START_DUR	REAL	-	%	Ratio of Start time to Operate time

4.5.2.11 Technical data

Table 658: PHPTUV Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or $\pm 0.002 \times U_n$
Start time[1)2)]	$U_{Fault} = 0.9 \times$ set *Start value*	Typically 24 ms (±15 ms)
Reset time		<40 ms
Reset ratio		Depends of the set *Relative hysteresis*
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms[3)]
Suppression of harmonics		DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

1) *Start value* = $1.0 \times U_n$, Voltage before fault = $1.1 \times U_n$, f_n = 50 Hz, undervoltage in one phase-to-phase with nominal frequency injected from random phase angle
2) Includes the delay of the signal output contact
3) Minimum *Start value* = $0.50 \times U_n$, *Start value* multiples in range of 0.90...0.20

4.5.2.12 Technical revision history

Table 659: PHPTUV technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for *Time multiplier* setting

4.5.3 Residual overvoltage protection ROVPTOV

4.5.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual overvoltage protection	ROVPTOV	Uo>	59G

4.5.3.2 Function block

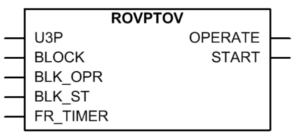


Figure 335: Function block

4.5.3.3 Functionality

The residual overvoltage protection ROVPTOV is used in distribution networks where the residual overvoltage can reach non-acceptable levels in, for example, high impedance earthing.

The function starts when the residual voltage exceeds the set limit. ROVPTOV operates with the definite time (DT) characteristic.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.5.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of residual overvoltage protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

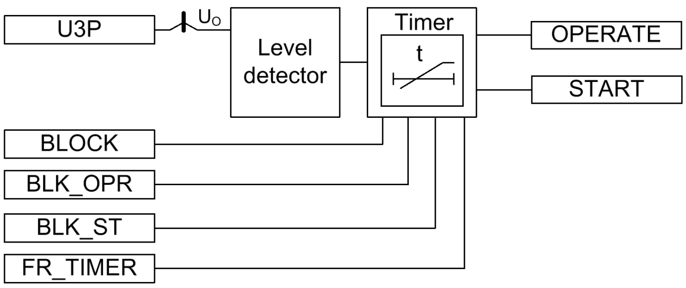


Figure 336: Functional module diagram. Group signal U3P is used for feeding the necessary analog signals to the function.

Level detector

The measured or calculated residual voltage is compared with the set *Start value*. If the value exceeds the set *Start value*, the level detector sends an enable signal to the timer.

Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

4.5.3.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the residual current or voltage-related settings, for example, "*Residual Grp 1*", "*Residual Grp 2*" and "*Residual Grp 3*". One of the groups to be used with the "Base value Sel Res" setting must be selected.

4.5.3.6 Application

ROVPTOV is designed to be used for earth-fault protection in isolated neutral, resistance earthed or reactance earthed systems. In compensated networks, starting of the function can be used to control the switching device of the neutral resistor. The function can also be used for the back-up protection of feeders for busbar protection when a more dedicated busbar protection would not be justified.

In compensated and isolated neutral systems, the system neutral voltage, that is, the residual voltage, increases in case of any fault connected to earth. Depending on the type of the fault and the fault resistance, the residual voltage reaches different values. The highest residual voltage, equal to the phase-to-earth voltage, is achieved for a single-phase earth fault. The residual voltage increases approximately the same amount in the whole system and does not provide any guidance in finding the faulty component. Therefore, this function is often used as a backup protection or as a release signal for the feeder earth-fault protection.

The protection can also be used for the earth-fault protection of generators and motors and for the unbalance protection of capacitor banks.

The residual voltage can be calculated internally based on the measurement of the three-phase voltage. This voltage can also be measured by a single-phase voltage transformer, located between a transformer star point and earth, or by using an open-delta connection of three single-phase voltage transformers.

4.5.3.7 Signals

Table 660: ROVPTOV Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer

Table 661: ROVPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal for residual overvoltage logic
START	BOOLEAN	Start signal for residual overvoltage logic

4.5.3.8 Settings

Table 662: ROVPTOV Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.010 - 1.000	pu	0.001	0.030	Residual overvoltage start value
Operate delay time	0.040 - 300.000	s	0.001	0.040	Operate delay time

Table 663: ROVPTOV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

Table 664: ROVPTOV Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.5.3.9 Measured values

Table 665: ROVPTOV Measured values

Name	Type	Default	Description
U0_AMPL	REAL	0.0	Residual voltage amplitude
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer

4.5.3.10 Monitored data

Table 666: ROVPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for residual overvoltage logic
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for residual overvoltage logic
START_DUR	REAL	-	%	Start duration in percentage of the total operating time

4.5.3.11 Technical data

Table 667: ROVPTOV Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × U_n
Start time[1)2)]	U_{Fault} = 1.1 × set *Start value*	Typically 27 ms (± 15 ms)
Reset time		<40 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Residual voltage before fault = 0.0 × U_n, f_n = 50 Hz, residual voltage with nominal frequency injected from random phase angle
2) Includes the delay of the signal output contact

4.5.4 Positive sequence overvoltage protection PSPTOV

4.5.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Positive-sequence overvoltage protection	PSPTOV	U1>	47O+

4.5.4.2 Function block

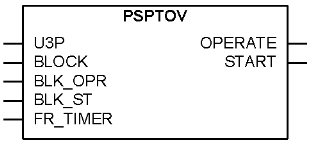


Figure 337: Function block

4.5.4.3 Functionality

The positive sequence overvoltage protection PSPTOV is used as an alternative to the ordinary three-phase overvoltage protection. PSPTOV is used for supervision and for detection of abnormal conditions, which, in combination with the other protection functions, increase the security of the complete protection system.

The function starts when the positive sequence voltage exceeds the set limit. PSPTOV operates on definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.5.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the positive-sequence overvoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

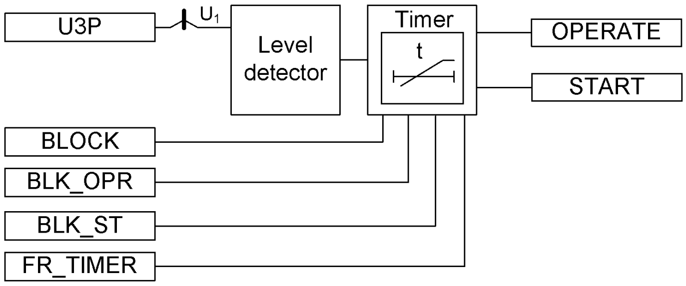


Figure 338: Functional module diagram. The U3P group signal is used for feeding the necessary analog signals to the function.

Level detector

The calculated positive-sequence voltage is compared to the set *Start value* setting. If the value exceeds the set *Start value*, the level detector enables the timer. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies from the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated if the overvoltage condition persists. If the positive sequence voltage normalizes before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets internal timers. The binary input `BLK_ST` can be used to block the start signals. The binary input `BLK_OPR` can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the `FR_TIMER` input.

4.5.4.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.5.4.6 Application

A sudden power loss, tap-changer regulating failures and open line ends on long lines are abnormal conditions which cause overvoltages in a power system. PSPTOV is applied to power system elements, such as generators, transformers, motors and power lines, to detect overvoltage conditions.

PSPTOV can be used in combination with low-current signals or a directional reactive overpower function to identify the distribution line with an open remote end. PSPTOV can also be used to initiate voltage correction measures like insertion of shunt reactors or switching out capacitor banks to control the voltage.

Overvoltage faced by the power transformer can lead to an overexcitation problem. The overexcitation occurs normally when the ratio of the voltage-to-frequency increases much above the design value resulting into transformer operation under a nonlinear region. Such an overvoltage situation can be faced by a transformer during a sudden loss of load due to underfrequency load shedding. The overexcitation results into increase in exciting current eventually resulting into heating of core and can damage the transformer. The positive sequence overvoltage protection along with the underfrequency protection can be used for the protection of the transformer during overexcitation.

Some common reasons leading to positive sequence overvoltages are:

- Broken conductor falling to a crossing overhead line, transformer flash overfault from high voltage winding to low voltage winding
- Malfunctioning of a voltage regulator or wrong settings under manual control (symmetrical voltage increase)
- Low load compared to the reactive power generation (symmetrical voltage increase)

PSPTOV prevents sensitive equipment from running overvoltage conditions causing the equipment to overheat or stress on insulation material.

4.5.4.7 Signals

Table 668: PSPTOV Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer

Table 669: PSPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal for Positive Sequence Overvoltage logic
START	BOOLEAN	Start signal for Positive Sequence Overvoltage logic

4.5.4.8 Settings

Table 670: PSPTOV Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.800 - 1.600	pu	0.001	1.100	Positive Sequence overvoltage start value
Operate delay time	0.040 - 120.000	s	0.001	0.040	Operate delay time

Table 671: PSPTOV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

Table 672: PSPTOV Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Relative hysteresis	1.0 - 5.0	%	0.1	4.0	Relative hysteresis for operation
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.5.4.9 Measured values

Table 673: PSPTOV Measured values

Name	Type	Default	Description
U1_AMPL	REAL	0.0	Positive sequence voltage amplitude
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer

4.5.4.10 Monitored data

Table 674: PSPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for Positive Sequence Overvoltage logic
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for Positive Sequence Overvoltage logic
START_DUR	REAL	-	%	Start duration in percentage of the total operating time

Table 675: PSPTOV Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$ ±1.5% of the set value or ±0.002 × U_n
Start time[1)2)]	U_{Fault} = 1.1 × set *Start value* U_{Fault} = 2.0 × set *Start value*	Typically 29 ms (±15 ms) Typically 24 ms (±15 ms)
Reset time		<40 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Positive-sequence voltage before fault = 0.0 × U_n, f_n = 50 Hz, positive-sequence overvoltage of nominal frequency injected from random phase angle
2) Includes the delay of the signal output contact

4.5.5 Negative sequence overvoltage protection NSPTOV

4.5.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overvoltage protection	NSPTOV	U2>	47O-

4.5.5.2 Function block

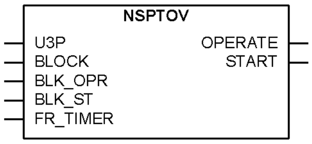


Figure 339: Function block

4.5.5.3 Functionality

The negative-sequence overvoltage protection NSPTOV is used to detect negative sequence overvoltage conditions. NSPTOV is used for the protection of machines.

The function starts when the negative sequence voltage exceeds the set limit. NSPTOV operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.5.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the negative-sequence overvoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

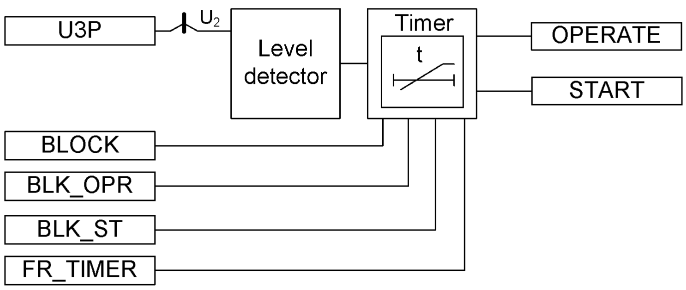


Figure 340: Functional module diagram. The U3P group signal is used for feeding the necessary analog signals to the function.

Level detector

The calculated negative-sequence voltage is compared to the set *Start value* setting. If the value exceeds the set *Start value*, the level detector enables the timer.

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated if the overvoltage condition persists. If the negative-sequence voltage normalizes before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

4.5.5.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.5.5.6 Application

A continuous or temporary voltage unbalance can appear in the network for various reasons. The voltage unbalance mainly occurs due to broken conductors or asymmetrical loads and is characterized by the appearance of a negative-sequence component of the voltage. In rotating machines, the voltage unbalance results in a current unbalance, which heats the rotors of the machines. The rotating machines, therefore, do not tolerate a continuous negative-sequence voltage higher than typically 1-2 percent x U_n.

The negative-sequence component current I_2, drawn by an asynchronous or a synchronous machine, is linearly proportional to the negative-sequence component voltage U_2. When U_2 is P% of U_n, I_2 is typically about 5 x P% x I_n.

The negative-sequence overcurrent NSPTOC blocks are used to accomplish a selective protection against the voltage and current unbalance for each machine separately. Alternatively, the protection can be implemented with the NSPTOV function, monitoring the voltage unbalance of the busbar.

If the machines have an unbalance protection of their own, the NSPTOV operation can be applied as a backup protection or it can be used as an alarm. The latter can be applied when it is not required to trip loads tolerating voltage unbalance better than the rotating machines.

If there is a considerable degree of voltage unbalance in the network, the rotating machines should not be connected to the network at all. This logic can be implemented by inhibiting the closure of the circuit breaker if the NSPTOV operation has started. This scheme also prevents connecting the machine to the network if the phase sequence of the network is not correct.

An appropriate value for the setting parameter *Voltage start value* is approximately 3 percent of U_n. A suitable value for the setting parameter *Operate delay time* depends on the application. If the NSPTOV operation is used as backup protection, the operate time should be set in accordance with the operate time of NSPTOC used as main protection. If the NSPTOV operation is used as main protection, the operate time should be approximately one second.

4.5.5.7 Signals

Table 676: NSPTOV Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer

Table 677: NSPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal for Negative Sequence Overvoltage logic
START	BOOLEAN	Start signal for Negative Sequence Overvoltage logic

4.5.5.8 Settings

Table 678: NSPTOV Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.010 - 1.000	pu	0.001	0.030	Negative sequence overvoltage start value
Operate delay time	0.040 - 120.000	s	0.001	0.040	Operate delay time

Table 679: NSPTOV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

Table 680: NSPTOV Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.5.5.9 Measured values

Table 681: NSPTOV Measured values

Name	Type	Default	Description
U2_AMPL	REAL	0.0	Negative sequence voltage amplitude
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer

4.5.5.10 Monitored data

Table 682: NSPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for Negative Sequence Overvoltage logic
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for Negative Sequence Overvoltage logic
START_DUR	REAL	-	%	Start duration in percentage of the total operating time

4.5.5.11 Technical data

Table 683: NSPTOV Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × U_n
Start time[1)2)]	U_{Fault} = 1.1 × set *Start value* U_{Fault} = 2.0 × set *Start value*	Typically 29 ms (± 15ms) Typically 24 ms (± 15ms)
Reset time		<40 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Negative-sequence voltage before fault = 0.0 × U_n, f_n = 50 Hz, negative-sequence overvoltage of nominal frequency injected from random phase angle
2) Includes the delay of the signal output contact

4.5.6 Positive sequence undervoltage protection PSPTUV

4.5.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Positive-sequence undervoltage protection	PSPTUV	U1<	47U+

4.5.6.2 Function block

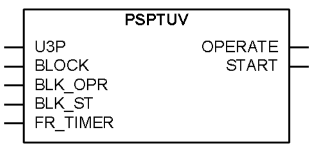


Figure 341: Function block

4.5.6.3 Functionality

The positive-sequence undervoltage protection PSPTUV is used to detect positive-sequence undervoltage conditions. PSPTUV is used for the protection of small power generation plants. The function helps in isolating an embedded plant from a fault line when the fault current fed by the plant is too low to start an overcurrent function but high enough to maintain the arc. Fast isolation of all the fault current sources is necessary for a successful autoreclosure from the network-end circuit breaker.

The function starts when the positive-sequence voltage drops below the set limit. PSPTUV operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.5.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the positive-sequence undervoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

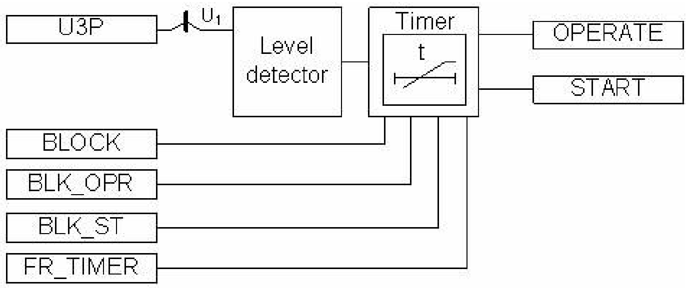


Figure 342: Functional module diagram. The U3P group signal is used for feeding the necessary analog signals to the function.

Level detector

The calculated positive-sequence voltage is compared to the set *Start value* setting. If the value drops below the set *Start value*, the level detector enables the timer. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies from the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

The level detector contains a low-level blocking functionality for cases where the positive-sequence voltage is below the desired level. This feature is useful when unnecessary starts and operates are wanted to avoid during, for example, an autoreclose sequence. The low-level blocking is activated by default (*Enable block value* is set to “Enabled”) and the blocking level can be set with the *Voltage block value* setting.

Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate* *delay time*, the OPERATE output is activated if the undervoltage condition persists. If the positive-sequence voltage normalizes before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block the operation signals. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

4.5.6.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.5.6.6 Application

PSPTUV can be applied for protecting a power station used for embedded generation when network faults like short circuits or phase-to-earth faults in a transmission or a distribution line cause a potentially dangerous situations for the power station. A network fault can be dangerous for the power station for various reasons. The operation of the protection can cause an islanding condition, also called a loss-of-mains condition, in which a part of the network, that is, an island fed by the power station, is isolated from the rest of the network. There is then a risk of an autoreclosure taking place when the voltages of different parts of the network do not synchronize, which is a straining incident for the power station. Another risk is that the generator can lose synchronism during the network fault. A sufficiently fast trip of the utility circuit breaker of the power station can avoid these risks.

The lower the three-phase symmetrical voltage of the network is, the higher is the probability that the generator loses the synchronism. The positive-sequence voltage is also available during asymmetrical faults. It is a more appropriate criterion for detecting the risk of loss of synchronism than, for example, the lowest phase-to-phase voltage.

Analyzing the loss of synchronism of a generator is rather complicated and requires a model of the generator with its prime mover and controllers. The generator can be able to operate synchronously even if the voltage drops by a few tens of percent for some hundreds of milliseconds. The setting of PSPTUV is thus determined by the need to protect the power station from the risks of the islanding conditions since that requires a higher setting value.

The loss of synchronism of a generator means that the generator is unable to operate as a generator with the network frequency but enters into an unstable condition in which it operates by turns as a generator and a motor. Such a condition stresses the generator thermally and mechanically. This kind of loss of synchronism should not be mixed with the one between an island and the utility network. In the islanding situation, the condition of the generator itself is normal but the phase angle and the frequency of the phase-to-phase voltage can be different from the corresponding voltage in the rest of the network. The island can have a frequency of its own relatively fast when fed by a small power station with a low inertia.

PSPTUV complements other loss-of-grid protection principles based on the frequency and voltage operation.

Motor stalling and failure to start can lead to a continuous undervoltage. The positive-sequence undervoltage is used as a backup protection against the motor stall condition.

4.5.6.7 Signals

Table 684: PSPTUV Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer

Table 685: PSPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal for Positive Sequence Undervoltage protection
START	BOOLEAN	Start signal for Positive Sequence Undervoltage logic

4.5.6.8 Settings

Table 686: PSPTUV Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.010 - 1.200	pu	0.001	0.900	Positive sequence undervoltage start value
Operate delay time	0.040 - 120.000	s	0.001	0.040	Operate delay time

Table 687: PSPTUV Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Voltage block value	0.01 - 1.00	pu	0.01	0.20	Internal blocking level
Enable block value	Disabled Enabled	-	-	Enabled	Enable Internal Blocking

Table 688: PSPTUV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

Table 689: PSPTUV Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Relative hysteresis	1.0 - 5.0	%	0.1	4.0	Relative hysteresis for operation
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

4.5.6.9 Measured values

Table 690: PSPTUV Measured values

Name	Type	Default	Description
U1_AMPL	REAL	0.0	Positive sequence voltage amplitude
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer

4.5.6.10 Monitored data

Table 691: PSPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for Positive Sequence Undervoltage protection
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for Positive Sequence Undervoltage logic
START_DUR	REAL	-	%	Start duration in percentage of the total operating time

4.5.6.11 Technical data

Table 692: PSPTUV Technical data

Characteristic		Value
Operation accuracy		At the frequency $f = f_n$
		±1.5% of the set value or ±0.002 × U_n
Start time[1)2)]	U_{Fault} = 0.9 × set *Start value*	Typically 28 ms (±15 ms)
Reset time		<40 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Positive-sequence voltage before fault = 1.1 × U_n, f_n = 50 Hz, positive-sequence undervoltage of nominal frequency injected from random phase angle
2) Includes the delay of the signal output contact

4.5.7 Overexitation protection OEPVPH

4.5.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Overexcitation protection	OEPVPH	U/f>	24

4.5.7.2 Function block

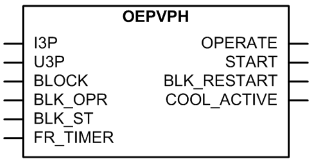


Figure 343: Function block

4.5.7.3 Functionality

The overexcitation protection OEPVPH is used to protect the generators and power transformers against an excessive flux density and saturation of the magnetic core.

The function calculates the U/f ratio (volts/hertz) proportional to the excitation level of the generator or transformer and compares this value to the setting limit. The function starts when the excitation level exceeds the set limit and operates when the set operating time has elapsed. The operating time characteristic can be selected to be either definite time (DT) or overexcitation inverse definite minimum time (overexcitation type IDMT).

This function contains a blocking functionality. It is possible to block the function outputs, reset timer or the function itself, if desired.

4.5.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the overexcitation protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

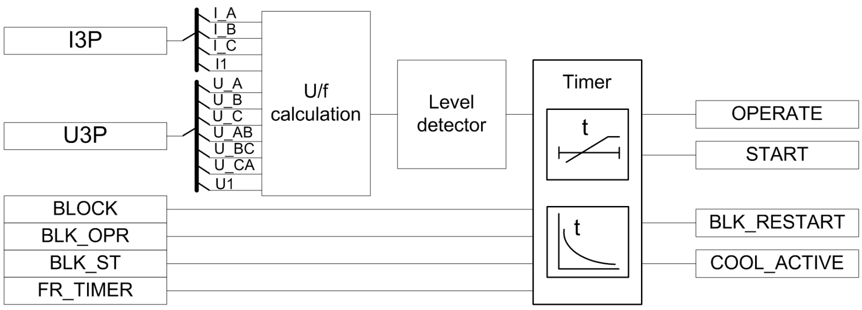


Figure 344: Functional module diagram

U/f calculation

This module calculates the U/f ratio, that is, the excitation level from the internal induced voltage (E) and frequency. The actual measured voltage (U_m) deviates from the internal induced voltage (emf) E, a value the equipment has to withstand. This voltage compensation is based on the load current (I_L) and the leakage reactance (X_{leak}) of the equipment. The leakage reactance of the transformer or generator is set through the *Leakage React* setting in percentage of the Z base.

The internal induced voltage (E) is calculated from the measured voltage. The settings *Voltage selection* and *Phase supervision* determine which voltages and currents are to be used. If the *Voltage selection* setting is set to "phase-to-earth" or "phase-to-phase", the *Phase supervision* setting is needed for determining which phases or phase-to-phase voltages ("A or AB", "B or BC" and "C or CA") and currents are to be used for the calculation of the induced voltage.

Table 693: Voltages and currents used for induced voltage E calculation

Voltage selection setting	*Phase supervision* setting	Calculation of internal induced voltage (emf) E
phase-to-earth	A or AB	$\overline{E} = \sqrt{3} \cdot \left(\overline{U_A} + \overline{I_A} \cdot (j \cdot X_{leak}) \right)$
phase-to-earth	B or BC	$\overline{E} = \sqrt{3} \cdot \left(\overline{U_B} + \overline{I_B} \cdot (j \cdot X_{leak}) \right)$
phase-to-earth	C or CA	$\overline{E} = \sqrt{3} \cdot \left(\overline{U_C} + \overline{I_C} \cdot (j \cdot X_{leak}) \right)$
phase-to-phase	A or AB	$\overline{E} = \overline{U_{AB}} + \left((\overline{I_A} - \overline{I_B}) \cdot (j \cdot X_{leak}) \right)$
phase-to-phase	B or BC	$\overline{E} = \overline{U_{BC}} + \left((\overline{I_B} - \overline{I_C}) \cdot (j \cdot X_{leak}) \right)$
phase-to-phase	C or CA	$\overline{E} = \overline{U_{CA}} + \left((\overline{I_C} - \overline{I_A}) \cdot (j \cdot X_{leak}) \right)$
Pos sequence	N/A	$\overline{E} = \sqrt{3} \cdot \left(\overline{U_1} + \overline{I_1} \cdot (j \cdot X_{leak}) \right)$
The voltages, currents and leakage reactance X_{leak} are given in volts, amps and ohms.		

If all three phase or phase-to-phase voltages and phase currents are fed to the IED, the positive-sequence alternative is recommended.

If the leakage reactance of the protected equipment is unknown or if the measured voltage U_m is to be used in the excitation level calculation, the leakage reactance setting is set to zero. The calculated induced voltage E is then equal to the measured voltage.

The calculated U/f ratio is scaled to a value based on the nominal U_n/f_n ratio. However, the highest allowed continuous voltage (in % U_n) can be defined by setting the parameter *Volt Max continuous* to change the basis of the voltage. The measured voltage is compared to the new base value to obtain the excitation level.

The excitation level (M) can be calculated:

$$M = \frac{\frac{E}{f_m}}{\frac{U_n}{f_n} \times \frac{Volt\ Max\ continuous}{100}}$$

(Equation 121)

M	the excitation level (U/f ratio or volts/hertz) in pu
E	the internal induced voltage (emf)
f_m	the measured frequency
U_n	the nominal phase-to-phase voltage
f_n	the nominal frequency

If the input frequency f_m is less than 20 percent of the nominal frequency f_n, the calculation of the excitation level is disabled and forced to zero value, that is, the function is blocked internally during low-frequency condition.

The calculated excitation level (U/f ratio or volts/hertz) VOLTPERHZ is available in the monitored data view.

Level detector

The level detector compares the calculated excitation level to the *Start value* setting. If the excitation level exceeds the set limit, the module sends an enabling signal to start the timer.

Timer

Once activated, the timer activates the `START` output. Depending on the value of the set *Operating curve type*, the time characteristics are according to DT or IDMT. When the operation timer has reached the value set by *Operate delay time* in the DT mode or the value defined by the inverse time curve, the `OPERATE` output is activated.

In a drop-off situation, that is, when the excitation level drops below *Start value* before the function operates, the reset timer is activated and the `START` output resets after the time delay of *Reset delay time* for the DT characteristics. For the

IDMT curves, the reset operation is as described in the Timer characteristics chapter.

For the IDMT curves, it is possible to define the maximum and minimum operating times via the *Minimum operate time* and *Maximum operate time* settings. The *Maximum operate time* setting is used to prevent the infinite start situations at low degrees of overexcitation. The *Time multiplier* setting is used for scaling the IDMT operate times.

The activation of the `OPERATE` output activates the `BLK_RESTART` output.

For the DT characteristics, the deactivation of the `OPERATE` output activates the cooling timer. The timer is set to the value entered in the *Cooling time* setting. The `BLK_RESTART` and `COOL_ACTIVE` outputs are kept active until the cooling timer is reset. If the excitation increases above the set value during this period, the `OPERATE` output is activated immediately. For IDMT, the deactivation of `BLK_RESTART` and `COOL_ACTIVE` depends on the curve type selected.

The operation timer counting can be frozen to the prevailing value by activating the `FR_TIMER` input.

The `T_ENARESTART` output indicates the duration in seconds for which the `BLK_RESTART` output still remains active. The value is available in the monitored data view.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The `BLOCK` binary input can be used for blocking the function. Activating the `BLOCK` input deactivates all the binary outputs and resets the internal timers. The binary input `BLK_ST` is used to block the start signals. The binary input `BLK_OPR` is used to block the operating signals.

4.5.7.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.5.7.6 Timer characteristics

OEPVPH supports both DT and IDMT characteristics. The DT timer characteristics can be selected as "ANSI Def. Time" or "IEC Def. Time" in the *Operating curve type* setting. The functionality is identical in both cases. When the

DT characteristics are selected, the functionality is only affected by the *Operate delay time* and *Reset delay time* settings.

OEPVPH also supports four overexcitation IDMT characteristic curves: "OvExt IDMT Crv1", "OvExt IDMT Crv2", "OvExt IDMT Crv3" and "OvExt IDMT Crv4".

Overexcitation inverse definite minimum time curve (IDMT)

In the inverse time modes, the operate time depends on the momentary value of the excitation: the higher the excitation level, the shorter the operate time. The operate time calculation or integration starts immediately when the excitation level exceeds the set *Start value* and the `START` output is activated.

The `OPERATE` output is activated when the cumulative sum of the integrator calculating the overexcitation situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used.

The *Minimum operate time* and *Maximum operate time* settings define the minimum operate time and maximum operate time possible for the IDMT mode. For setting these parameters, a careful study of the particular IDMT curves is recommended.

The operation time of the function block can vary much between different operating curve types even if other setting parameters for the curves were not changed.

Once activated, the timer activates the `START` output for the IDMT curves. If the excitation level drops below the *Start value* setting before the function operates, the reset timer is activated and the `START` output resets immediately. If `START` reoccurs during the reset time, the operation calculation is made based on the effects of the period when `START` was previously active. This is intended to allow an operating condition to occur in less time to account for the heating effects from the previous active start period.

For the IDMT curves, when `START` is deactivated, the integral value calculated during `START` is continuously decremented by a constant that causes its value to become zero when the reset time elapses during the reset period. If a fault reoccurs, the integration continues from the current integral value and the start time is adjusted, as shown in Figure 345. The start time becomes the value at the time when the fault dropped off minus the amount of reset time that occurred. If the reset period elapses without a fault being detected, the saved values of the start time and integration are cleared.

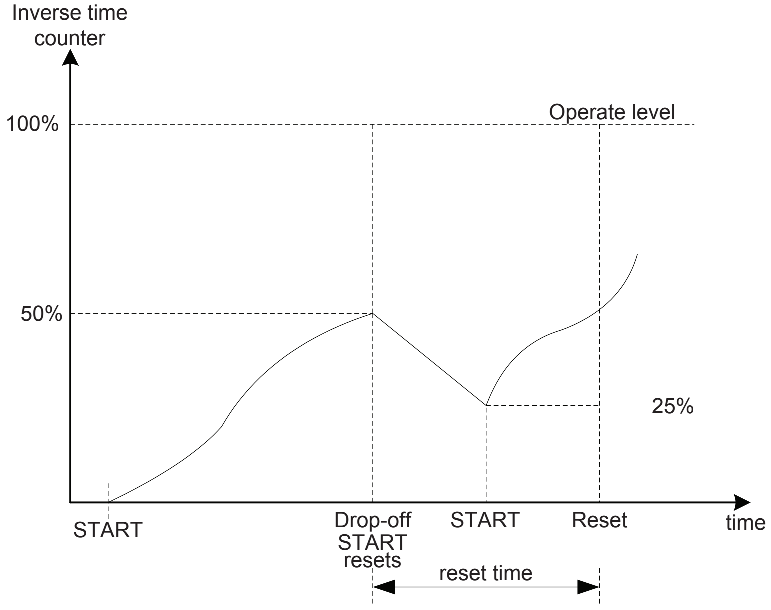


Figure 345: An example of a delayed reset in the inverse time characteristics. When the start becomes active during the reset period, the operate time counter continues from the level corresponding to the drop-off (reset time = 0.50 · Cooling time).

Overexcitation IDMT curves 1, 2 and 3

The base equation for the IDMT curves "OvExt IDMT Crv1", "OvExt IDMT Crv2" and "OvExt IDMT Crv3" is:

$$t(s) = 60 \cdot e^{\left(\frac{ak+b-100M}{c}\right)}$$

(Equation 122)

t(s) the operate time in seconds

M excitation level (U/f ratio or volts/hertz) in pu

k the *Time multiplier* setting

The constant "60" in Equation 122 converts time from minutes to seconds.

Table 694: Parameters a, b and c for different IDMT curves

Operating curve type setting	a	b	c
OvExt IDMT Crv1	2.5	115.00	4.886
OvExt IDMT Crv2	2.5	113.50	3.040
OvExt IDMT Crv3	2.5	108.75	2.443

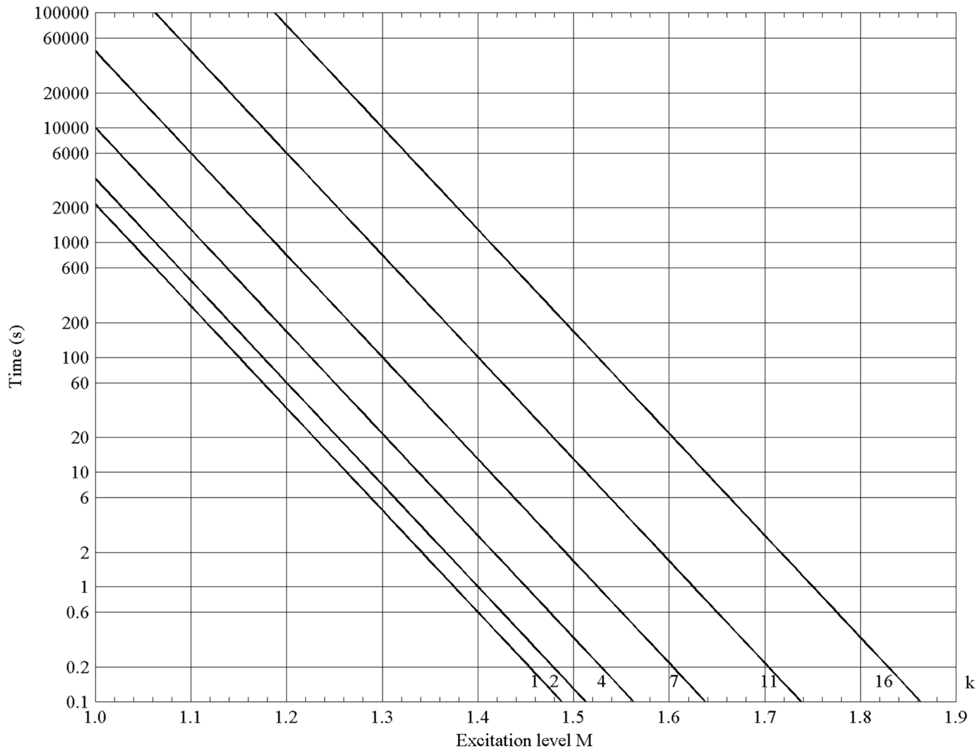


Figure 346: Operating time curves for the overexcitation IDMT curve ("OvExt IDMT Crv1") for parameters a = 2.5, b = 115.0 and c = 4.886.

Overexcitation IDMT curve 4

The base equation for the IDMT curve "OvExt IDMT Crv4" is:

$$t(s) = d + \frac{0.18k}{(M-1)^2}$$

(Equation 123)

t(s)	the operate time in seconds
d	the *Constant delay* setting in seconds
M	the excitation value (U/f ratio or volts/hertz) in pu
k	the *Time multiplier* setting

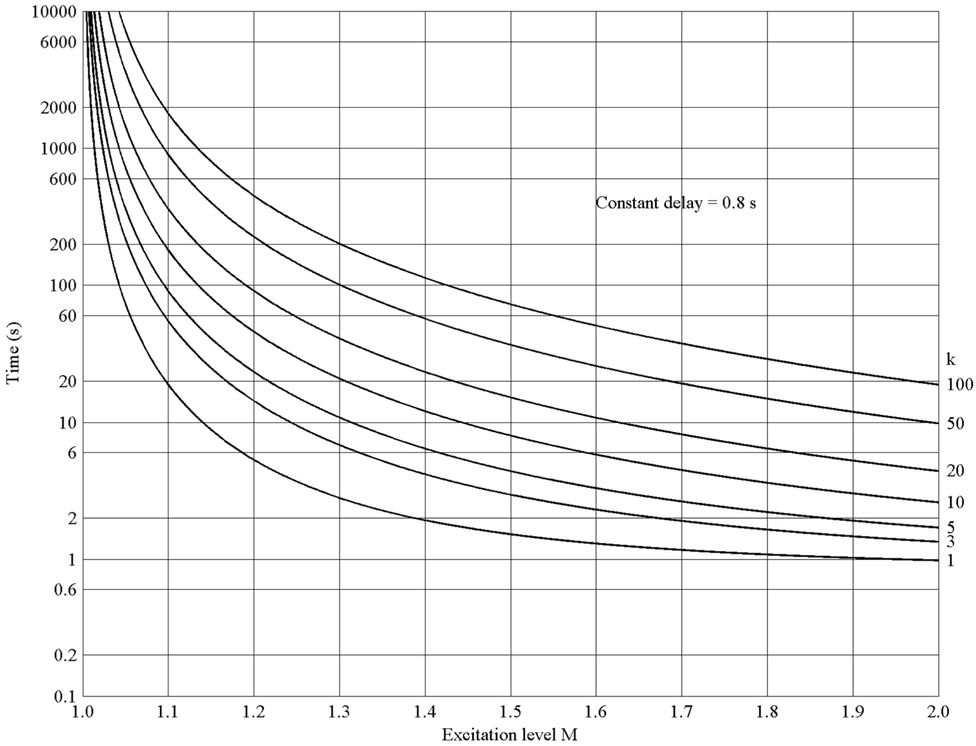


Figure 347: Operating time curves for the overexcitation IDMT curve 4 ("OvExt IDMT Crv4") for different values of the Time multiplier setting when the Constant delay is 0.8 sec.

The activation of the OPERATE output activates the BLK_RESTART output.

For the IDMT characteristic "OvExt IDMT Crv4", the deactivation of the OPERATE output activates the cooling timer. The timer is set to the value entered in the *Cooling time* setting. The COOL_ACTIVE output is kept active until the cooling timer is reset, whereas the BLK_RESTART output remains active until the timer exceeds the value to enable the restart time, given in Equation 124. The *Ena restart level* setting determines the level when BLK_RESTART should be released.

$$enable\ restart\ time = \left(\frac{100 - Ena\ restart\ level}{100}\right) \cdot Cooling\ time$$

(Equation 124)

If the excitation level increases above the set value when BLK_RESTART is active, the OPERATE output is activated immediately.

If the excitation level increases above the set value when BLK_RESTART is not active but COOL_ACTIVE is active, the OPERATE output is not activated instantly. In this case, the remaining part of the cooling timer affects the calculation of the operate timer as shown in Figure 348. This compensates for the heating effect and makes the overall operate time shorter.

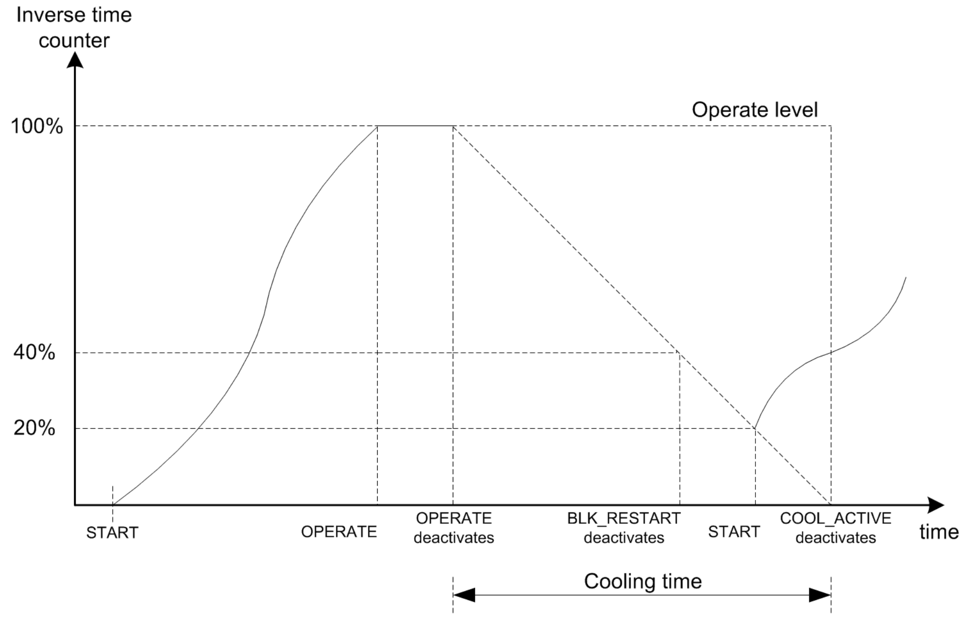


Figure 348: Example of an inverse time counter operation if `START` *occurs when* `BLK_RESTART` *is not active but* `COOL_ACTIVE` *is active. (The Ena restart level setting is considered to be 40 percent)*

4.5.7.7 Application

If the laminated core of a power transformer or generator is subjected to a magnetic flux density beyond its designed limits, the leakage flux increases. This results in a heavy hysteresis and eddy current losses in the non-laminated parts. These losses can cause excessive heating and severe damage to the insulation and adjacent parts in a relatively short time.

Overvoltage, underfrequency or a combination of the two results in an excessive flux density level. Since the flux density is directly proportional to the voltage and inversely proportional to the frequency, the overexcitation protection calculates the relative V/Hz ratio instead of measuring the flux density directly. The nominal level (nominal voltage at nominal frequency) is usually considered as the 100-percent level, which can be exceeded slightly based on the design.

The greatest risk for overexcitation exists in a thermal power station when the generator-transformer unit is disconnected from the rest of the network or in the network islands where high voltages or low frequencies can occur.

Overexcitation can occur during the startup and shutdown of the generator if the field current is not properly adjusted. The loss-of-load or load shedding can also result in overexcitation if the voltage control and frequency governor do not function properly. The low frequency in a system isolated from the main network can result in overexcitation if the voltage-regulating system maintains a normal voltage.

Overexcitation protection for the transformer is generally provided by the generator overexcitation protection, which uses the VTs connected to the generator terminals. The curves that define the generator and transformer V/Hz limits must be coordinated properly to protect both equipments.

If the generator can be operated with a leading power factor, the high-side voltage of the transformer can have a higher pu V/Hz than the generator V/Hz. This needs to be considered in a proper overexcitation protection of the transformer. Also, measurement for the voltage must not be taken from any winding where OLTC is located.

It is assumed that overexcitation is a symmetrical phenomenon caused by events such as loss-of-load. It should be noted that a high phase-to-earth voltage does not mean overexcitation. For example, in an unearthed power system, a single-phase-to-earth fault means high voltages on the two healthy phases but no overexcitation on any winding. The phase-to-phase voltages remain essentially unchanged. The voltage to be considered for the overexcitation is the voltage between the two ends of each winding.

Example calculations for overexcitation protection

Example 1

Nominal values of the machine

Nominal phase-to-phase voltage (U_n)	11000 V
Nominal phase current (I_n)	7455 A
Nominal frequency (f_n)	50 Hz
Leakage reactance (X_{leak})	20% or 0.2 pu

Measured voltage and load currents of the machine

Phase A-to-phase B voltage (U_{AB})	11500∠0° V
Phase A current (I_A)	5600∠-63.57° A
Phase B current (I_B)	5600∠176.42° A
Measured frequency (f_m)	49.98 Hz
The setting *Volt Max continuous*	100%
The setting *Voltage selection*	phase-to-phase
The setting *Phase supervision*	A or AB

The pu leakage reactance X_{leakPU} is converted to ohms.

$$X_{leak\Omega} = X_{leakPU} \times \left(U_n \big/ \left(I_n \times \sqrt{3} \right) \right) = 0.2 \times \left(11000 \big/ \left(7455 \times \sqrt{3} \right) \right) = 0.170378\ Ohms$$

(Equation 125)

The internal induced voltage E of the machine is calculated.

$$\overline{E} = \overline{U_{AB}} + (\overline{I_A} - \overline{I_B}) \times (jX_{leak})$$

(Equation 126)

E = 11500∠0°+ (5600∠-63.57°- 5600∠176.42°) x (0.170378∠90°) = 12490 V

The excitation level M of the machine is calculated.

$$Excitation\,level\ M = \frac{12490 \big/ 49.98}{11000 \big/ 50 \times 1.00} = 1.1359$$

Example 2

The situation and the data are according to example 1. In this case, the manufacturer of the machine allows the continuous operation at 105 percent of the nominal voltage at the rated load and this value to be used as the base for overexcitation.

Usually, the U/f characteristics are specified so that the ratio is 1.00 at the nominal voltage and nominal frequency. Therefore, the value 100 percent for the setting *Volt Max continuous* is recommended.

If the *Volt Max continuous* setting is 105 percent, the excitation level M of the machine is calculated with the equation.

$$Excitation\,level\ M = \frac{12490 \big/ 49.98}{11000 \big/ 50 \times 1.05} = 1.0818$$

Example 3

In this case, the function operation is according to IDMT. The *Operating curve type* setting is selected as "OvExt IDMT Crv2". The corresponding example settings for the IDMT curve operation are given as: *Start value* = 110%, *Volt Max continuous* = 100%, *Time multiplier* = 4, *Maximum operate time* = 1000 s and *Minimum operate time* = 1.0 s.

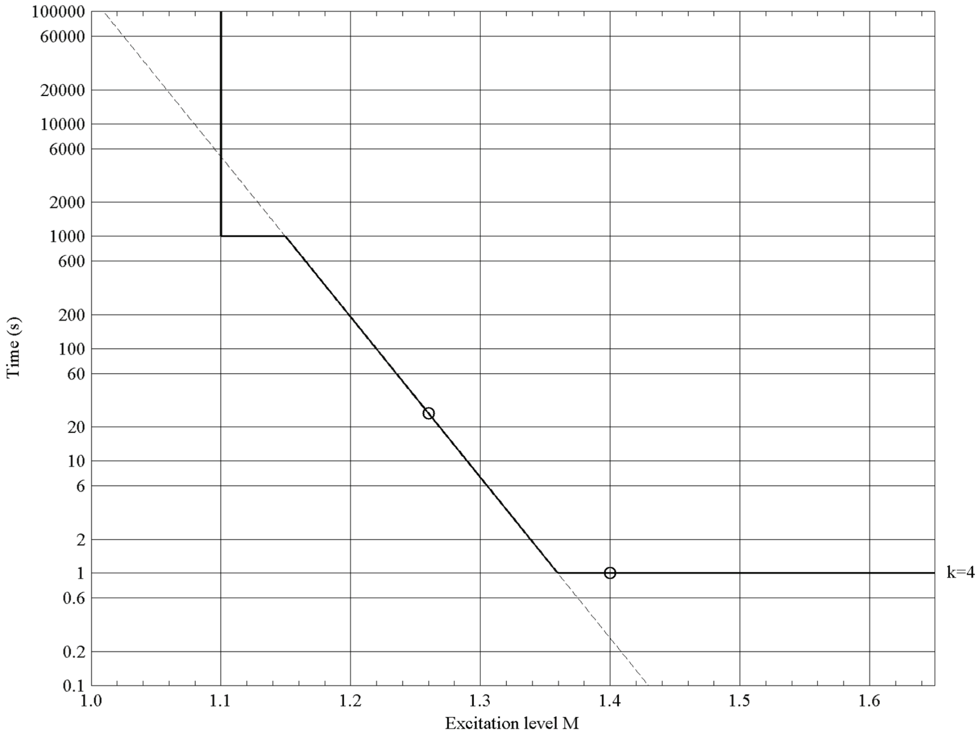


Figure 349: Operating curve of "OvExt IDMT Crv2" based on the settings specified in example 3. The two dots marked on the curve are referred to in the text.

If the excitation level stays at 1.26, the operation occurs after 26.364 seconds as per the marked dot in Figure 349 for operating curve with the settings specified as per example 3. For the excitation level of 1.4, the second dot in Figure 349, the curve "OvExt IDMT Crv2" gives 0.2636 sec as per Equation 122, but the *Minimum operate time* setting limits the operate time to 1.0 second.

The *Maximum operate time* setting limits the operate time to 1000 seconds if the excitation level stays between 1.1 and 1.16.

In general, however, the excitation level seldom remains constant. Therefore, the exact operate times in any inverse time mode are difficult to predict.

Example 4

In this case, the function operation is according to IDMT. The *Operating curve type* setting is selected as "OvExt IDMT Crv4". The corresponding example settings for the IDMT curve operation are given as: *Start value* = 110%, *Volt Max* *continuous* = 100%, *Time multiplier* = 5, *Maximum operate time* = 3600 s and *Constant delay* = 0.8 s.

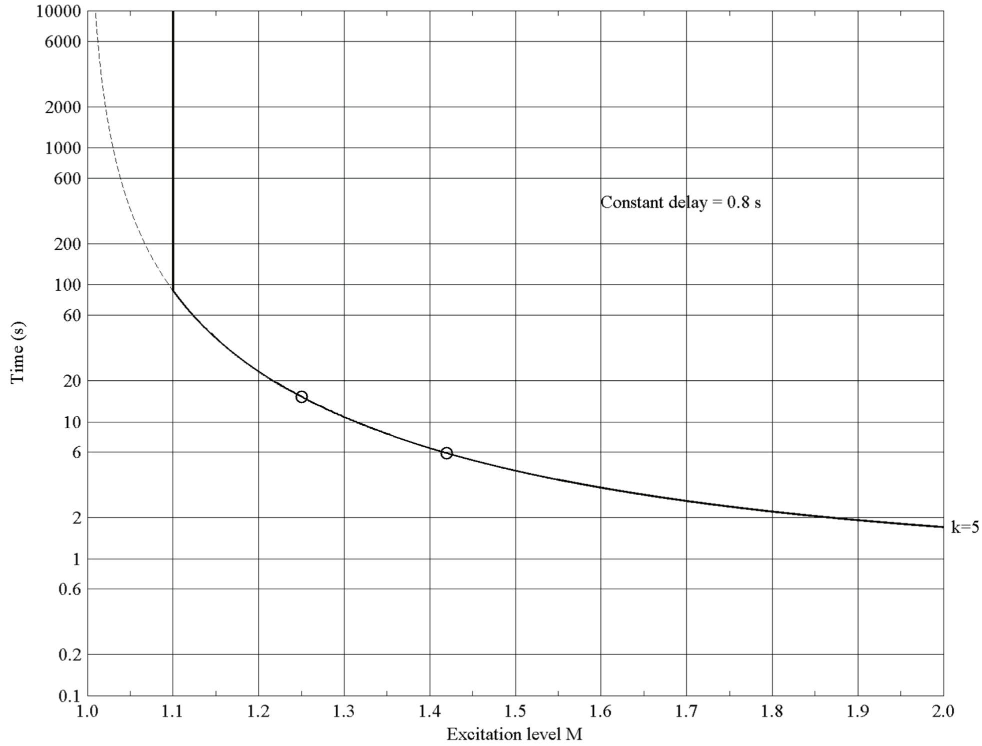


Figure 350: Operating curve of “OvExt IDMT Crv4” based on the specified settings. The two dots marked on the curve are referred to in the text.

If the excitation level stays at 1.25, the operation occurs after 15.20 s. At the excitation level of 1.42, the time to operation would be 5.90 s as per the two dots in Figure 350. In this case, the setting *Maximum operate time* = 3600 s does not limit the maximum operate time because the operate time at *Start value* = 110% (1.1 pu) is approximately 75 seconds.

4.5.7.8 Signals

Table 695: OEPVPH Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timer

Table 696: OEPVPH Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started
BLK_RESTART	BOOLEAN	Signal for blocking reconnection of an overheated machine
COOL_ACTIVE	BOOLEAN	Signal to indicate machine is in cooling process

4.5.7.9 Settings

Table 697: OEPVPH Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	100 - 200	%UB/f	1	100	Over excitation start value
Time multiplier	0.10 - 100.00	-	0.10	3.00	Time multiplier for Overexcitation IDMT curves
Operating curve type	ANSI Def. Time IEC Def. Time OvExt IDMT Crv1 OvExt IDMT Crv2 OvExt IDMT Crv3 OvExt IDMT Crv4	-	-	IEC Def. Time	Selection of time delay curve type
Operate delay time	0.10 - 200.00	s	0.01	0.50	Operate delay time in definite- time mode

Table 698: OEPVPH Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Voltage selection	phase-to-earth phase-to-phase Pos Seq	-	-	Pos Seq	Selection of phase / phase-to-phase / pos sequence voltages
Phase supervision	A or AB B or BC C or CA	-	-	A or AB	Parameter for phase selection

Table 699: OEPVPH Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On
Leakage React	0.0 - 50.0	% Zb	0.1	0.0	Leakage reactance of the machine

Table 700: OEPVPH Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Restart Ena level	0 - 100	%	1	0	Determines the level in % when block restart is released
Voltage Max Cont	80 - 160	%UB	1	110	Maximum allowed continuous operating voltage ratio
Reset delay time	0.00 - 60.00	s	0.01	0.10	Resetting time of the operate time counter in DT mode
Maximum operate time	500.00 - 10000.00	s	0.01	1000.00	Maximum operate time for IDMT curves
Minimum operate time	0.00 - 60.00	s	0.01	0.10	Minimum operate time for IDMT curves
Cooling time	5 - 10000	s	1	600	Time required to cool the machine
Constant delay	0.10 - 120.00	s	0.01	0.80	Parameter constant delay

4.5.7.10 Measured values

Table 701: OEPVPH Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timer

4.5.7.11 Monitored data

Table 702: OEPVPH Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
BLK_RESTART	BOOLEAN	0=FALSE 1=TRUE	-	Signal for blocking reconnection of an overheated machine
COOL_ACTIVE	BOOLEAN	0=FALSE 1=TRUE	-	Signal to indicate machine is in cooling process
VOLTPERHZ	REAL	-	xUB/f	Excitation level, i.e U/f ratio or Volts/Hertz
T_ENARESTART	INTEGER	-	s	Estimated time to reset of block restart
START_DUR	REAL	-	%	Ratio of start time / operate time (in %)

4.5.7.12 Technical data

Table 703: OEPVPH Technical data

Characteristic	Value	
Operation accuracy	At the frequency $f = f_n$	
	±2.5% of the set value or 0.01 × Ub/f	
Start time [1)2)]	Frequency change	Typically 200 ms (±20 ms)
	Voltage change	Typically 100 ms (±20 ms)
Reset time	<60 ms	
Reset ratio	Typically 0.96	
Retardation time	<45 ms	
Operate time accuracy in definite-time mode	±1.0% of the set value or ±20 ms	
Operate time accuracy in inverse-time mode	±5.0% of the theoretical value or ±50 ms	

1) Results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.5.7.13 Technical revision history

Table 704: OEPVPH technical revision history

Technical revision	Change
B	Change in the function description available in PCM600

4.5.8 Voltage vector shift protection VVSPPAM

4.5.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage vector shift protection	VVSPPAM	VS	78V

4.5.8.2 Function block

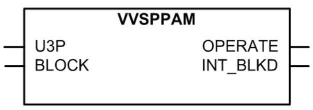


Figure 351: Function block

4.5.8.3 Functionality

Voltage vector shift protection function VVSPPAM (which can be called also vector surge or delta phi function) measures continuously the duration of a voltage cycle. At the instance of islanding, the duration of measured voltage cycle becomes shorter or longer than the previous one, that is, the measured voltage cycle shifts with time. This shifting of voltage is measured in terms of phase angle. VVSPPAM issues instantaneous trip when shift in voltage vector exceeds the set value.

VVSPPAM contains a blocking functionality. It is possible to block the function outputs, timer or the function itself.

4.5.8.4 Operation principle

The *Operation* setting is used to enable or disable the function. When "On" is selected, the function is enabled and when "Off" is selected, the function is disabled.

The operation of VVSPPAM can be described using a module diagram. All modules in the diagram are explained in the next sections.

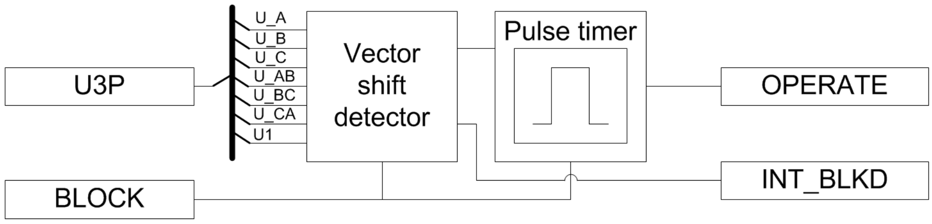


Figure 352: Functional module diagram

Vector shift detector

This module measures the duration of each cycle of the voltage signal phase. The duration of the present cycle is compared to the previous cycle (which is considered as reference). When the mains is lost, a sudden change is seen in the cycle length (Figure 353), if loading of the generator changes suddenly and power mismatch or unbalance (generation vs. load) in the islanded part of the network is large enough. The cycle shifts with time, that is, the frequency may not change but a vector shift is seen in phase as shown in the Figure 353.

This step is measured in degrees for each voltage signal defined by the *Phase supervision* setting. The *Phase supervision* setting determines which voltage is used for vector shift detection. The available *Phase supervision* options are “All” and “Pos sequence”. If the calculated value of $\Delta\delta$ exceeds the set *Start value* setting for all the defined phases, the module sends an enable signal to start the Pulse timer.

The *Voltage selection* setting is used to select whether the available voltage signal is phase-to-earth or phase-to-phase voltages.

Phase supervision selected as “Pos sequence” is recommended and hence kept as default.

If the magnitude of the voltage level of any of the monitored voltage signal (defined by the *Phase supervision* setting) drops below *Under Volt Blk value* or exceeds *Over Volt Blk value*, the calculation of vector shift is disabled and the INT_BLKD output is activated.

The function is blocked and LOWAMPL_BLKD is activated if the measured frequency deviates ±5% from the nominal value.

The magnitude of calculated vector shift for three phases-to-earth / phase-to-phase voltages, USHIFT_A_AB, USHIFT_B_BC and USHIFT_C_CA or positive sequence voltage U1SHIFT which resulted into activation of last OPERATE output are available in the monitored data view.

The activation of BLOCK input deactivates the INT_BLKD output.

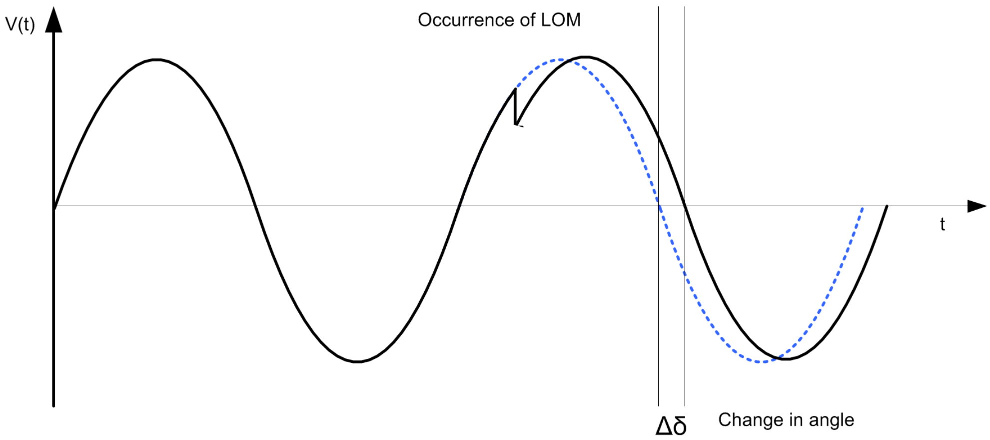


Figure 353: Vector shift during Loss of Mains

Pulse timer

Once the Pulse timer is activated, it activates the OPERATE output. The pulse length of OPERATE is fixed to 100 ms.

The activation of the BLOCK input deactivates the OPERATE binary output and resets timer.

4.5.8.5 Base value

In this function block, some of the settings are set in per unit (pu). These pu values are relational to the base values. For example, the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example, “Phase Grp 1”, “Phase Grp 2” and “Phase Grp 3”. One of the groups must be selected with the *Base value Sel phase* settings.

4.5.8.6 Application

Use of distributed generation (DG) units is increasing due to liberalized markets (deregulation) and the global trend to use more renewable sources of energy. They generate power in the range of 10 kW to 10 MW and most of them are interconnected to the distribution network. They can supply power into the network as well as to the local loads. It is not common to connect generators directly to the distribution networks and thus the distributed generation can cause some challenges for the protection of distribution networks. From the protection point of view, one of the most challenging issue is islanding.

Islanding is defined as a condition in which a distributed generation unit continues to supply power to a certain part of the distribution network when power from the larger utility main grid is no longer available after opening of a circuit-breaker. Islanding is also referred as Loss of Mains (LOM) or Loss of Grid (LOG). When LOM occurs, neither the voltage nor the frequency is controlled by the utility supply. Also, these distributed generators are not equipped with voltage and frequency control; therefore, the voltage magnitude of an islanded network may not be kept within the desired limits resulting into undefined voltage magnitudes during islanding situations and frequency instability. Further, uncontrolled frequency represents a high risk for drives and other machines. Islanding can occur as a consequence of a fault in the network, due to circuit-breaker maloperation or due to circuit-breaker opening during maintenance. If the distributed generator continues its operation after the utility supply is disconnected, faults do not clear under certain conditions as the arc is charged by the distributed generators. Moreover, the distributed generators are incompatible with the current reclosing practices. During the reclosing sequence dead time, the generators in the network usually tend to drift out of synchronism with the grid and, reconnecting them without synchronizing may damage the generators introducing high currents and voltages in the neighbouring network.

Due to the technical difficulties mentioned above, protection should be provided, which disconnects the distributed generation once it is electrically isolated from the main grid supply. Various techniques are used for detecting Loss of Mains. However, the present function focuses on voltage vector shift.

The vector shift detection guarantees fast and reliable detection of mains failure in almost all operational conditions when a distributed generation unit is running in parallel with the mains supply, but in certain cases this may fail.

If the active and reactive power generated by the distributed generation units is nearly balanced (for example, if the power mismatch or unbalance is less than 5...10%) with the active and reactive power consumed by loads, a large enough voltage phase shift may not occur which can be detected by the vector shift algorithm. This means that the vector shift algorithm has a small non-detection-zone (NDZ) which is also dependent on the type of generators, loads, network and start or operate value of the vector shift algorithm. Other network events like capacitor switching, switching of very large loads in weak network or connection of parallel transformer at HV/MV substation, in which the voltage magnitude is not changed considerably (unlike in faults) can potentially cause maloperation of vector shift algorithm, if very sensitive settings are used.

The vector shift detection also protects synchronous generators from damaging due to islanding or loss-of-mains. To detect loss-of-mains with vector shift function, the generator should aim to export or import at least 5...10% of the generated power to the grid, in order to guarantee detectable change in loading after islanding or loss-of-mains.

Multicriteria Loss of Mains

Apart from vector shift, there are other passive techniques which are used for detecting Loss of Mains. Some of these passive techniques are over/under voltage, over/under frequency, rate of change of frequency, voltage unbalance, rate of change of power and so on. These passive methods use voltage and frequency to identify Loss of Mains. The performance of these methods depends on the power mismatch between local generation and load. The advantage of all these methods is that, they are simple and cost effective, but each method has a non detectable zone. To overcome this problem, it is recommended to combine different criteria for detecting Loss of Mains.

Two or more protection functions run in parallel to detect Loss of Mains. When all criteria are fulfilled to indicate Loss of Mains, an alarm or a trip can be generated. Vector shift and rate of change of frequency are two parallel criteria typically used for detection of Loss of Mains.

For REG630, chosen protection criteria can be included in the Application Configuration tool (ACT) to create multicriteria loss of mains alarm or trip.

4.5.8.7 Signals

Table 705: VVSPPAM Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Group signal for voltage inputs
BLOCK	BOOLEAN	0	Blocks all binary output signals (includes timer reset)

Table 706: VVSPPAM Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
INT_BLKD	BOOLEAN	Protection function internally blocked

4.5.8.8 Settings

Table 707: VVSPPAM Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	2 - 30	Deg	1	6	Start value for vector shift

Table 708: VVSPPAM Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Phase supervision	All Pos sequence	-	-	Pos sequence	Monitored voltage phase
Over Volt Blk value	0.40 - 1.50	pu	0.01	0.70	Voltage above which function will be internally blocked
Under Volt Blk value	0.15 - 1.00	pu	0.01	0.45	Voltage below which function will be internally blocked

Table 709: VVSPPAM Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Voltage selection	phase-to-earth phase-to-phase	-	-	phase-to-phase	Parameter to select phase or phase-to-phase voltages

Table 710: VVSPPAM Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase

4.5.8.9 Measured values

Table 711: VVSPPAM Measured values

Name	Type	Default	Description
U_AMPL_A	REAL	0.0	Phase-to-ground voltage amplitude phase A
U_AMPL_B	REAL	0.0	Phase-to-ground voltage amplitude phase B
U_AMPL_C	REAL	0.0	Phase-to-ground voltage amplitude phase C
U_ANGL_A	REAL	0.0	Phase-to-ground voltage angle phase A
U_ANGL_B	REAL	0.0	Phase-to-ground voltage angle phase B
U_ANGL_C	REAL	0.0	Phase-to-ground voltage angle phase C
U_AMPL_AB	REAL	0.0	Phase-to-phase voltage amplitude AB
U_AMPL_BC	REAL	0.0	Phase-to-phase voltage amplitude BC
U_AMPL_CA	REAL	0.0	Phase-to-phase voltage amplitude CA
U_ANGL_AB	REAL	0.0	Phase-to-phase voltage angle AB
Table continues on next page			

Name	Type	Default	Description
U_ANGL_BC	REAL	0.0	Phase-to-phase voltage angle BC
U_ANGL_CA	REAL	0.0	Phase-to-phase voltage angle CA
U1_AMPL	REAL	0.0	Positive sequence voltage amplitude
U1_ANGL	REAL	0.0	Positive sequence voltage angle
BLOCK	BOOLEAN	0	Blocks all binary output signals (includes timer reset)

4.5.8.10 Monitored data

Table 712: VVSPPAM Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate
INT_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Protection function internally blocked
VEC_SHT_A_AB	REAL	-	deg	Vector shift for ph-earth voltage A or ph-ph voltage AB
VEC_SHT_B_BC	REAL	-	deg	Vector shift for ph-earth voltage A or ph-ph voltage BC
VEC_SHT_C_CA	REAL	-	deg	Vector shift for ph-earth voltage A or ph-ph voltage CA
VEC_SHT_U1	REAL	-	deg	Vector shift for positive sequence voltage

4.5.8.11 Technical data

Table 713: VVSPPAM Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$ ±0.5% of the set value or ±0.01°
Operate time	Typically 60 ms

4.5.9 Low voltage ride through protection LVRTPTUV

4.5.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Low voltage ride through protection function	LVRTPTUV	U<RT	27RT

4.5.9.2 Function block

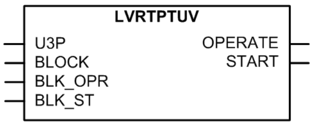


Figure 354: Functional block

4.5.9.3 Functionality

Low voltage ride through protection LVRTPTUV is principally a three-phase undervoltage protection. It differs from the traditional three-phase undervoltage protection PHPTUV by allowing the grid operators to define its own Low-Voltage-Ride-Through (LVRT) curve for generators, as defined by local or national grid codes. The LVRT curve can be defined accurately according to the requirements by setting the appropriate time-voltage coordinates.

This function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

4.5.9.4 Operation principle

The *Operation* setting is used to enable or disable the function. When "On" is selected, the function is enabled and when "Off" is selected, the function is disabled.

The operation of LVRTPTUV is described using a module diagram. All modules in the diagram are explained in the next sections.

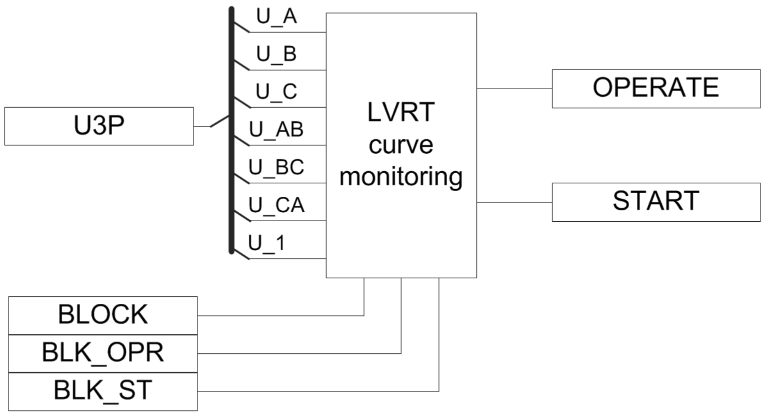


Figure 355: Functional module diagram

LVRT curve monitoring

LVRT curve monitoring starts with detection of under voltage. Under voltage detection depends on *Voltage selection* setting. All selectable options are based on fundamental frequency components.

Function uses phase-to-earth voltages when *Voltage selection* is set to “Highest Ph-to-E” or “Lowest Ph-to-E” and phase-to-phase voltages when *Voltage selection* is set to “Highest Ph-to-Ph” or “Lowest Ph-to-Ph”.

When the *Voltage selection* setting is set to “Highest Ph-to-E”, “Lowest Ph-to-E”, “Highest Ph-to-Ph” or “Lowest Ph-to-Ph”, the measured three phase voltages are compared phase-wise to the set *Voltage start value* setting. If the measured value is lower than the set *Voltage start value* setting in number of phases equal to that set *Num of start phases*, the `START` output is activated.

When the *Voltage selection* setting is “Positive Seq”, the positive sequence component is compared with the set *Voltage start value* setting. If it is lower than the set *Voltage start value* setting, the `START` output is activated.

Once `START` is activated, the function monitors the behavior of the voltage defined by *Voltage selection setting* with the defined LVRT curve. When defined voltage enters the operating area, the `OPERATE` output is activated instantaneously. The pulse length of `OPERATE` is fixed to 100 ms. `START` also deactivates along with `OPERATE`.

If a drop-off situation occurs, that is, voltage restores above *Voltage start value*, before `OPERATE` is activated, the function does not reset until maximum recovery time under consideration has elapsed, that is, `START` output remains active.

LVRT curve is defined using time-voltage settings coordinates. The settings available are *Recovery time 1…Recovery time 10* and *Voltage level 1…Voltage level 10*. The number of coordinates required to define a LVRT curve is set by *Active coordinate* settings.

When *Recovery time 1* is set to non-zero value, it results into horizontal characteristics from point of fault till *Recovery time 1.*

Two examples of LVRT curve are defined in Figure 356 and Figure 357 with corresponding settings in Table 714.

It is necessary to set the coordinate points correctly in order to avoid mal-operation. For example, setting for *Recovery time 2* should be greater than *Recovery time 1*. *Recovery time 1…Recovery time 10* are the respective time setting from the point of fault.

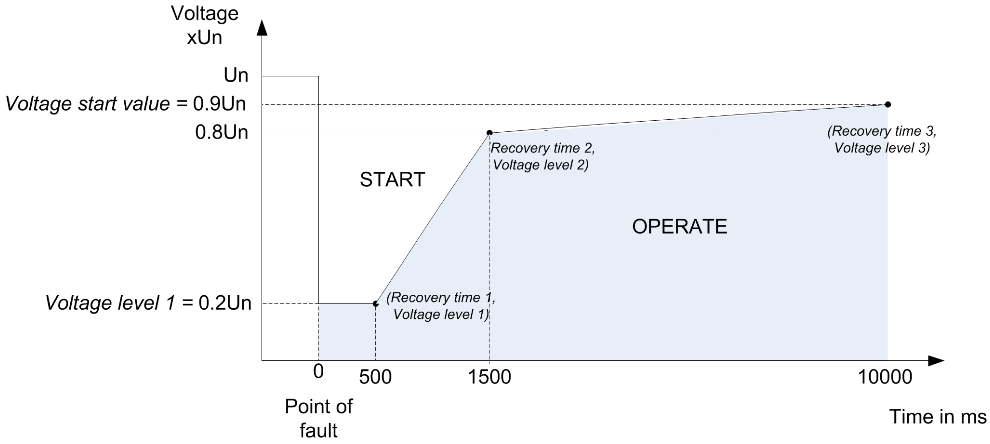


Figure 356: Low voltage ride through example curve A

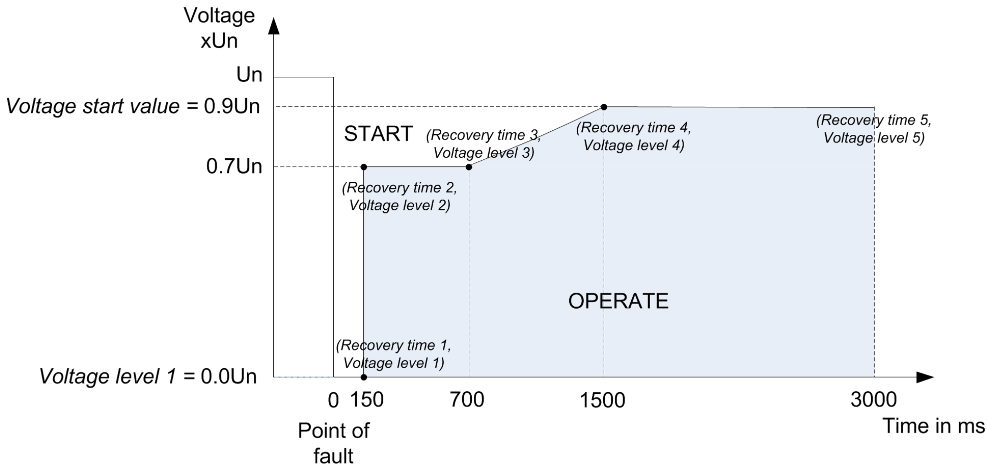


Figure 357: Low voltage ride through example curve B

Table 714: Settings for example A and B

Settings	Curve A	Curve B
Voltage start value	0.9×Un	0.9×Un
Active coordinates	3	5
Voltage level 1	0.2×Un	0×Un
Recovery time 1	500 ms	150 ms
Voltage level 2	0.8×Un	0.7×Un
Recovery time 2	1000 ms	150 ms
Voltage level 3	0.9×Un	0.7×Un
Recovery time 3	10000 ms	700 ms
Voltage level 4	-	0.9×Un
Table continues on next page		

Settings	Curve A	Curve B
Recovery time 4	-	1500 ms
Voltage level 5	-	0.9×Un
Recovery time 5	-	3000 ms

It is necessary that the last active *Voltage level X* setting should be set greater than or equal to *Voltage start value*. If it is less than the *Voltage start value* setting, function automatically considers it to be equal to *Voltage start value*.

Figure 358 describes an example of operation of LVRTPTUV protection function set to operate with *Num of start phases* set to “Exactly 2 of 3” and *Voltage selection* as “Lowest Ph-to-Ph” voltage.

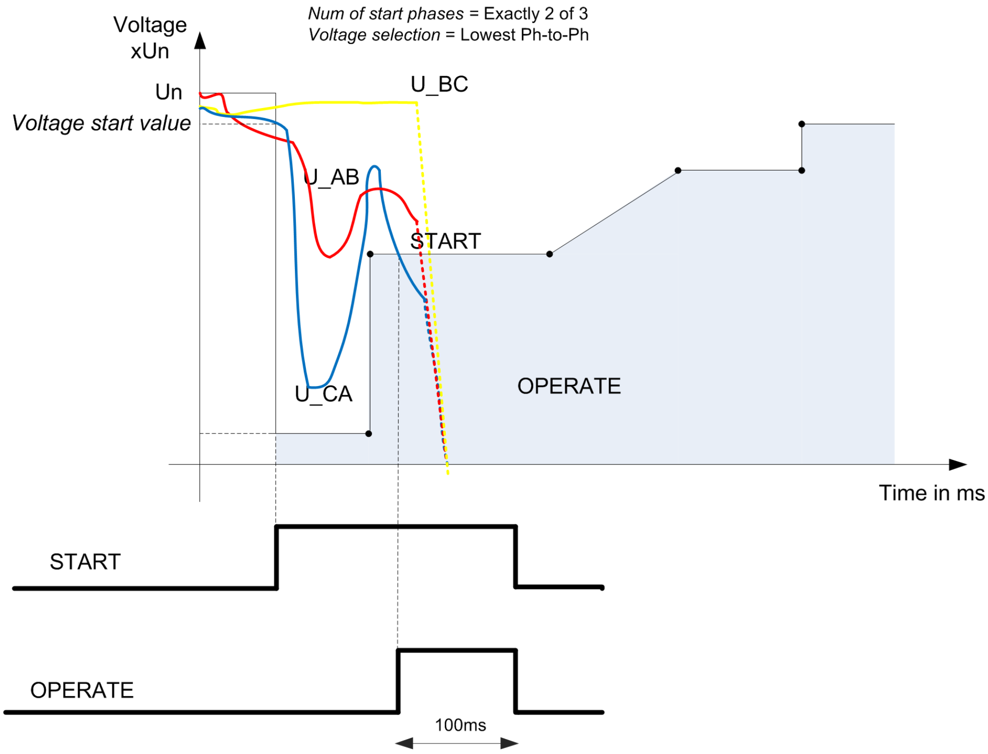


Figure 358: Typical example of operation of LVRTPTUV function

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The binary input BLK_ST can be used to block the start signals. The binary input BLK_OPR can be used to block both the operation signals.

4.5.9.5 Base value

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example, the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example, “Phase Grp 1”, “Phase Grp 2” and “Phase Grp 3”. Select one of the groups to be used with the *Base value Sel phase* settings.

4.5.9.6 Application

Distributed generation mainly wind and solar farms are rapidly increasing due to liberalized markets (deregulation) and the global trend to use more renewable sources of energy. These farms are directly connected to girds, and due to their large size it may influence the behavior of the grid. Thus these farms are now required to comply with stringent grid connection requirement which was previously mandatory only for high capacity power plants. Few of these requirements include helping grid in maintaining system stability, reactive power support, transient recovery and voltage-frequency regulation. These requirements make necessary for the wind and solar farms to remain in operation in the event of network disturbances.

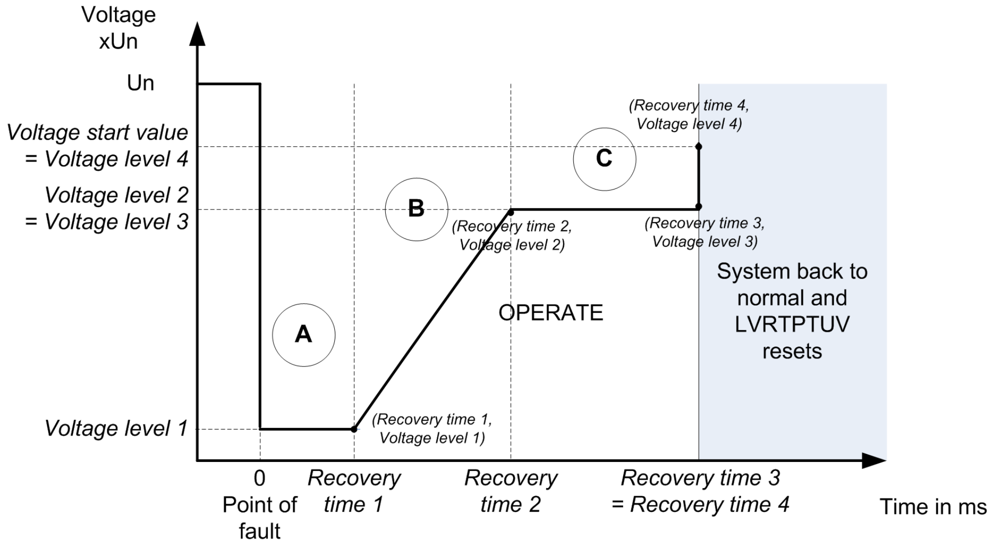
Many grid codes now demand that the distributed generation connected to HV grids must withstand voltage dips to a certain percentage of nominal voltage (down to 0% in some cases) and for a specific duration. Such requirements are knows as Low Voltage Ride through (LVRT) or Fault Ride through (FRT) and are described by a voltage vs time characteristics.

Typical LVRT behaviors of a distributed generation can be divided into three areas according to the variation in voltage over time.

- At the time of system faults, the magnitude of the voltage may dip to *Voltage level 1* for time defined by *Recovery time 1*. The generating unit has to remain connected to the network during such condition. This boundary defines area A.
- Area B defines the linear growth recovery voltage level from *Voltage level 1* to *Voltage level 2* in a time period from *Recovery time 1* to *Recovery time 2*.
- Area C is the zone where voltage stabilizes. *Voltage level 3* is defined to same value as *Voltage level 2*. The system should remain above this voltage in a time period from *Recovery time 2* to *Recovery time 3*.

System restores to a normal state and function resets when the voltage is equal or greater than *Voltage level 4* after *Recovery time 4* time period.

When the voltage at the point of common coupling is above the LVRT curve, the generation unit must remain connected, and must be disconnected only if the voltage takes values below the curve.



The LVRT requirement depends on the power system characteristics and the protection employed, it varies significantly from each other. Requirement also differs from country to country. LVRTPTUV function incorporates four types of LVRT curves which satisfy most of the power system needs. Grid operators can fine-tune the LVRT curve by setting the parameters as per their requirement, making the use simpler in comparison with different conventional undervoltage protection with different operate time setting and logics.

4.5.9.7 Signals

Table 715: LVRTPTUV Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Group signal for voltage inputs
BLOCK	BOOLEAN	0	Block all binary outputs by resetting timers
BLK_OPR	BOOLEAN	0	Block operate outputs
BLK_ST	BOOLEAN	0	Block start outputs

Table 716: LVRTPTUV Output signals

Name	Type	Description
START	BOOLEAN	Started
OPERATE	BOOLEAN	Operate

4.5.9.8 Settings

Table 717: LVRTPTUV Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.05 - 1.20	pu	0.01	0.90	Voltage value below which function starts

Table 718: LVRTPTUV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Num of start phases	Exactly 1 of 3 Exactly 2 of 3 Exactly 3 of 3	-	-	Exactly 1 of 3	Number of faulty phases
Voltage selection	Highest Ph-to-E Lowest Ph-to-E Highest Ph-to-Ph Lowest Ph-to-Ph Positive Seq	-	-	Lowest Ph-to-Ph	Parameter to select voltage for curve monitoring
Active coordinates	1 - 10	-	1	3	Coordinates used for defining LVRT curve
Voltage level 1	0.00 - 1.20	pu	0.01	0.20	1st voltage coordinate for defining LVRT curve
Recovery time 1	0.00 - 300.00	s	0.01	0.50	1st time coordinate for defining LVRT curve
Voltage level 2	0.00 - 1.20	pu	0.01	0.80	2nd voltage coordinate for defining LVRT curve
Recovery time 2	0.00 - 300.00	s	0.01	1.00	2nd time coordinate for defining LVRT curve
Voltage level 3	0.00 - 1.20	pu	0.01	0.90	3rd voltage coordinate for defining LVRT curve
Recovery time 3	0.00 - 300.00	s	0.01	10.00	3rd time coordinate for defining LVRT curve
Voltage level 4	0.00 - 1.20	pu	0.01	0.90	4th voltage coordinate for defining LVRT curve
Recovery time 4	0.00 - 300.00	s	0.01	10.0	4th time coordinate for defining LVRT curve
Voltage level 5	0.00 - 1.20	pu	0.01	0.90	5th voltage coordinate for defining LVRT curve
Recovery time 5	0.00 - 300.00	s	0.01	10.0	5th time coordinate for defining LVRT curve
Voltage level 6	0.00 - 1.20	pu	0.01	0.90	6th voltage coordinate for defining LVRT curve
Recovery time 6	0.00 - 300.00	s	0.01	10.0	6th time coordinate for defining LVRT curve
Voltage level 7	0.00 - 1.20	pu	0.01	0.90	7th voltage coordinate for defining LVRT curve
Recovery time 7	0.00 - 300.00	s	0.01	10.0	7th time coordinate for defining LVRT curve
Voltage level 8	0.00 - 1.20	pu	0.01	0.90	8th voltage coordinate for defining LVRT curve
Recovery time 8	0.00 - 300.00	s	0.01	10.0	8th time coordinate for defining LVRT curve
Voltage level 9	0.00 - 1.20	pu	0.01	0.90	9th voltage coordinate for defining LVRT curve

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Recovery time 9	0.00 - 300.00	s	0.01	10.00	9th time coordinate for defining LVRT curve
Voltage level 10	0.00 - 1.20	pu	0.01	0.90	10th voltage coordinate for defining LVRT curve
Recovery time 10	0.00 - 300.00	s	0.01	10.00	10th time coordinate for defining LVRT curve

Table 719: LVRTPTUV Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase

4.5.9.9 Measured values

Table 720: LVRTPTUV Measured values

Name	Type	Default	Description
U_AMPL_A	REAL	0.0	Phase to earth voltage A
U_AMPL_B	REAL	0.0	Phase to earth voltage B
U_AMPL_C	REAL	0.0	Phase to earth voltage C
U_AMPL_AB	REAL	0.0	Phase to phase voltage AB
U_AMPL_BC	REAL	0.0	Phase to phase voltage BC
U_AMPL_CA	REAL	0.0	Phase to phase voltage CA
U1_AMPL	REAL	0.0	Positive sequence voltage
BLOCK	BOOLEAN	0	Block all binary outputs by resetting timers
BLK_OPR	BOOLEAN	0	Block operate outputs
BLK_ST	BOOLEAN	0	Block start outputs

4.5.9.10 Monitored data

Table 721: LVRTPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate

4.5.9.11 Technical data

Table 722: LVRTPTUV Technical data

Characteristic	Value
Operation accuracy	At the frequency f = f_n ±1.5% of the set value or ±0.002 × U_n
Start time	Typically 40 ms
Reset time	Based on maximum value of *Recovery time* setting
Operate time accuracy in definite time mode	±1.0% of the set value or ±40 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5 and so on

4.6 Frequency protection

4.6.1 Overfrequency protection DAPTOF

4.6.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Overfrequency protection	DAPTOF	f>	81O

4.6.1.2 Function block

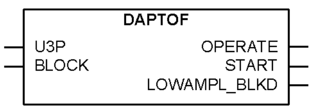


Figure 359: Function block

4.6.1.3 Functionality

The overfrequency protection function DAPTOF can be used to protect network components from possible damage caused by overfrequency conditions. DAPTOF can also be used as a sub-nominal frequency stage initiating load restoring.

The frequency must exceed the set start frequency value before the function can start and operate. DAPTOF operates with definite time (DT) characteristics. To avoid unwanted operation due to an uncertain frequency measurement at a low voltage magnitude, a voltage-controlled blocking of the function is available, that is, if the voltage is lower than the set minimum voltage, the function is blocked. The frequency measurement is based on the voltage available only for preprocessor function SMAI internally. This voltage is dependent on all connected phase-to-earth or phase-to-phase voltages. If only one phase-to-earth or phase-to-phase voltage is connected then, that is used.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

4.6.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the overfrequency protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

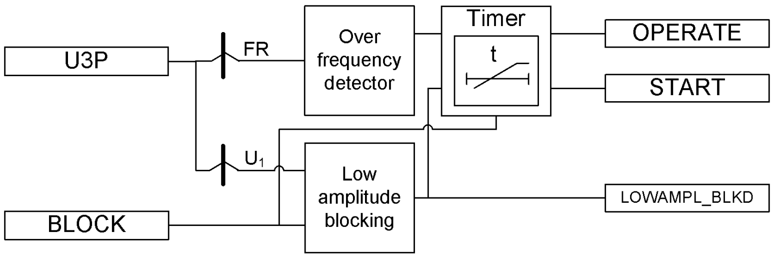


Figure 360: Functional module diagram

Overfrequency detector

The fundamental frequency is compared to the *Start value* setting. If the frequency exceeds the set *Start value*, the enable signal is sent to the timer.

Low amplitude blocking

The voltage is compared to the value of the *MinValFreqMeas* setting. If the voltage magnitude is below the set value, the LOWAMPL_BLKD output is activated, which also resets the timer.

MinValFreqMeas is the setting related to the preprocessor function SMAI. The setting level is compared to the physically connected voltages. For example, if phase-to-phase voltages are physically connected (phase-to-earth voltages virtual), the 10% setting results in ten percent of the normal phase-to-phase voltage. If phase-to-earth voltages are connected (phase-to-phase voltages virtual), the 10% setting results in 17 percent of the normal phase-to-earth voltage. This is assuming the base voltage is set to be the normal/ nominal phase-to-phase voltage.

The activation of the BLOCK input deactivates the LOWAMPL_BLKD output.

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated. If the frequency becomes normal before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

For a detailed description of the definite timer, see the General function block features section in this manual.

The activation of the BLOCK input resets the timer and deactivates the OPERATE and START outputs.

4.6.1.5 Application

DAPTOF is applicable in all situations where high levels of the fundamental frequency of power system voltage must be reliably detected. A high fundamental frequency in a power system indicates that there is an unbalance between production and consumption. In this case, the available generation is too large compared to the power demanded by the load connected to the power grid. This can occur due to a sudden loss of a significant amount of load or due to failures in the turbine governor system. If the situation continues and escalates, the power system loses its stability. The overfrequency function detects such situations and provides an output signal suitable for example for generator shedding . The function can also be used as a sub-nominal frequency stage initiating load restoring. The overfrequency function is very sensitive and accurate and can also be used to alert operators that frequency has slightly deviated from the set-point and that manual actions can suffice.

Traditionally, frequency protection is highly recommended to be based on a phase-to-phase voltage which is less dependent on the asymmetry of separate phase voltages and less sensitive to harmonics. The third harmonic, for instance, is not present in phase-to-phase voltages. However, the DAPTOF is also able to measure the frequency reliably and accurately using a single phase-to-earth voltage.

4.6.1.6 Signals

Table 723: DAPTOF Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for pos seq voltage inputs
BLOCK	BOOLEAN	0	Block of function

Table 724: DAPTOF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal for overfrequency protection
START	BOOLEAN	Start signal for overfrequency protection
LOWAMPL_BLKD	BOOLEAN	Blocking indication due to low amplitude.

4.6.1.7 Settings

Table 725: DAPTOF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	35.00 - 64.00	Hz	0.01	51.20	Frequency setting/start value
Operate delay time	0.08 - 200.00	s	0.01	0.08	Operate time delay

Table 726: DAPTOF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 727: DAPTOF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Reset delay time	0.00 - 60.00	s	0.01	0.02	Time delay for reset

4.6.1.8 Measured values

Table 728: DAPTOF Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function

4.6.1.9 Monitored data

Table 729: DAPTOF Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for overfrequency protection
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for overfrequency protection
LOWAMPL_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Blocking indication due to low amplitude.
FREQ	REAL	-	Hz	Measured frequency
START_DUR	REAL	-	%	Start duration in percents of the total operation time.

4.6.1.10 Technical data

Table 730: DAPTOF Technical data

Characteristic		Value
Operation accuracy		At the frequency f = 35...66 Hz
		±0.003 Hz
Start time[1)2)]	f_{Fault} = 1.01 × set *Start value*	Typically <190 ms
Reset time		<190 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±30 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Frequency before fault = 0.99 × f_n, f_n = 50 Hz
2) Includes the delay of the signal output contact

4.6.1.11 Technical revision history

Table 731: DAPTOF technical revision history

Technical revision	Change
B	• Removed one decimal from *Reset delay time* and *Operate delay time* setting • Added one decimal for *Start value* setting • Minimum setting value changed from 0.170 to 0.08, maximum setting value changed from 60.000 to 200.00 and default setting value changed from 0.200 to 0.08 for the *Operate delay time* setting • Internal improvements

4.6.2 Underfrequency protection DAPTUF

4.6.2.1 Identification

Table 732: Function identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Underfrequency protection	DAPTUF	f<	81U

4.6.2.2 Function block

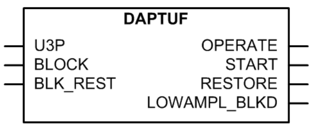


Figure 361: Function block

4.6.2.3 Functionality

The underfrequency protection function DAPTUF is used to detect low power system frequency. DAPTUF is used, for example, in load shedding systems, remedial action schemes and gas turbine startup.

The function starts and operates when the frequency drops below the set start frequency value. The operate time characteristics are according to definite time (DT).

To avoid the unwanted operation due to an uncertain frequency measurement at a low voltage magnitude, the voltage-controlled blocking of DAPTUF is available. If the voltage is lower than the set blocking voltage, the function is blocked and no start or operate signal is issued. The frequency measurement is based on a voltage available only for preprocessor function SMAI internally. This voltage is dependent on all connected phase-to-earth or phase-to-phase voltages. If only one phase-to-earth or phase-to-phase voltage is connected then, that is used.

The function contains a blocking functionality. Blocking deactivates all outputs and resets the timers.

4.6.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of underfrequency protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

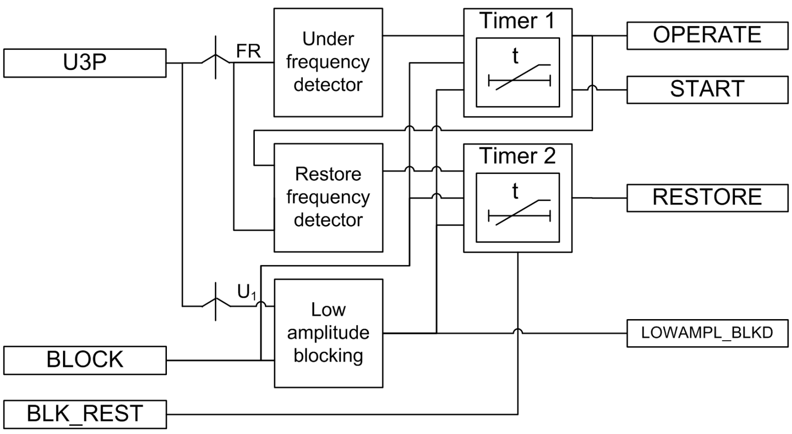


Figure 362: Functional module diagram. Group signal U3P is used for feeding the necessary analog signals to the function.

Underfrequency detector

The fundamental frequency is compared to the *Start value* setting. If the frequency is lower than the set *Start value*, the enabling signal is sent to the Timer 1. The measured frequency (FREQ) is available in the monitored data view.

Timer 1

Once activated, Timer 1 activates the START output. The time characteristic is according to DT. When the operation timer reaches the value set by *Operate delay time*, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

For a detailed description of the definite timer, see the General function block features section in this manual.
The activation of the BLOCK input resets the timer and deactivates the OPERATE and START outputs.

Restoring frequency detector

The restoring frequency detector is enabled after the OPERATE output of Timer 1 is activated. When enabled, the fundamental frequency is compared to the set *Restore start Val* setting. When the frequency has returned to a value higher than the value of *Restore start Val*, Timer 2 is enabled.

Timer 2

Once activated, the RESTORE output is activated after the set *Restore delay time*. The time characteristic is according to DT. If the frequency drops below *Restore start Val* before RESTORE is activated, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, Timer 2 is reset. The RESTORE output remains active for 100 ms.

Activating the BLOCK output cancels the restoring operation. If the restoring command is cancelled, the RESTORE output can be activated only when the next load-shedding operation is detected, that is, when the OPERATE output is activated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the ongoing restoring situation and the set *Restore delay time*. The value is available in the monitored data view.

For a detailed description of the definite timers, see the General function block features section in this manual.

The activation of the BLK_REST input deactivates the RESTORE output. The restore functionality can be disabled by setting the *Reset delay time* value to 0.0 s.

Low amplitude blocking

The voltage is compared to the set *MinValFreqMeas* setting. If the voltage magnitude is lower than the set value, the LOWAMPL_BLKD output is activated which resets the timers Timer 1 and Timer 2.

MinValFreqMeas is the setting related to preprocessor function SMAI. The setting level is compared to the physically connected voltages. For example, if phase-to-phase voltages are physically connected (phase-to-earth voltages virtual), the 10% setting results in ten percent of the normal phase-to-phase voltage. If phase-to-earth voltages are connected (phase-to-phase voltages virtual), the 10% setting results in 17 percent of the normal phase-to-earth voltage. This is assuming the base voltage is set to be the normal/nominal phase-to-phase voltage.

The activation of the BLOCK input deactivates the LOWAMPL_BLKD output.

4.6.2.5 Application

DAPTUF is applicable in all situations where a reliable detection of a low fundamental power system voltage frequency is needed. A low fundamental frequency in a power system indicates that the power generated is too low to meet the power demanded by the load connected to the power grid.

An underfrequency can occur as a result of an overload of the generators operating in an isolated system. It can also occur as a result of a serious fault in the power system due to the deficit of generation when compared to the load. This can happen due to a fault in the grid system on transmission lines that link two parts of the system. As a result, the system splits in two with one part having the excess load and the other part the corresponding deficit. The frequency dips rapidly in the latter, resulting in load shedding either by the load shedding relays or by the operator action. DAPTUF detects such situations and provides an output signal suitable for load shedding, generator boosting, set point change in sub-transmission DC systems, gas turbine startup and so on

In some cases, to reduce the power system voltage and the voltage dependent part of the load, shunt reactors are automatically switched on at low frequencies. The DAPTUF function is very sensitive and accurate and can also be used to alert the operators that the frequency deviates slightly from the set-point and that manual actions can be sufficient enough to ensure the stability of the system. The underfrequency signal is also used for over-excitation detection. This is especially important for generator step-up transformers during a rollout sequence when the transformers can be connected to the generator but disconnected from the grid. If the generator is still energized, the system experiences over-excitation due to the low frequency.

When the system recovers from the disturbance after the action of the underfrequency protection, the operating frequency recovers to nominal frequency. The load that was shed during the disturbance can be restored.

4.6.2.6 Signals

Table 733: DAPTUF Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for pos seq voltage inputs
BLOCK	BOOLEAN	0	Block of function
BLK_REST	BOOLEAN	0	Blocking restore output.

Table 734: DAPTUF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal for underfrequency protection
START	BOOLEAN	Start signal for underfrequency protection
RESTORE	BOOLEAN	Restore signal for load restoring purposes.
LOWAMPL_BLKD	BOOLEAN	Blocking indication due to low amplitude.

4.6.2.7 Settings

Table 735: DAPTUF Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	35.00 - 64.00	Hz	0.01	48.80	Frequency setting/start value.
Operate delay time	0.08 - 200.00	s	0.01	0.08	Operate time delay

Table 736: DAPTUF Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Restore start Val	35.00 - 64.00	Hz	0.01	49.90	Restore frequency setting value
Restore delay time	0.00 - 60.00	s	0.01	0.00	Restore time delay

Table 737: DAPTUF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 738: DAPTUF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Reset delay time	0.00 - 60.00	s	0.01	0.02	Time delay for reset

4.6.2.8 Measured values

Table 739: DAPTUF Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_REST	BOOLEAN	0	Blocking restore output.

4.6.2.9 Monitored data

Table 740: DAPTUF Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for underfrequency protection
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for underfrequency protection
RESTORE	BOOLEAN	0=FALSE 1=TRUE	-	Restore signal for load restoring purposes.
LOWAMPL_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Blocking indication due to low amplitude.
FREQ	REAL	-	Hz	Measured frequency
START_DUR	REAL	-	%	Start duration in percents of the total operation time.

4.6.2.10 Technical data

Table 741: DAPTUF Technical data

Characteristic		Value
Operation accuracy		At the frequency f = 35...66 Hz
		±0.003 Hz
Start time1)2)	f_{Fault} = 0.99 × set *Start value*	Typically <190 ms
Reset time		<190 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±30 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Frequency before fault = 1.01 × f_n, f_n = 50 Hz
2) Includes the delay of the signal output contact

4.6.2.11 Technical revision history

Table 742: DAPTUF technical revision history

Technical revision	Change
B	• Removed one decimal from *Reset delay time*, *Restore delay time* and *Operate delay time* setting • Added one decimal for *Start value* and *Restore start Val* setting • Minimum setting value changed from 0.170 to 0.08, maximum setting value changed from 60.000 to 200.00 and default setting value changed from 0.200 to 0.08 for the *Operate delay time* setting • Internal improvements

4.6.3 Frequency gradient protection DAPFRC

4.6.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Frequency gradient protection function	DAPFRC	df/dt>	81R

4.6.3.2 Function block

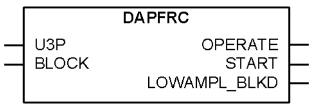


Figure 363: Function block

4.6.3.3 Functionality

The frequency gradient protection or the rate of change of frequency protection DAPFRC is used to detect the increase or decrease of the fast power system frequency at an early stage. DAPFRC gives an early indication of a disturbance in the system. The function can be used for generation shedding, load shedding and remedial action schemes.

The rate of change of the fundamental frequency is calculated and compared to the set frequency gradient value before the function can start and operate. DAPFRC operates with the definite time (DT) characteristics. The function can discriminate between a positive or negative change in frequency.

A voltage-controlled blocking feature is available to avoid unwanted operation due to uncertain frequency measurement at a low-voltage magnitude, that is, if the voltage is lower than the set blocking voltage, the function is blocked. The frequency measurement is based on a voltage available only for the preprocessor function SMAI internally. This voltage is dependent on all connected phase-to-earth or phase-to-phase voltages. If only one phase-to-earth or phase-to-phase voltage is connected, that is used.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

4.6.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of frequency gradient protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

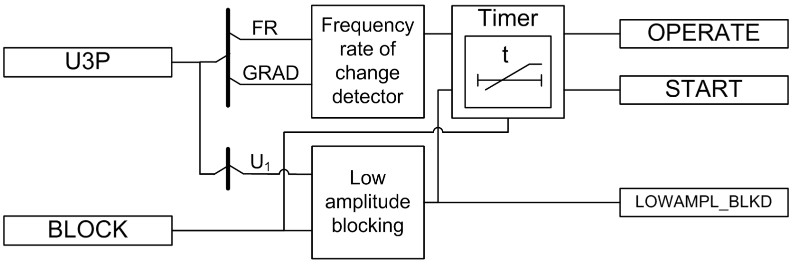


Figure 364: Functional module diagram. Group signal U3P is used for feeding the necessary analog signals to the function.

Frequency rate of change detector

The rate of change of the frequency of the positive sequence voltage is calculated from phase-to-phase or phase-to-earth voltages and compared to the set *Start value*. If the measured frequency rate of change is higher than the set *Start value*, the timer module is enabled.

The sign of the set *Start value* controls DAPFRC to react on a positive change or on a negative change in frequency. A positive setting of *Start value* sets the frequency rate of change detector to react on increases of the frequency. Similarly, a negative setting of *Start value* results in a decrease of frequency.

Low amplitude blocking

The voltage is compared to the set *MinValFreqMeas* value. If the voltage magnitude is detected to be below the set value, the `LOWAMPL_BLKD` output is activated, which resets the timer.

MinValFreqMeas is the setting related to Preprocessor function SMAI. The setting level is compared to the physically connected voltages. For example, if phase-to-phase voltages are physically connected (phase-to-earth voltages virtual), the 10% setting results in ten percent of the normal phase-to-phase voltage. If phase-to-earth voltages are connected (phase-to-phase voltages virtual), the 10% setting results in 17 percent of the normal phase-to-earth voltage. This is assuming the base voltage is set to be the normal/ nominal phase-to-phase voltage.

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer reaches the value set by *Operate delay time*, the OPERATE output is activated. If the frequency rate of change condition disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The activation of the BLOCK input resets the timer and deactivates the START and OPERATE outputs.

4.6.3.5 Application

DAPFRC is applicable in all the situations where the change of the fundamental power system voltage frequency should be detected reliably. DAPFRC can be used for both increasing and decreasing of the frequencies. This function provides an output signal suitable for load shedding, generator shedding, generator boosting and gas turbine startup. The frequency gradient is often used in combination with a low frequency signal, especially in smaller power systems where the loss of a fairly large generator requires quick remedial actions to secure the power system's integrity. In such situations, load shedding actions are required at a rather high frequency level, but in combination with a large negative frequency gradient, the underfrequency protection can be used at a high setting.

4.6.3.6 Signals

Table 743: DAPFRC Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block of function

Table 744: DAPFRC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal for frequency gradient
START	BOOLEAN	Start signal for frequency gradient
LOWAMPL_BLKD	BOOLEAN	Blocking indication due to low amplitude.

4.6.3.7 Settings

Table 745: DAPFRC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	-10.00 - 10.00	Hz/s	0.01	0.50	Frequency gradient start value. Sign defines direction
Operation delay time	0.12 - 60.00	s	0.01	0.20	Operate time delay

Table 746: DAPFRC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 747: DAPFRC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Reset delay time	0.00 - 60.00	s	0.01	0.02	Time delay for reset

4.6.3.8 Measured values

Table 748: DAPFRC Measured values

Name	Type	Default	Description
FREQ	REAL	50.0	Measured analog signal frequency [Hz]
FREQGRAD	REAL	0	Measured analog signal frequency gradient, df/dt. [Hz/s].
BLOCK	BOOLEAN	0	Block of function

4.6.3.9 Monitored data

Table 749: DAPFRC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for frequency gradient
START	BOOLEAN	0=FALSE 1=TRUE	-	Start signal for frequency gradient
LOWAMPL_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Blocking indication due to low amplitude.
START_DUR	REAL	-	%	Start duration in percents of the total operation time

4.6.3.10 Technical data

Table 750: DAPFRC Technical data

Characteristic		Value
Operation accuracy		df/dt < ±10 Hz/s: ±10 mHz/s Undervoltage blocking: ±1.5% of the set value or ±0.002 × U_n
Start time[1)2)]	*Start value* = 0.05 Hz/s df/dt_{FAULT} = ±1.0 Hz/s	Typically 110 ms (±15 ms)
Reset time		<150 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±30 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Frequency before fault = 1.0 × f_n, f_n = 50 Hz
2) Includes the delay of the signal output contact

4.6.3.11 Technical revision history

Table 751: DAPFRC technical revision history

Technical revision	Change
B	• Removed one decimal from *Reset delay time* and *Operate delay time* setting • Internal improvements

4.6.4 Load shedding LSHDPFRQ

4.6.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Load shedding	LSHDPFRQ	UFLS/R	81LSH

4.6.4.2 Function block

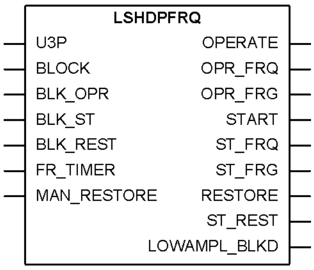


Figure 365: Function block

4.6.4.3 Functionality

The Load shedding function LSHDPFRQ is capable of performing load shedding based on underfrequency and the rate of change of the frequency. The load that is shed during the frequency disturbance can be restored once the frequency has stabilized to the normal level.

The measured system frequency is compared to the set value to detect the underfrequency condition. The measured rate of change of frequency (df/dt) is compared to the set value to detect a high frequency reduction rate. The combination of the detected underfrequency and the high df/dt is used for the activation of the load shedding. There is a definite time delay between the detection of the underfrequency and high df/dt and the activation of LSHDPFRQ. This time delay can be set and it is used to prevent unwanted load-shedding actions when the system frequency recovers to the normal level.

Once the frequency has stabilized, LSHDPFRQ can restore the load that is shed during the frequency disturbance. The restoration is possible manually or automatically.

An undervoltage restraint condition is used to disable the load-shedding operation, avoid decisions based on invalid data or avoid load shedding in the condition of a fault.

The frequency measurement is based on a voltage available only for the preprocessor function SMAI internally. This voltage is dependent on all connected phase-to-earth or phase-to-phase voltages. If only one phase-to-earth or phase-to-phase voltage is connected, that is used.

Throughout this document, “high df/dt” is used to mean “a high rate of change of the frequency in negative direction.”

4.6.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the load-shedding function can be described using a module diagram. All the modules are explained in the next sections.

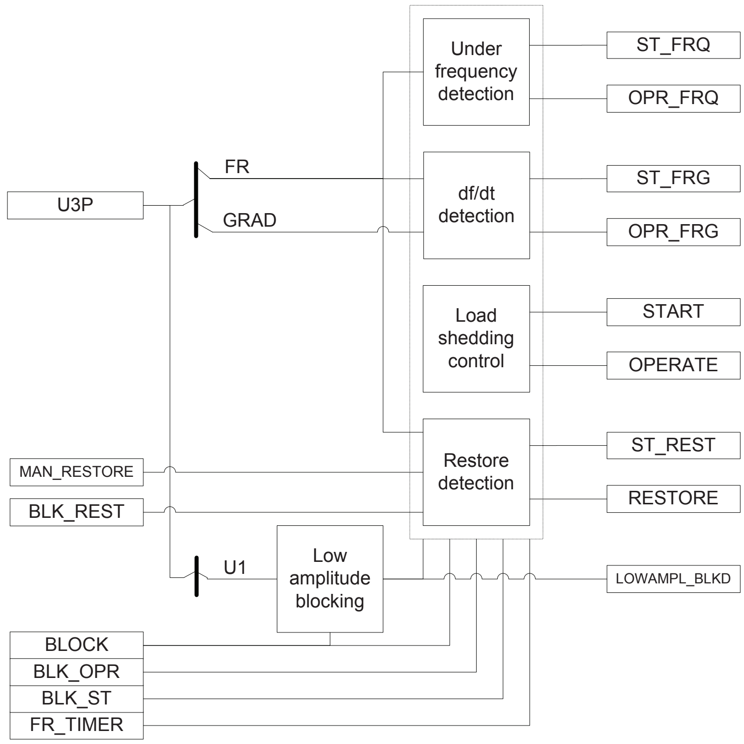


Figure 366: Functional module diagram. Group signal U3P is used for feeding the necessary analog signals to the function.

Underfrequency detection

The underfrequency detection measures the input frequency calculated from the voltage signal. An underfrequency is detected when the measured frequency drops below the set value of the *Start Val frequency* setting.

The underfrequency detection module includes a timer with the Definite Time (DT) characteristics. Upon detection of underfrequency, operation timer activates the `ST_FRQ` output. When the underfrequency timer has reached the value set by *Frequency Op delay*, the `OPR_FRQ` output is activated if the underfrequency condition still persists. If the frequency becomes normal before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the timer resets and the `ST_FRQ` output is deactivated.

The activation of the `FR_TIMER` input causes the timer to freeze, that is, it holds the value from the last execution round. The activation of the `FR_TIMER` input has no effect on the operation of the ST_FRQ output. However, the activation of the OPR_FRQ output is delayed by the time for which the FR_TIMER input remains high.

The timer is reset by the activation of the BLOCK input. It is possible to block the individual start and operate outputs ST_FRQ and OPR_FRQ by the activation of the BLK_ST and BLK_OPR inputs respectively.

df/dt detection

The df/dt detection measures the input frequency calculated from the voltage signal and calculates its gradient. A high df/dt condition is detected by comparing the gradient to the *Start value df/dt* setting. The *Start value df/dt* setting is set in terms of positive values. The df/dt detection is activated when the frequency gradient decreases at a faster rate than the set value of *Start value df/dt*.

The df/dt detection module includes a timer with the DT characteristics. Upon detection of df/dt, operation timer activates the ST_FRG output. When the timer has reached the value set by *Df/dt operate delay*, the OPR_FRG output is activated if the df/dt condition still persists. If df/dt becomes normal before the module operates, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the ST_FRG output is deactivated.

Load-shedding control

The way of load shedding, that is, whether to operate based on underfrequency or high df/dt or both, is defined with the *Load shed mode* user setting. The valid operation modes for the *Load shed mode* settings are "Freq<", "Freq< AND df/dt" and "Freq< OR df/dt".

Once the selected operation mode conditions are satisfied, the START and OPERATE output signals are activated.

When the START output is active, the percentage of the elapsed delay time can be monitored through START_DUR which is available as monitored data.

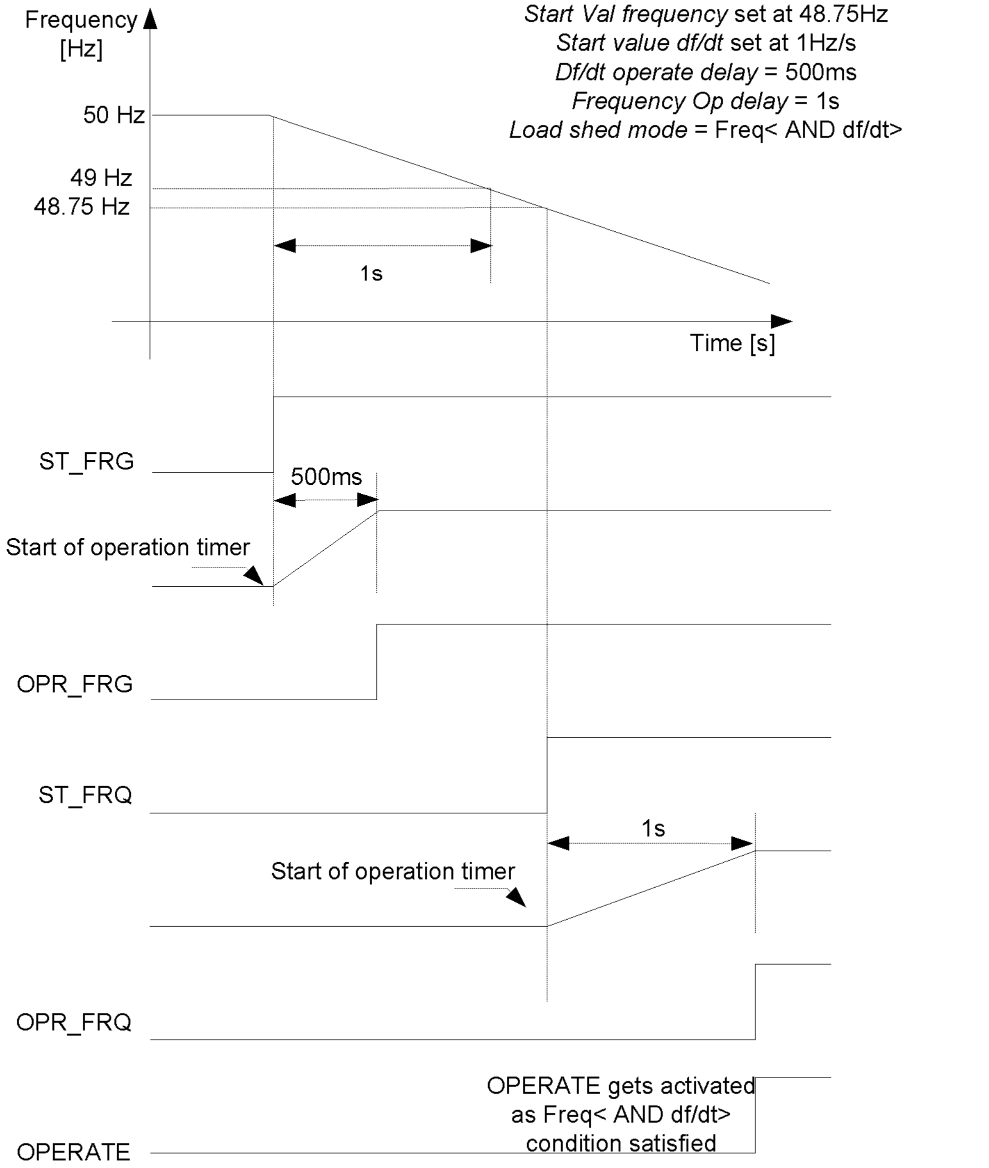


Figure 367: Load-shedding operation in the "Freq< AND df/dt>" mode when both Freq< and df/dt conditions are satisfied (Rated frequency=50 Hz)

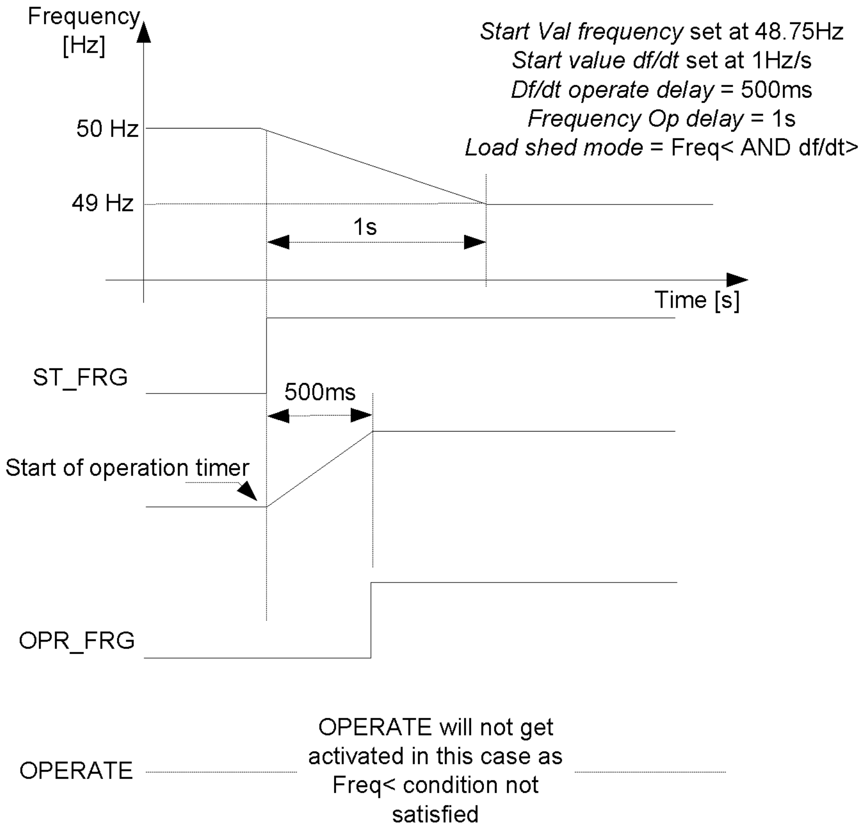


Figure 368: Load-shedding operation in the “Freq< AND df/dt>” mode when only the df/dt condition is satisfied (Rated frequency=50 Hz)

Restore detection

If after the activation of the `OPERATE` input the frequency recovers to a level above the *Restore start Val* setting, the `RESTORE` signal output is activated. The `RESTORE` output remains active for a 100 ms. The *Restore mode* setting is used to select the restoring mode to be "Disabled", "Auto" or "Manual".

Restoring mode	Description
Disabled	Load restoration is disabled.
Auto	In the “Auto” mode, input frequency is continuously compared to the *Restore start Val* setting. The restore detection module includes a timer with the DT characteristics. Upon detection of restoring, the operation timer activates the ST_REST output. When the timer has reached the value of the *Restore delay time* setting, the RESTORE output is activated if the restoring condition still persists. If the frequency drops below the *Restore start Val* before the RESTORE output is activated, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the ST_REST start output is deactivated.
Manual	In the “Manual” mode, a manual restoration is possible through the MAN_RESTORE input or via communication. The ST_REST output is activated if the MAN_RESTORE command is available and the frequency has exceeded the *Restore start Val* setting. The manual restoration includes a timer with the DT characteristics. When the timer has reached the set value of the *Restore delay time* setting, the RESTORE output is activated if the restoring condition still persists. If the frequency drops below the *Restore start Val* setting before the RESTORE output is activated, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the ST_REST start output is deactivated.

A condition can arise where the restoring operation needs to be canceled. Activating the BLK_REST input for the "Auto" or "Manual" modes cancels the restoring operation. In the "Manual" restoring mode, the cancellation happens even if MAN_RESTORE is present.

Once the RESTORE output command is cancelled, the reactivation of RESTORE is possible only after the reactivation of the OPERATE output, that is, when the next load-shedding operation is detected.

Low amplitude blocking

The voltage is compared to the set *MinValFreqMeas* setting. If the voltage magnitude is lower than the set value, the LOWAMPL_BLKD output is activated which resets the timers of the underfrequency and df/dt detection modules.

MinValFreqMeas is the setting related to the preprocessor function SMAI. The setting level is compared to the physically connected voltages. For example, if phase-to-phase voltages are physically connected (phase-to-earth voltages virtual), the 10% setting results in ten percent of the normal phase-to-phase voltage. If phase-to-earth voltages are connected (phase-to-phase voltages virtual), the 10% setting results in 17 percent of the normal phase-to-earth voltage. This is assuming the base voltage is set to be the normal/ nominal phase-to-phase voltage.

Undervoltage detection is blocked by the activation of the BLOCK input.

4.6.4.5 Application

An AC power system operates at a defined rated frequency. The nominal frequency in most systems in the world is 50 Hz or 60 Hz. The nominal frequency is such that the operating frequency value remains approximately at the nominal frequency value by a small margin. The safe margin of operation is usually less than ±0.5 Hz. The system frequency stability is one of the main concerns in the transmission and distribution network operation and control. To protect the frequency-sensitive electrical equipment in the network, departure from the allowed band for safe operation should be inhibited.

Any increase in the connected load requires an increase in the real power generation to maintain the system frequency. Frequency variations form whenever there are system conditions that result in an unbalance between the generation and load. The rate of change of the frequency represents the magnitude of the difference between the load and generation. A reduction in frequency and a negative rate of change of the frequency are observed when the load is greater than the generation, and an increase in the frequency along with a positive rate of change of the frequency are observed if the generation is greater than the load. The rate of change of the frequency is used for a faster decision of load shedding. In an underfrequency situation, the load shedding trips out the unimportant loads to stabilize the network. Thus, loads are normally prioritized so that the less important loads are shed before the important loads.

During the operation of some of the protective schemes or other system emergencies, the power system is divided into small islands. There is always a load - generation imbalance in such islands that leads to a deviation in the operating frequency from the nominal frequency. This off-nominal frequency operation is harmful to power system components like turbines and motors. Therefore, such situation must be prevented from continuing. The frequency-based load-shedding scheme should be applied to restore the operation of the system to normal frequency. This is achieved by quickly creating the load - generation balance by disconnecting the load.

As the formation of the system islands is not always predefined, several load-shedding relays are required to be deployed at various places near the load centers. A quick shedding of a large amount of load from one place can cause a significant disturbance in the system. The load-shedding scheme can be made most effective if the shedding of load feeders is distributed and discrete, that is, the loads are shed at various locations and in distinct steps until the system frequency reaches the acceptable limits.

Due to the action of load-shedding schemes, the system recovers from the disturbance and the operating frequency value recovers towards the nominal frequency. The load that was shed during the disturbance can be restored. The load-restoring operation should be done stepwise in such a way that it does not lead the system back to the emergency condition. This is done through an operator intervention or in case of remote location through an automatic load restoration function. The load restoration function also detects the system frequency and restores the load if the system frequency remains above the value of the set restoration frequency for a predefined duration.

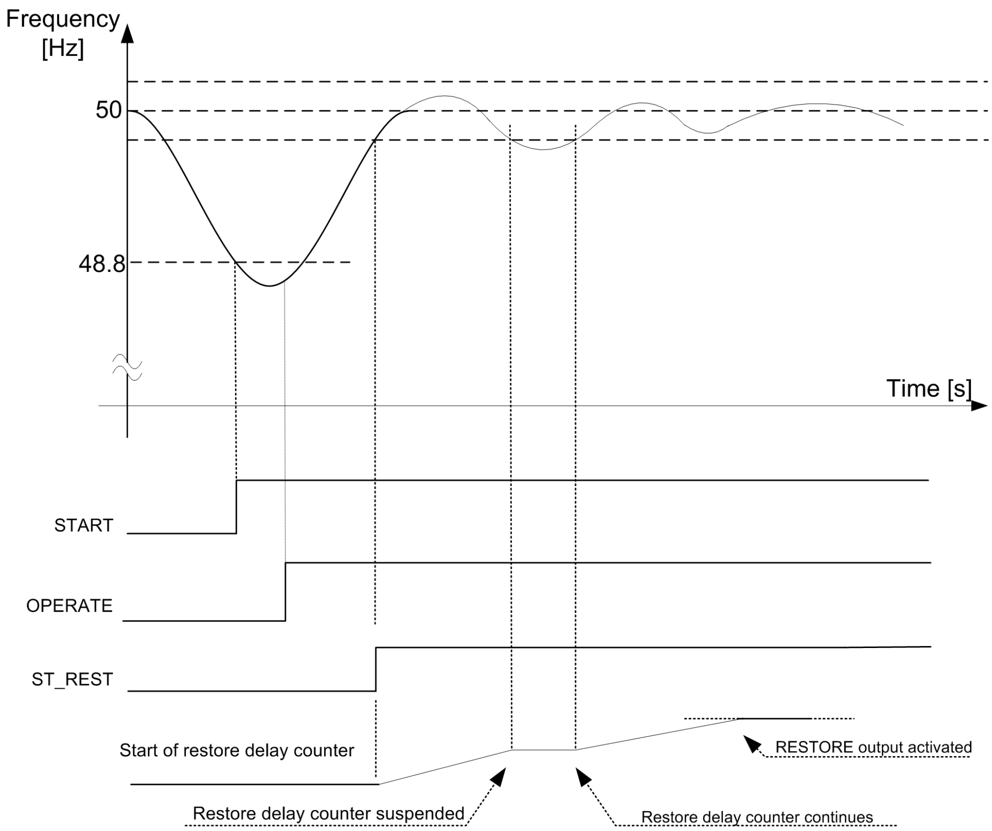


Figure 369: Operation of the load-shedding function

Power system protection by load shedding

The decision on the amount of load that is required to be shed is taken through the measurement of frequency and the rate of change of frequency (df/dt). At a single location, many steps of load shedding can be defined based on different criteria of the frequency and df/dt. Typically, the load shedding is performed in six or four steps with each shedding increasing the portion of load from five to twenty-five percent of full load within a few seconds. After every shedding, the system frequency is read back and further shedding actions are taken only if necessary. In order to take the effect of any transient, a sufficient time delay should be set.

The value of the setting has to be well below the lowest occurring normal frequency and well above the lowest acceptable frequency of the system. The setting level, the number of steps and the distance between two steps (in time or in frequency) depend on the characteristics of the power system under consideration. The size of the largest loss of generation compared to the size of the power system is a critical parameter. In large systems, the load shedding can be set at a high frequency level and the time delay is normally not critical. In small systems, the frequency start level has to be set at a low value and the time delay must be short.

If a moderate system operates at 50 Hz, an underfrequency should be set for different steps from 49.2 Hz to 47.5 Hz in steps of 0.3 – 0.4 Hz. The operating time for the underfrequency can be set from a few seconds to a few fractions of a second stepwise from a higher frequency value to a lower frequency value.

Table 752: Setting for a five-step underfrequency operation

Load-shedding steps	Start Val frequency	Frequency Op delay
1	0.984 · Fn (49.2 Hz)	45000 ms
2	0.978 · Fn (48.9 Hz)	30000 ms
3	0.968 · Fn (48.4 Hz)	15000 ms
4	0.958 · Fn (47.9 Hz)	5000ms
5	0.950 · Fn (47.5 Hz)	500 ms

The rate of change of frequency function is not instantaneous since the function needs time to supply a stable value. It is recommended to have a time delay long enough to take care of the signal noise.

Small industrial systems can experience the rate of change of frequency as large as 5 Hz/s due to a single event. Even large power systems can form small islands with a large imbalance between the load and generation when severe faults or combinations of faults are cleared. Up to 3 Hz/s has been experienced when a small island becomes isolated from a large system. For normal severe disturbances in large power systems, the rate of change of the frequency is much less, often just a fraction of 1.0 Hz/s.

Similarly, the setting for df/dt can be from 0.1 Hz/s to 1.2 Hz/s in steps of 0.1 Hz/s to 0.3 Hz/s for large distributed power networks, with the operating time varying from a few seconds to a few fractions of a second. Here, the operating time should be kept in minimum for the higher df/dt setting.

Table 753: Setting for a five-step df/dt< operation

Load-shedding steps	Start value df/dt	Df/dt operate delay
1	-0.005 · Fn /s (-0.25 Hz)	8000 ms
2	-0.010 · Fn /s (-0.50 Hz)	2000 ms
3	-0.015 · Fn /s (-0.75 Hz)	1000 ms
4	-0.020 · Fn /s (-1.00 Hz)	500 ms
5	-0.025 · Fn /s (-1.25 Hz)	250 ms

Once the frequency has stabilized, the shed load can be restored. The restoring operation should be done stepwise, taking care that it does not lead the system back to the emergency condition.

Table 754: Setting for a five-step restoring operation

Load-shedding steps	Restoring start Val	Restore delay time
1	0.990 · Fn (49.5 Hz)	200000 ms
2	0.990 · Fn (49.5 Hz)	160000 ms
3	0.990 · Fn (49.5 Hz)	100000 ms
4	0.990 · Fn (49.5 Hz)	50000 ms
5	0.990 · Fn (49.5 Hz)	10000 ms

4.6.4.6 Signals

Table 755: LSHDPFRQ Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group input for voltages
BLOCK	BOOLEAN	0	Block of load shed function
BLK_OPR	BOOLEAN	0	Blocks the operate output of the function
BLK_ST	BOOLEAN	0	Block of start output of the function
BLK_REST	BOOLEAN	0	Cancels activation of restore output
FR_TIMER	BOOLEAN	0	Freezes time count of all definite timers to previous values
MAN_RESTORE	BOOLEAN	0	manual activation of restore output

Table 756: LSHDPFRQ Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operation of load shedding
OPR_FRQ	BOOLEAN	Operate signal for under frequency
OPR_FRG	BOOLEAN	Operate signal for high df/dt
START	BOOLEAN	General start. Under frequency or high df/dt detected
ST_FRQ	BOOLEAN	Pick-Up signal for under frequency detection
ST_FRG	BOOLEAN	Pick-Up signal for high df/dt detection
RESTORE	BOOLEAN	Restore signal for load restoring purposes
ST_REST	BOOLEAN	Restore frequency attained and restore timer started
LOWAMPL_BLKD	BOOLEAN	Signal indicating internal blocking due to low amplitude

4.6.4.7 Settings

Table 757: LSHDPFRQ Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Load shed mode	Freq< freq< AND dfdt> Freq< OR dfdt>	-	-	Freq<	Set the operation mode for load shedding function
Restore mode	Disabled Auto Manual	-	-	Disabled	Mode of operation of restore functionality
Start Val frequency	35.00 - 60.00	Hz	0.01	48.80	Frequency setting/start value
Start value df/dt	0.10 - 10.00	Hz/s	0.01	0.50	Setting of frequency gradient for df/dt detection
Restore start Val	45.00 - 60.00	Hz	0.01	49.90	Restore frequency setting value
Frequency Op delay	0.08 - 200.00	s	0.01	0.08	Time Delay to operate for under frequency stage
Df/dt operate delay	0.12 - 60.00	s	0.01	0.20	Time Delay to operate for df/dt stage
Restore delay time	0.17 - 60.00	s	0.01	0.30	Time Delay to restore

Table 758: LSHDPFRQ Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation off/On

Table 759: LSHDPFRQ Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Reset delay time	0.00 - 60.00	s	0.01	0.05	Time Delay after which the definite timers will reset

4.6.4.8 Measured values

Table 760: LSHDPFRQ Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of load shed function
BLK_OPR	BOOLEAN	0	Blocks the operate output of the function
BLK_ST	BOOLEAN	0	Block of start output of the function
BLK_REST	BOOLEAN	0	Cancels activation of restore output
FR_TIMER	BOOLEAN	0	Freezes time count of all definite timers to previous values
MAN_RESTORE	BOOLEAN	0	manual activation of restore output

4.6.4.9 Monitored data

Table 761: LSHDPFRQ Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operation of load shedding
OPR_FRQ	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for under frequency
OPR_FRG	BOOLEAN	0=FALSE 1=TRUE	-	Operate signal for high df/dt
START	BOOLEAN	0=FALSE 1=TRUE	-	General start. Under frequency or high df/dt detected
ST_FRQ	BOOLEAN	0=FALSE 1=TRUE	-	Pick-Up signal for under frequency detection
ST_FRG	BOOLEAN	0=FALSE 1=TRUE	-	Pick-Up signal for high df/dt detection
RESTORE	BOOLEAN	0=FALSE 1=TRUE	-	Restore signal for load restoring purposes
ST_REST	BOOLEAN	0=FALSE 1=TRUE	-	Restore frequency attained and restore timer started
LOWAMPL_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Signal indicating internal blocking due to low amplitude
START_DUR	REAL	-	%	Start duration in percents of the total operation time

4.6.4.10 Technical data

Table 762: LSHDPFRQ Technical data

Characteristic		Value
Operation accuracy		At the frequency f = 35...66 Hz
		±0.003 Hz
Start time[1)2)]	*Load shed mode*	Typically 175 ms (±15 ms) Typically 250 ms (±15 ms)
	Freq<: f_{Fault} = 0.80 × set *Start value* freq< AND dfdt>: df/dt = 0.3 Hz/s	
Reset time		<190 ms
Operate time accuracy in definite time mode		±1.0% of the set value or ±30 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Frequency before fault = 1.2 × f_n, f_n = 50 Hz
2) Includes the delay of the signal output contact

4.6.4.11 Technical revision history

Table 763: LSHDPFRQ technical revision history

Technical revision	Change
B	• Removed one decimal from *Reset delay time*, *Restore delay time*, *Df/dt operate delay* and *Frequency Op delay* setting • Minimum setting value changed from 0.170 to 0.08, maximum setting value changed from 60.000 to 200.00 and default setting value changed from 0.200 to 0.08 for the *Frequency Op delay* setting • Minimum setting value changed from 0.170 to 0.12 for *Df/dt operate delay* setting • Internal improvements

4.7 Impedance protection

4.7.1 Distance protection DSTPDIS

4.7.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase distance protection function	DSTPDIS	Z<	21, 21P, 21N

4.7.1.2 Function block

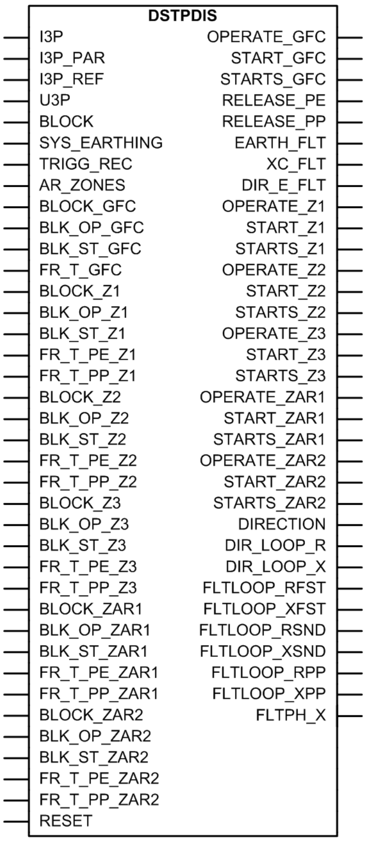


Figure 370: Function block

4.7.1.3 Functionality

Three-phase distance protection DSTPDIS provides a full-scheme distance protection function for distribution networks where three-phase tripping is allowed for all kinds of faults.

DSTPDIS has three flexible, configurable impedance zones for protection (Z1, Z2 and Z3) and two impedance zones for auto-reclosing schemes (ZAR1 and ZAR2).

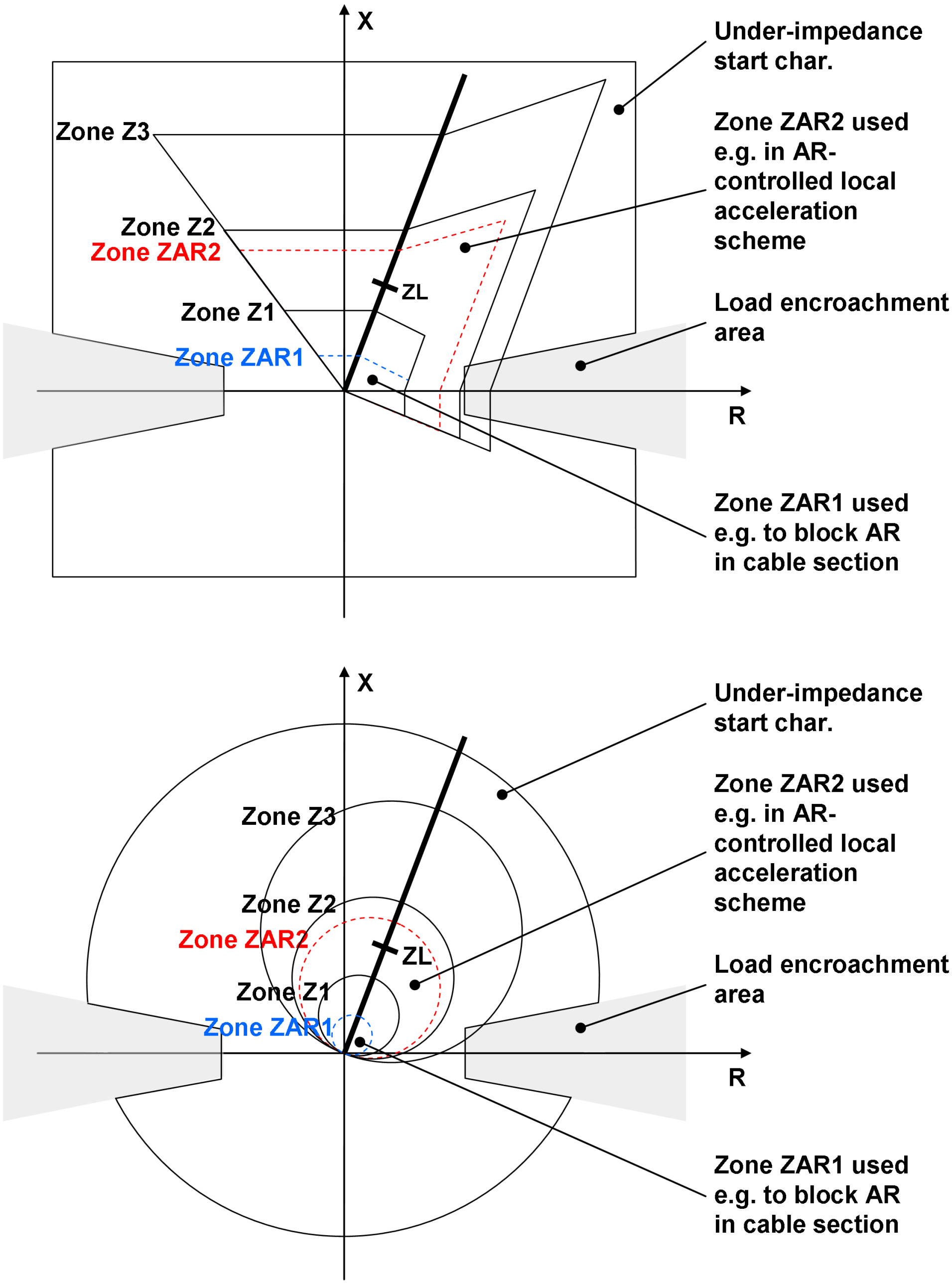


Figure 371: Zones of DSTPDIS function

The supported zone characteristic shapes are quadrilateral, mho (circular) or bullet (quadrilateral and mho characteristics combined). Mho can be combined with directional lines to secure directionality and to enable increased fault resistance coverage with an offset mho circle.

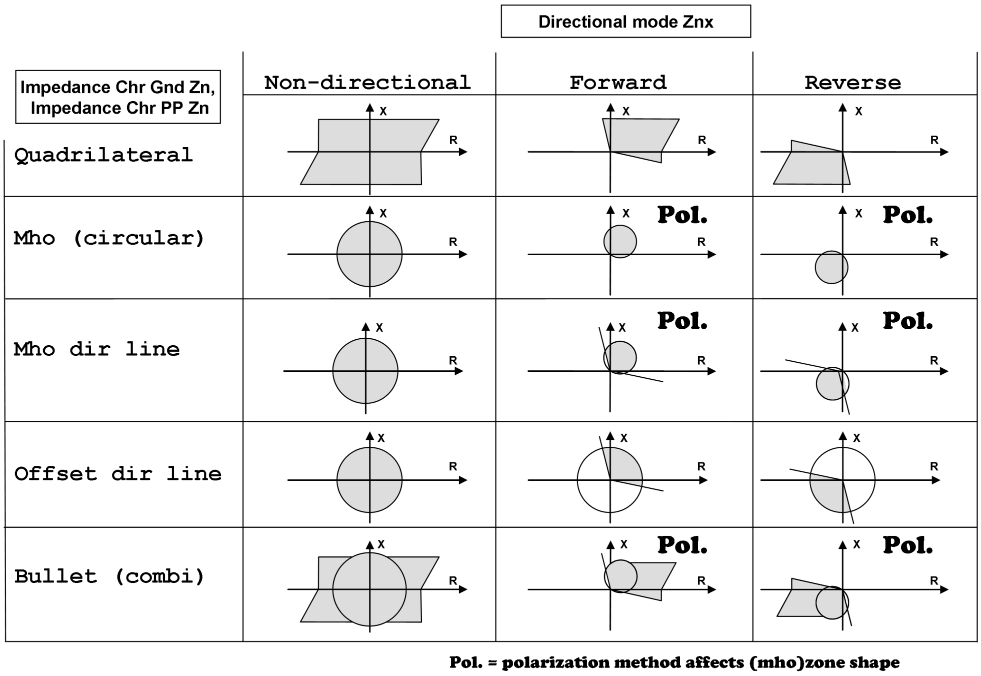


Figure 372: Possible combinations of Directional mode Zx and Zone characteristics settings. Pol. here means that the shape of the characteristic is affected by the selected polarization method of mho circle (Pol quantity zone = "Cross Pol", "Pos Seq Pol")

The directional lines are polarized with positive sequence voltage for all impedance measuring elements. In addition, the memory voltage is used with three-phase impedance measurement elements if the positive sequence voltage drops too low.

DSTPDIS has separate and independent measurement elements for each separate fault loop in the respective distance protection zone. In addition to the full scheme design, the separate measuring elements are used for general fault detection and faulted phase selection.

DSTPDIS supports both fault-detection dependent control of zone timers and zone dedicated timer control for maximum application flexibility.

The impedance measurement is always done the same way regardless of the zone shape. The operation is based on the impedance mapping approach where the fault loop impedance is first calculated and then compared to the zone boundaries. If impedance is recognized within the operation zone, the corresponding operate output is activated after the operate time has elapsed.

The impedance measurement is based on full cycle DFT filtered current and voltage phasors. The minimum operate time that can be achieved is 40...50 ms.

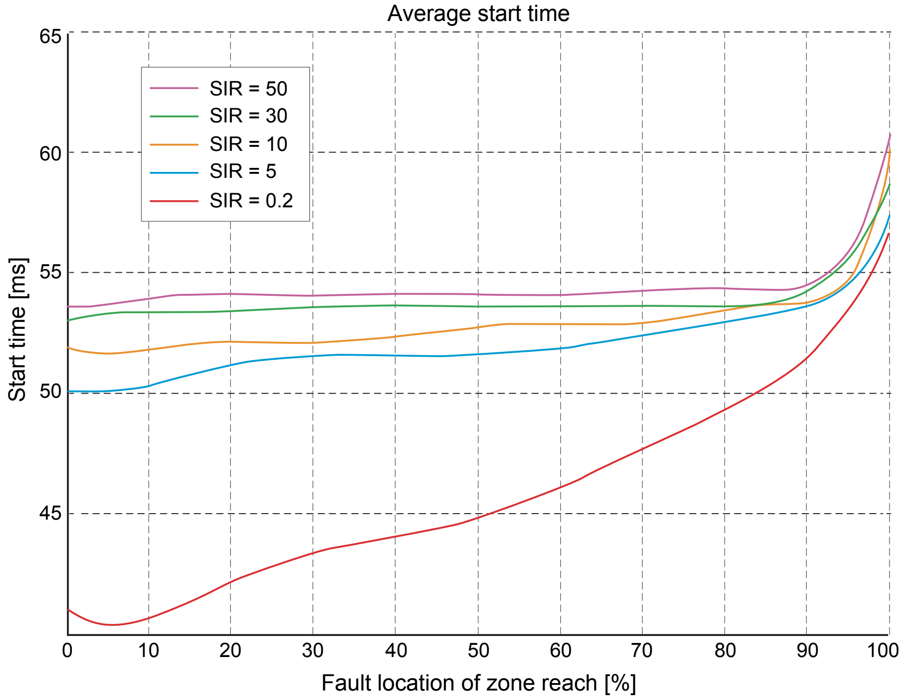


Figure 373: Average start time of distance protection function according to IEC 60255-121 network models Short line and Long line (50 Hz)

SIR curves are plotted from the data which includes variation of fault location (0…100% of zone reach, 5% step), fault type (LN, LL, LLN, LLL) and fault inception angle (0, 30, 60, 90 degrees). Each combination is repeated ten times giving the total number of 16800 shots. Start times include the delay of relay output contacts.

4.7.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The function consists of sub-functions which are described in the next sections.

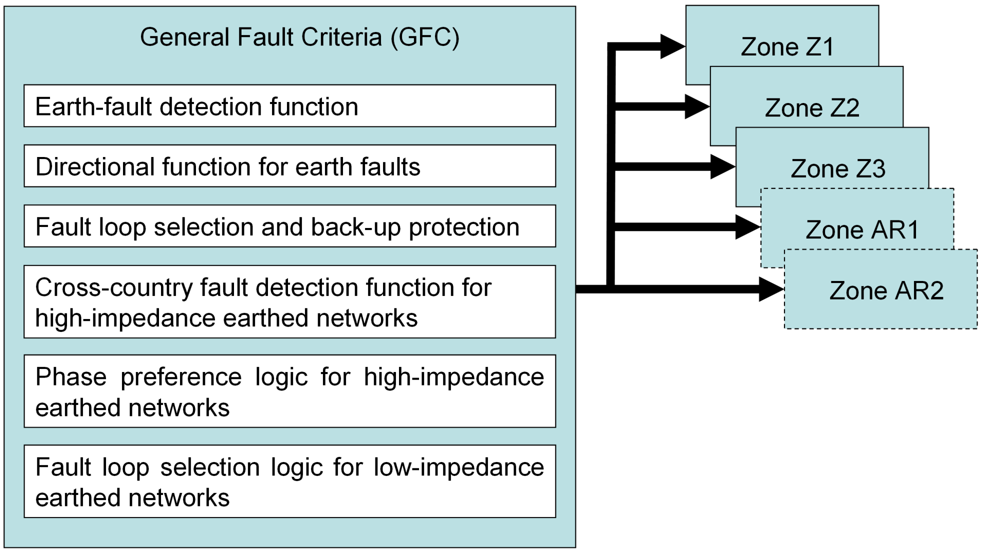


Figure 374: Main functionality of DSTPDIS

All outputs and the operation of all sub-functions can be blocked with the `BLOCK` binary input signal. In addition, it resets the timers.

Earth-fault detection function

The recognition of an earth fault is an important part in identifying the correct fault type. This information is used in faulted loop (phase) selection to release the correct impedance-measuring elements. The earth-fault recognition is always required to release the phase-to-earth impedance-measuring elements.

The earth-fault detection is indicated with the `EARTH_FLT` output. The earth-fault detection criterion can be defined with the "EF detection Mod GFC " setting. The fundamental criterion is based on the residual current. The residual voltage and reference neutral current, measured from the transformer neutral point, can be used for the earth-fault detection criteria.

Table 764: Selection of earth-fault detection criteria

Setting	Enumerator name
EF detection Mod GFC	• Io • Io OR Uo • Io AND Uo • Io AND Ioref

If the residual current Io is derived from the phase currents either by the summation connection of CTs, that is, the Holmgreen connection, or by internally summing the phase currents, there is a risk of a false earth-fault detection due to apparent residual current from the current transformer errors. This risk can be eliminated using a stabilized residual current measurement. The stabilization is enabled by setting the *EF Det neutral A GFC* setting to "Virtual". The stabilization increases the residual current *Gnd Op current GFC* threshold setting when the maximum phase current exceeds the base current. The increase is defined with the *Stab slope 1 GFC* setting. The apparent residual current may exist during short circuits and in inrush current situations if the CTs saturate partially. The earth-fault detection function takes the CT saturation into account with additional stabilization settings *Gnd Op current 2 GFC*, *A Ph Stab value GFC* and *Stab slope 2 GFC*.

Setting *EF Det neutral A GFC* to "Measured" disables the stabilization of the residual current measurement and should be used only when the residual current is measured with a cable current transformer. The residual current threshold setting for earth-fault detection is *Gnd Op current GFC*. If residual current is measured from a transformer neural point, *Gnd Op A Ref GFC* is used. This is valid when the setting *EF detection mod GFC* is "Io AND Ioref".

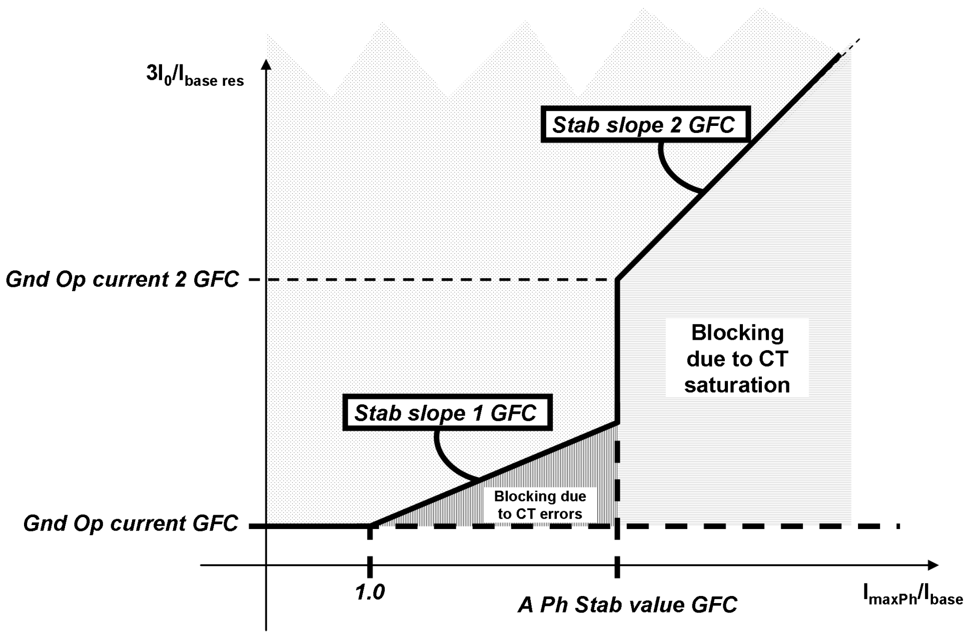


Figure 375: Stabilized residual current measurement for earth-fault detection

The residual voltage can also be used as a complementary criterion for earth-fault detection. This is valid when the setting *EF detection Mod GFC* is "Io OR Uo" or *EF detection Mod GFC* is "Io AND Uo". The threshold setting for the residual voltage is *Gnd Str voltage GFC*.

Directional function for earth faults

In low-impedance earthed networks, when the *System grounding GFC* setting is set to "Low impedance", the earth-fault detection function can be optionally supervised by a directional function which can be enabled with the *Dir Mode EF GFC* setting. If *Dir mode EF GFC* is set to "Forward" or "Reverse", the earth-fault detection function becomes directional. In this case, in addition to satisfying the operation criteria, the detection of an earth-fault requires that the calculated direction of the earth-fault matches the *Dir mode EF GFC* setting. The calculated direction for the earth-fault is indicated in the DIR_E_FLT output ("Unknown", "Forward", "Reverse", "Both").

The directional function for earth faults is common for all zones and can therefore only be applied when the directionality of all zones is set similarly, that is, "Forward" or "Reverse".

The operation characteristic of the directional function is defined by three settings: *Chr angle GFC*, *Min phase angle GFC* and *Max phase angle GFC*.

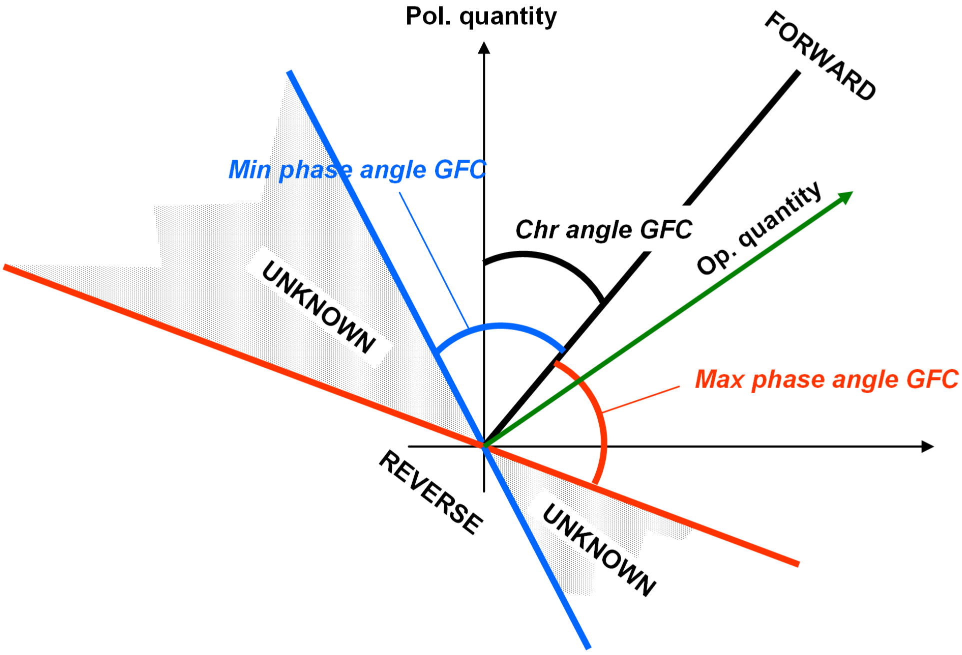


Figure 376: Characteristic of the directional function for earth faults

The *Chr angle GFC* setting, also known as relay characteristic angle or basic angle, is used to turn the directional characteristic. It has a positive value when the operating quantity lags the polarizing quantity and a negative value when the operating quantity leads the polarizing quantity. For low-impedance earthed networks, *Chr angle GFC* equals the angle of the fault loop impedance and is typically positive.

The *Min phase angle GFC* and *Max phase angle GFC* settings define the width of the operating sector.

The directional function for earth faults must operate at fault current values below the magnitude of the load currents. The use of sequence quantities is preferred for polarizing quantity as the phase quantities are affected by the load currents. Four possibilities are available and defined by the *Pol quantity GFC* setting.

Table 765: Polarizing quantities for optional directional function for earth fault in low-impedance earthed networks

Pol quantity GFC	Polarizing quantity	Operating quantity	Description
Zero seq. volt.	$-U_0$	I_0	Zero-sequence voltage polarization
Neg. seq. volt.	$-U_2$	I_2	Negative-sequence voltage polarization
Zero seq. cur.	I_{oref}	I_0	Zero-sequence current polarization
Zro vol.OR cur.	$-U_0$ OR I_{oref}	I_0	Dual polarization

The polarizing quantity is $-U_0$ and the operating quantity is I_0 in case of zero-sequence voltage polarization.
The polarizing quantity is $-U_2$ and the operating quantity is I_2 in case of negative-sequence polarization.

In case of zero-sequence current polarization "Zero seq. cur.", the zero-sequence current I_0 of the protected line is the operating quantity while another reference zero-sequence current I_{0ref} is the polarizing quantity. I_{0ref}, for example, could be the current from the neutral of a power transformer. In case of zero-sequence current polarization, the relay characteristic angle *Chr angle GFC* is fixed and is equal to zero degrees. The zero-sequence current direction must remain unchanged during all network configurations and faults. Therefore, all transformer configurations or constructions are not suitable for polarization.

In case of dual polarization "Zro vol. OR cur.", the zero-sequence voltage polarization and zero-sequence current polarization elements are logically OR:ed. Typically, when I_0 is high, U_0 is low, and when I_0 is low, U_0 is high. Hence the protection can benefit from both elements as the two polarization methods complement each other. If the zero-sequence current polarization source is switched off for service, the flexibility is increased as the zero-sequence voltage polarization can be used.

Faulted loop phase selection

A reliable identification of a fault and faulted phases is needed to guarantee a selective operation of the distance protection. This information is used to release correct measuring elements of the protection zones.

In DSTPDIS, the faulted phase selection can be done in various ways and defined with the *Phase Sel mode GFC* setting.

Table 766: Supported methods for phase selection

Setting	Enumerator value
Phase Sel mode GFC	• Overcurrent • Voltdep overcur • Under impedance

The “Overcurrent” method is the basic method for identifying the faulted phases. It can be used in applications where the fault current magnitude exceeds the load current despite the possible changes in the network configuration and fault type.

The “Voltdep overcur” method combines overcurrent and undervoltage conditions. An undervoltage condition allows lower current threshold settings and increases the sensitivity of the fault detection.

The “Under impedance” method uses fault loop impedance for identifying the faulted phases. The underimpedance characteristic can be either quadrilateral or circular in shape. The sensitivity of the fault detection is defined by an independent setting in resistive and reactive reaches. The underimpedance method is supervised by a load encroachment logic which ensures that the load impedance does not interfere with the faulted phase selection.

All phase selection methods require that all three phase currents are measured and all three phase-to-earth voltages are available. In case only phase-to-phase voltages are available (*Phase voltage Meas* = “PP without Uo”), only phase-to-phase measuring loops can be released for measurement. The release of phase-to-earth fault measuring elements is then blocked, `RELEASE_PE` = “No releases”.

The operation of the faulted phase selection function is highly dependent on the earth-fault detection function, which can be supervised by the directional function in low impedance earthed networks. The phase preference or faulted loop selection logic can be set to filter the faulted phases to be released for measurement in the protection zones.

The general indication of a fault is given in the binary-output `START_GFC`. The faulted phase information can be found from the integer-type output signal `STARTS_GFC`.

Table 767: Enumeration values for integer output signal ***STARTS_GFC***

Enumeration name	Value
No starts	0
Start PhA	1
Start PhB	2
Start PhA, PhB	3
Start PhC	4
Start PhC, PhA	5
Start PhB, PhC	6
St PhA, PhB, PhC	7

The fault loops released for measurement are indicated with the integer-type output signals `RELEASE_PE` and `RELEASE_PP`. These outputs may be filtered by the phase preference of the faulted loop selection logic.

Table 768: Enumeration values for integer output signal **RELEASE_PE**

Enumeration name	Value
No releases	0
Release PhA	1
Release PhB	2
Release PhA, PhB	3
Release PhC	4
Release PhC, PhA	5
Release PhB, PhC	6
Release PhA, B, C	7

Table 769: Enumeration values for integer output signal **RELEASE_PP**

Enumeration value	Value
No releases	0
Release PhAB	1
Release PhBC	2
Rel PhAB, PhBC	3
Release PhCA	4
Rel PhAB, PhCA	5
Rel PhBC, PhCA	6
PhAB, PhBC, PhCA	7
Release PhABC	8
Rel PhAB, PhABC	9
Rel PhBC, PhABC	10
PhAB, PhBC, PhABC	11
Rel PhCA, PhABC	12
PhAB, PhCA, PhABC	13
PhBC, PhCA, PhABC	14
PhAB, BC, CA, ABC	15

The phase selection function can be set to issue a trip as the faulted phase selection uses independent measuring elements from the distance protection zones. This can be applied as a back-up protection for the measurement zones. The time delay of the trip signals is defined with the "Operate delay GFC" setting. The trip signal is the binary output OPERATE_GFC.

All the outputs from the faulted loop phase selection function (OPERATE_GFC, START_GFC, STARTS_GFC, RELEASE_PE, RELEASE_PP, EARTH_FLT, XC_FLT, DIR_E_FLT and CONFLICT_GFC) can be blocked and the timers are also reset with the binary-input signal BLOCK_GFC. The start outputs can be blocked with the binary-input signal BLK_ST_GFC. The OPERATE output can be blocked with the binary-input signal BLK_OP_GFC. The timers of the fault measuring elements in the phase selection function can be stopped with the binary-input signal FR_T_GFC.

Faulted loop phase selection by the overcurrent method

The "Overcurrent" method is the basic method used for identifying the faulted phases. It can be used in applications where the fault current magnitude exceeds the load current despite the possible changes in the network configuration and fault type.

In the overcurrent-based faulted phase selection method, the amplitude of each phase current is compared to the *Ph Str A Ph Sel GFC* threshold setting. If the phase current magnitude exceeds the value of *Ph Str A Ph Sel GFC*, that particular phase is faulty.

Earth-fault recognition is always required to release a phase-to-earth impedance-measuring element.

Table 770: Conversion from element start to output signals

Start of element	START_GFC	STARTS_GFC	RELEASE_PE	RELEASE_PP
I_A> & EARTH_FLT	TRUE	Start PhA	Release PhA	No releases
I_B> & EARTH_FLT	TRUE	Start PhB	Release PhB	No releases
I_C> & EARTH_FLT	TRUE	Start PhC	Release PhC	No releases
I_A> & I_B>	TRUE	Start PhA, PhB	No releases	Release PhAB
I_B> & I_C>	TRUE	Start PhB, PhC	No releases	Release PhBC
I_C> & I_A>	TRUE	Start PhC, PhA	No releases	Release PhCA
I_A> & I_B> & EARTH_FLT	TRUE	Start PhA, PhB	Release PhA, PhB	Release PhAB
I_B> & I_C> & EARTH_FLT	TRUE	Start PhB, PhC	Release PhB, PhC	Release PhBC
I_C> & I_A> & EARTH_FLT	TRUE	Start PhC, PhA	Release PhC, PhA	Release PhCA
I_A> & I_B> & I_C> 1)	TRUE	St PhA, PhB, PhC	No releases	Release PhABC
I_A> & I_B> & I_C> & EARTH_FLT2)	TRUE	St PhA, PhB, PhC	No releases	Release PhABC

1) This applies for near 3-phase fault and in case voltages are still relatively high, all PP releases will be given.
2) This applies for near 3-phase fault with EF indication. In case voltages are still relatively high, all PE and PP releases (except PhABC) will be given.

In case of a high-impedance earthed network, a phase preference logic can be added to complement the phase selection in case of a cross-country fault. This can affect the RELEASE_PE signals.

In case of a low-impedance earthed network, a faulted loop selection logic can be added to complement the phase selection in case of a two-phase-to-earth fault. This can affect the RELEASE_PE and RELEASE_PP signals.

Faulted phase selection, the voltdep overcur method

The "Voltdep overcur" method combines the overcurrent and undervoltage conditions. The phase current amplitude is compared to the *Ph Str A Ph Sel GFC* threshold setting but a lower current *Ph Lo A Ph Sel GFC* threshold is valid during an undervoltage condition. This increases the sensitivity of the fault detection. The amplitude of phase-to-earth and phase-to-phase voltages is compared to the *Ph V Ph Sel GFC* and *PP V Ph Sel GFC* settings. In case of a three-phase fault, the phase-to-phase voltages are monitored and compared to the *PP V Ph Sel GFC* setting.

Earth-fault recognition is required to release a phase-to-earth impedance measuring element.

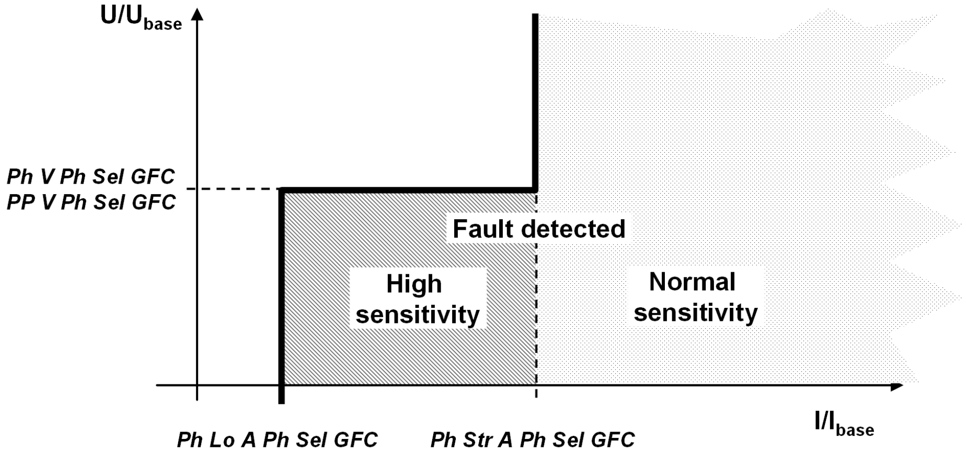


Figure 377: Overcurrent/undervoltage characteristics

Table 771: Conversion from element start to output signals

Start of element	START_GFC	STARTS_GFC	RELEASE_PE	RELEASE_PP
I_A> & U_A< & EARTH_FLT | I_A>> & EARTH_FLT	TRUE	Start PhA	Release PhA	No release
I_B> & U_B< & EARTH_FLT | I_B>> & EARTH_FLT	TRUE	Start PhB	Release PhB	No release
I_C> & U_C< & EARTH_FLT | I_C>> & EARTH_FLT	TRUE	Start PhC	Release PhC	No release
I_A> & I_B> & U_{AB}< | I_A>> & I_B>>	TRUE	Start PhA, PhB	No release	Release PhAB
I_B> & I_C> & U_{BC}< | I_B>> & I_C>>	TRUE	Start PhB, PhC	No release	Release PhBC
I_C> & I_A> & U_{CA}< | I_C>> & I_A>>	TRUE	Start PhC, PhA	No release	Release PhCA
I_A> & I_B> & U_{AB}< & EARTH_FLT | I_A>> & I_B>> & EARTH_FLT	TRUE	Start PhA, PhB	Release PhA, PhB	Release PhAB
I_B> & I_C> & U_{BC}< & EARTH_FLT | I_B>> & I_C>> & EARTH_FLT	TRUE	Start PhB, PhC	Release PhB PhC	Release PhBC
I_C> & I_A>& U_{CA}< & EARTH_FLT | I_C>> & I_A>> & EARTH_FLT	TRUE	Start PhC, PhA	Release PhC, PhA	Release PhCA
I_A> & I_B> & I_C> & U_{AB}<& U_{BC}<& U_{CA}<| I_A>> & I_B>> & I_C>> 1)	TRUE	St PhA, PhB, PhC	No release	Release PhABC
I_A>& I_B >& I_C <&U_{AB}<&U_{BC}<&U_{CA} <& EARTH_FLT| I_A>> & I_B>> & I_C>> & EARTH_FLT2)	TRUE	St PhA, PhB, PhC	No release	Release PhABC

1) This applies for near 3-phase fault and in case voltages are still relatively high, all PP releases will be given.
2) This applies for near 3-phase fault with EF indication. In case voltages are still relatively high, all PE and PP releases (except PhABC) will be given.

Ix> the phase current exceeds the *Ph Lo A Ph Sel GFC* setting.

Ix>> the current exceeds the *Ph Str A Ph Sel GFC* setting.

Ux< the phase voltage is under the "Ph V Ph Sel GFC" setting.

Uxy< means the phase-to-phase voltage is under the *PP V Ph Sel GFC* setting.

In case of a high-impedance earthed network, a phase preference logic can be added to complement the phase selection in case of a cross-country fault. This can affect the `RELEASE_PE` signals.

In case of a low-impedance earthed network, a faulted loop selection logic can be added to complement the phase selection in case of a two-phase-to-earth fault. This can affect the `RELEASE_PE` and `RELEASE_PP` signals.

Faulted phase selection, the underimpedance method

The "Under impedance" method uses fault loop impedance for identifying the faulted phases. The advantage of the underimpedance criterion is that the sensitivity of the fault detection is independent of the source impedance. The underimpedance function has six impedance measuring elements. The phase-to-earth measuring elements are calculated:

$$\underline{Z}_A = \frac{\underline{U}_A}{\underline{I}_A}$$

(Equation 127)

$$\underline{Z}_B = \frac{\underline{U}_B}{\underline{I}_B}$$

(Equation 128)

$$\underline{Z}_C = \frac{\underline{U}_C}{\underline{I}_C}$$

(Equation 129)

The phase-to-phase measuring elements are based on the formula:

$$\underline{Z}_{AB} = \frac{\underline{U}_{AB}}{\underline{I}_{AB}}$$

(Equation 130)

$$\underline{Z}_{BC} = \frac{\underline{U}_{BC}}{\underline{I}_{BC}}$$

(Equation 131)

$$\underline{Z}_{CA} = \frac{\underline{U}_{CA}}{\underline{I}_{CA}}$$

(Equation 132)

The faulted phase identification is done by comparing the measured impedance to the operating characteristics in the impedance domain. If a measured fault loop impedance is inside the characteristics, the corresponding phase(s) is identified as faulty.

The earth return path impedance is included in the calculated fault loop impedance of the phase-to-earth measuring element.

The shape of the characteristic is selected with the *Z Chr Mod Ph Sel GFC* setting. Two shapes are available and they have flexible configuration:

- "Mho (circular)", Non-directional mho
- "Quadrilateral", Non-directional quadrilateral.

The two shapes can be flexibly configured. It is possible to set the reactive reaches independently in forward and reverse direction and for phase-to-earth (Gnd) and phase-to-phase (PP) measurement elements, for example, the *X Gnd Fwd reach GFC*, *X Gnd Rv reach GFC*, *X PP Fwd reach GFC* and *X PP Rv reach GFC* settings. Also, the resistive reach in case of quadrilateral characteristic can be set independently of reactive reaches, for example, the *Ris Gnd Rch GFC* and *Resistive PP Rch GFC* settings. The characteristic is always mirror-symmetric around the reactance-axis.

The impedance settings are in primary ohms.

In case of heavy loaded feeders, the optional load encroachment logic can be enabled with the *Load Dsr mode GFC* setting. The logic reserves an area for load impedance defined by the *Ris reach load GFC* and *Angle load area GFC* settings.

The underimpedance characteristics in case of phase-to-earth measuring elements are illustrated in Figure 378 and Figure 379. Similar characteristics apply also for phase-to-phase measuring elements with independent settings.

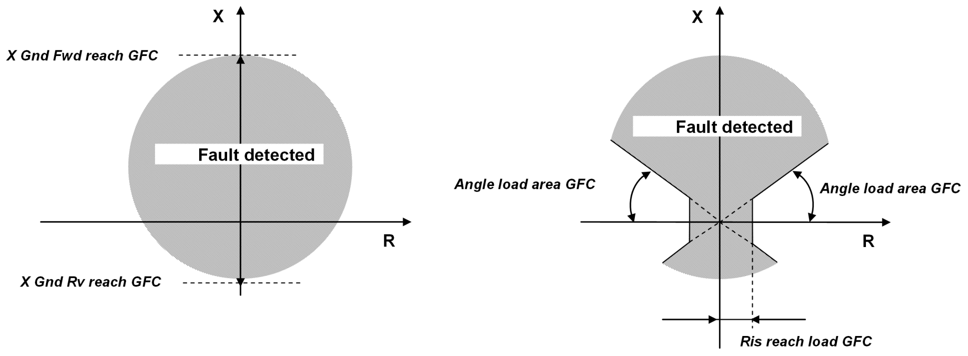


Figure 378: Circular mho underimpedance characteristics

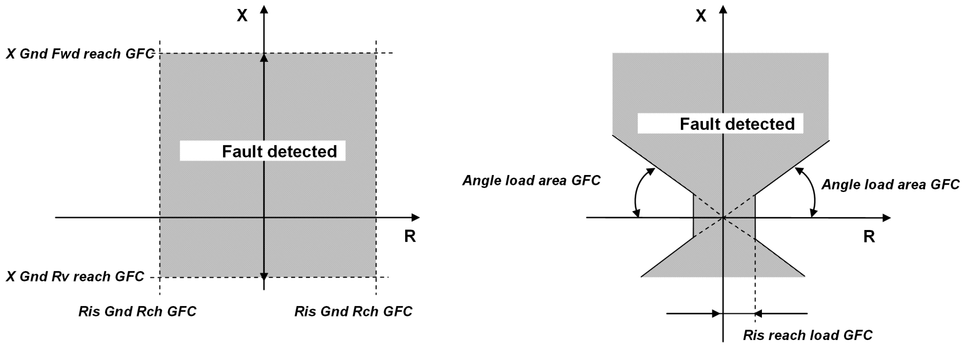


Figure 379: Quadrilateral underimpedance characteristics

The earth-fault recognition is always required to release a phase-to-earth impedance measuring element.

Table 772: Conversion from element start to output signals

Start of element	START_GFC	STARTS_GFC	RELEASE_PE	RELEASE_PP
Z_A< & EARTH_FLT	TRUE	Start PhA	Release PhA	No release
Z_B< & EARTH_FLT	TRUE	Start PhB	Release PhB	No release
Z_C< & EARTH_FLT	TRUE	Start PhC	Release PhC	No release
Z_{AB}<	TRUE	Start PhA, PhB	No release	Release PhAB
Z_{BC}<	TRUE	Start PhB, PhC	No release	Release PhBC
Z_{CA}<	TRUE	Start PhC, PhA	No release	Release PhCA
Z_{AB}< & EARTH_FLT	TRUE	Start PhA, PhB	Release PhA, PhB	Release PhAB
Z_{BC}< & EARTH_FLT	TRUE	Start PhB, PhC	Release PhB, PhC	Release PhBC
Z_{CA}< & EARTH_FLT	TRUE	Start PhC, PhA	Release PhC, PhA	Release PhCA
Z_{AB}< & Z_{BC}< & Z_{CA}< 1)	TRUE	Start PhA, PhB, PhC	No release	PhABC
Z_A< & Z_B< & Z_C< & EARTH_FLT 2)	TRUE	Start PhA, PhB, PhC	No release	PhABC

1) This applies for near 3-phase fault. In case voltages are still relatively high, all PP releases could be given, depending on impedances seen inside GFC zone.
2) This applies for near 3-phase fault with EF indication. In case voltages are still relatively high, all or some PE and PP releases (except PhABC) could be given, depending on impedances seen inside GFC zone.

In case of a high-impedance earthed network, a phase preference logic can be added to complement the phase selection in case of a cross-country fault. This can affect the RELEASE_PE signals.

In case of a low-impedance earthed network, a faulted loop selection logic can be added to complement the phase selection in case of a two-phase-to-earth fault. This can affect the RELEASE_PE and RELEASE_PP output signals.

Cross-country fault detection function for high impedance earthed networks

In isolated and high impedance earthed networks, the overvoltages produced by a single-phase earth fault may lead to a cross-country fault, where two simultaneously single-phase earth faults are present in the system but in different locations and phases. The cross-country fault is hazardous because the magnitude of the fault current through earth can be as high as in the case of a two-phase short-circuit fault. The protection must therefore remove the cross-country fault quickly without sacrificing the selectivity. This can be done with the help of a phase preference logic which is activated by the cross-country fault detection function. The phase preference logic transforms the fault back to an ordinary single-phase earth fault by tripping selectively one of the faulted feeders.

Only the cross-country detecting function becomes active if the network is either isolated or high impedance earthed (*System grounding GFC* = "High impedance").

The fault detection is based on monitoring two quantities:

- Residual current
- Phase-to-phase voltages.

A cross-country fault is detected if:

- An earth fault is detected, EARTH_FLT = TRUE.
  AND
- The calculated residual current exceeds the value of the *Gnd Op A XC GFC* setting. This setting value should exceed the highest expected single-phase earth-fault current. The residual current is calculated from phase currents and also monitored because the cable current transformer saturates easily due to the high fault current.
  AND
- The residual overcurrent condition must be valid at least for the duration defined by the *Cross-country Dl GFC* setting. This shows that the detection is not misled by the high magnitude initial transients of a single-phase earth fault.
  OR
- Any phase-to-phase voltage drops below the value of the *PP voltage XCF GFC* setting. The undervoltage condition is based on the fact that during a single-phase earth fault, the phase-to-phase voltages are unaffected in isolated and high impedance earthed networks. The fulfilment of this criterion avoids the need for any delays in combination with the residual overcurrent condition.

The detection of a cross-country fault is indicated by the XC_FLT output signal.

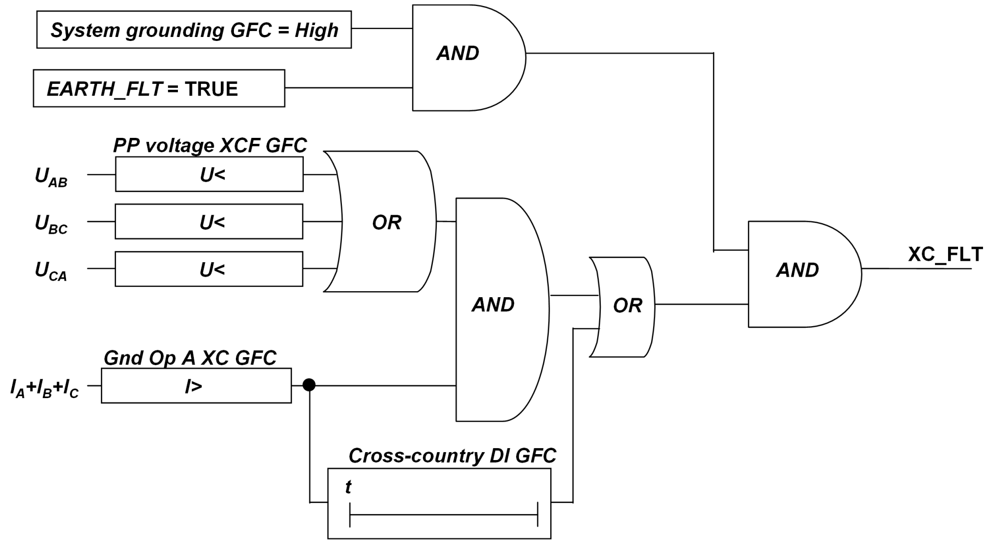


Figure 380: Cross-country fault detection logic for high impedance earthed networks

Phase preference logic for high impedance earthed networks

The phase preference logic for high impedance earthed networks is a supplement to the faulted phase identification function. It provides selective filtering of phase-to-earth measurement elements in case of a cross-country fault or double earth-fault in isolated and high impedance earthed networks.

The logic releases the preferred phase-to-earth loop for measurement when a cross-country fault with two faulted phase-to-earth loops are detected. If only one faulted phase-to-earth loop is detected by phase selection logic (GFC), another faulted phase-to-earth loop is determined based on analyzing voltages. The phase preference scheme must be set in the same way for the entire system so that all distance relays measure the same preferred phase-to-earth loop. As a result, the cross-country fault is changed back into and ordinary single-phase earth-fault by tripping selectively one of the faulted feeders.

The phase preference logic influences only the selection of the phase-earth loops and has no effect on the selection of the phase-to-phase loops. The influence is seen in the RELEASE_PE output. The logic does not affect the RELEASE_PP or START/STARTS outputs.

The phase preference logic is applicable only in isolated and high impedance earthed networks with *System grounding GFC* = "High impedance".

All schemes except "No-filter" require a cross-country fault detection XC_FLT = TRUE; otherwise all the phase-to-earth measuring elements are blocked, RELEASE_PE = No release. This guarantees that tripping at single-phase earth fault in high impedance earthed network is blocked.

If a cross-country fault is detected, XC_FLT = TRUE and only a single fault loop can be identified as faulty by the faulted phase selection function, then that loop is directly selected for measurement. In such case, simultaneous tripping of both faulted feeders during a cross-country is expected.

Example: consider a cross-country fault where phases A and B become faulted simultaneously. All relays, R1, R2, R3 and R4, are equipped with an "Acyc C-A-B" phase preference scheme.

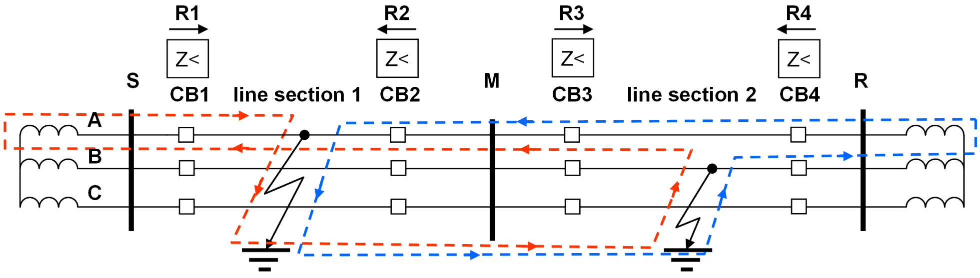


Figure 381: Cross-country fault (or double earth-fault) in high impedance earthed system

The expected operations of the relays are:

- R1: The cross-country fault cannot be detected as the residual current does not flow through the R1 relay. The phase-to-phase loop AB is measured in the forward direction but the estimated impedance represents an average impedance between two fault locations and therefore is not seen in the Z1 zone.
- R2: The cross-country fault is detected as large residual current flowing through the R2 relay. Phase A earth fault is seen in forward direction and phase B earth fault in reverse direction. Based on "Acyc C-A-B" phase preference scheme, phase A is selected for measurement. The R2 relay operates without delay and opens the CB2 circuit breaker.
- R3: The cross-country fault is detected when a large residual current flows through the R3 relay. The phase A earth fault is seen in reverse direction and phase B earth fault in forward direction. Based on the "Acyc C-A-B" phase preference scheme, phase A is selected for measurement. As fault direction does not coincide with zone direction, the R3 relay does not operate.
- R4: Same as the R1 relay.

As a result of the circuit-breaker CB2 operation, the cross-country fault is transformed back to an ordinary single-phase earth fault.

The tables summarize the available phase preference logic schemes and their operation in different fault scenarios. The logic is selected with the *Ph Prf mode Hi Z GFC* setting. In case the logic is not required, then the "No-filter" option should be selected.

"No-filter" option does not block the single-phase earth-faults, and therefore this option should be used with caution.

Table 773: Output `RELEASE_PE` with supported phase preference logic schemes for high impedance earthed networks and their operation in case of single phase start with and without cross-country fault detection

Ph Prf mode Hi Z GFC		Faulted loops					
		A & `EARTH_FLT`	B & `EARTH_FLT`	C & `EARTH_FLT`	A & `XC_FLT`	B & `XC_FLT`	C & `XC_FLT`
1	No-filter	Release PhA	Release PhB	Release PhC	Release PhA	Release PhB	Release PhC
2	No preference	No release	No release	No release	Release PhA	Release PhB	Release PhC
3	Cyc A-B-C-A	No release	No release	No release	Release PhA	Release PhB	Release PhC
4	Cyc A-C-B-A	No release	No release	No release	Release PhA	Release PhB	Release PhC
5	ACyc A-B-C	No release	No release	No release	Release PhA	Release PhB	Release PhC
6	ACyc A-C-B	No release	No release	No release	Release PhA	Release PhB	Release PhC
7	ACyc B-A-C	No release	No release	No release	Release PhA	Release PhB	Release PhC
8	ACyc B-C-A	No release	No release	No release	Release PhA	Release PhB	Release PhC
9	ACyc C-A-B	No release	No release	No release	Release PhA	Release PhB	Release PhC
10	ACyc C-B-A	No release	No release	No release	Release PhA	Release PhB	Release PhC

Table 774: Supported phase preference logic schemes for high impedance earthed networks and their operation in case two phase start without cross-country fault detection

Ph Prf mode Hi Z GFC		Faulted loops					
		A & B `EARTH_FLT`	B & C `EARTH_FLT`	C & A `EARTH_FLT`	A & B `EARTH_FLT`	B & C `EARTH_FLT`	C & A `EARTH_FLT`
1	No-filter	Release PhA, PhB	Release PhB, PhC	Release PhC, PhA	Release PhAB	Release PhBC	Release PhCA
2	No preference	No release	No release	No release	Release PhAB	Release PhBC	Release PhCA
3	Cyc A-B-C-A	No release	No release	No release	Release PhAB	Release PhBC	Release PhCA
4	Cyc A-C-B-A	No release	No release	No release	Release PhAB	Release PhBC	Release PhCA
5	ACyc A-B-C	No release	No release	No release	Release PhAB	Release PhBC	Release PhCA
6	ACyc A-C-B	No release	No release	No release	Release PhAB	Release PhBC	Release PhCA
7	ACyc B-A-C	No release	No release	No release	Release PhAB	Release PhBC	Release PhCA
8	ACyc B-C-A	No release	No release	No release	Release PhAB	Release PhBC	Release PhCA
9	ACyc C-A-B	No release	No release	No release	Release PhAB	Release PhBC	Release PhCA
10	ACyc C-B-A	No release	No release	No release	Release PhAB	Release PhBC	Release PhCA

Table 775: Supported phase preference logic schemes for high impedance earthed networks and their operation in case two phase starts with cross-country fault detection

Ph Pref logic Hi Imp		Faulted loops					
		A & B `XC_FLT`	B & C `XC_FLT`	C & A `XC_FLT`	A & B `XC_FLT`	B & C `XC_FLT`	C & A `XC_FLT`
1	No-filter	Release PhA, PhB	Release PhB, PhC	Release PhC, PhA	Release PhAB	Release PhBC	Release PhCA
2	No preference	Release PhA, PhB	Release PhB, PhC	Release PhC, PhA	Release PhAB	Release PhBC	Release PhCA
3	Cyc A-B-C-A	Release PhA	Release PhB	Release PhC	Release PhAB	Release PhBC	Release PhCA
4	Cyc A-C-B-A	Release PhB	Release PhC	Release PhA	Release PhAB	Release PhBC	Release PhCA
5	ACyc A-B-C	Release PhA	Release PhB	Release PhA	Release PhAB	Release PhBC	Release PhCA
6	ACyc A-C-B	Release PhA	Release PhC	Release PhA	Release PhAB	Release PhBC	Release PhCA
7	ACyc B-A-C	Release PhB	Release PhB	Release PhA	Release PhAB	Release PhBC	Release PhCA
8	ACyc B-C-A	Release PhB	Release PhB	Release PhC	Release PhAB	Release PhBC	Release PhCA
9	ACyc C-A-B	Release PhA	Release PhC	Release PhC	Release PhAB	Release PhBC	Release PhCA
10	ACyc C-B-A	Release PhB	Release PhC	Release PhC	Release PhAB	Release PhBC	Release PhCA

Faulted loop phase selection for low impedance earthed networks

The faulted loop selection logic for low-impedance earthed networks serves as a supplement to the faulted phase identification function and it provides a selective filtering of measurement element in case of a two-phase-to-earth fault in low-impedance earthed networks. The individual earth faults can be located close to each other:

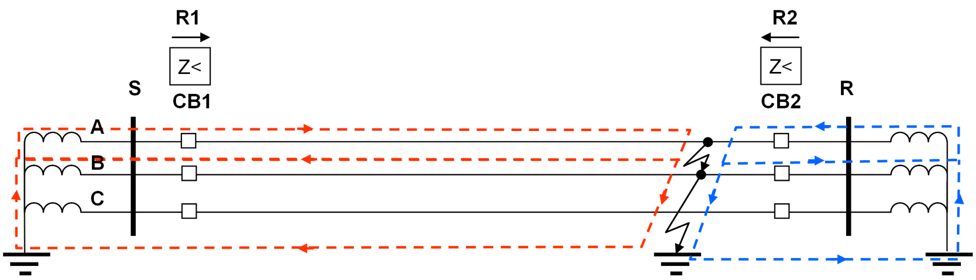


Figure 382: Two-phase-to-earth fault in low-impedance earthed system

Impedance can be measured during a two-phase-to-earth fault when individual earth faults are located in the same direction and they are in close proximity to each other. Generally, too large an impedance is measured for the lagging phase-to-earth loop, for example phase B in an AB-E-fault. Similarly, low Impedance is measured for the leading phase-to-earth loop, for example phase A in an AB-E-fault. The corresponding phase-to-phase loop is measured correctly, for example phase-to-phase loop AB in an AB-E-fault.

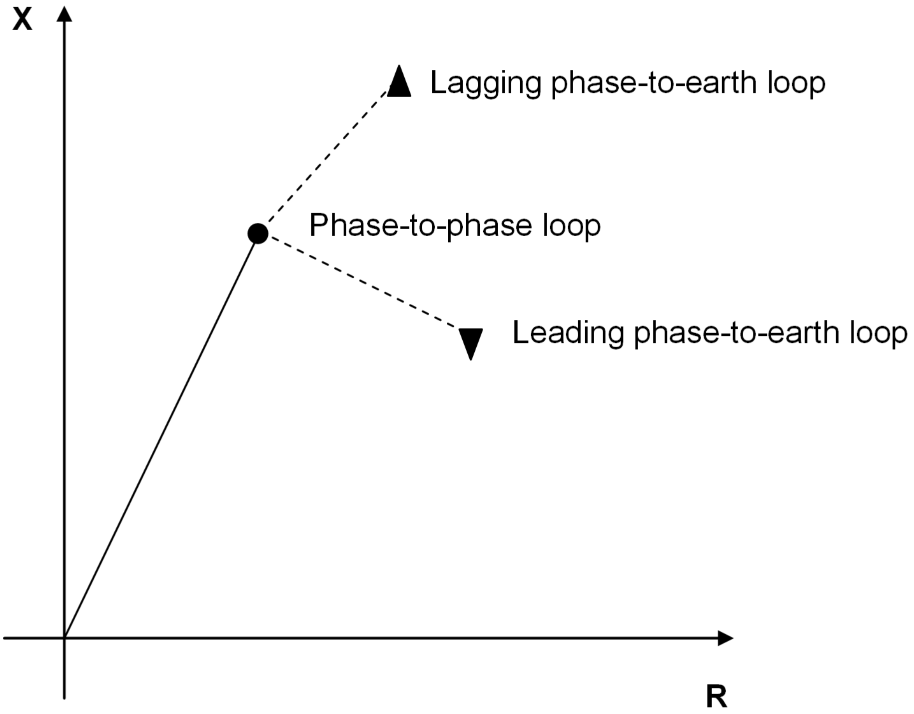


Figure 383: Impedance measured during a two-phase-to-earth fault

The available faulted loop selection logic schemes allows blocking the phase-earth loop of the leading phase to prevent overreaching *Ph Prf mode Lo Z GFC* = "BLK leading PE".

It is also possible to block the lagging phase-earth loop, *Ph Prf mode Lo Z GFC* = "BLK lagging PE". In case only the phase-to-phase loop or phase-to-earth loops are to be measured, select the *Ph Prf mode Lo Z GFC* = "PP only" or *Ph Prf mode Lo Z GFC* = "PE only" settings and if the logic is not required, "All loops" option should be selected.

The tables summarize the available faulted loop selection logic schemes and their operations. The logic is selected with the "Ph Prf mode Lo Z GFC" setting.

Table 776: Supported faulted loop phase selection schemes for low impedance earthed networks and their influence on the **RELEASE_PE** *output*

	Ph Prf mode Lo Z GFC				
Element start	"All loops"	"PE only"	"PP only"	"BLK leading PE"	"BLK lagging PE"
	RELEASE_PE				
A & B & EARTH_FLT	Release PhA, PhB	Release PhA, PhB	No release	Release PhB	Release PhA
B & C & EARTH_FLT	Release PhB, PhC	Release PhB, PhC	No release	Release PhC	Release PhB
C & A & EARTH_FLT	Release PhC, PhA	Release PhC, PhA	No release	Release PhA	Release PhC

Table 777: *Supported faulted loop phase selection schemes for low impedance earthed networks and their influence on the RELEASE_PP output*

	Ph Prf mode Lo Z GFC				
Element start	"All loops"	"PE only"	"PP only"	"BLK leading PE"	"BLK lagging PE"
	RELEASE_PP				
A & B & EARTH_FLT	Release PhAB	No release	Release PhAB	Release PhAB	Release PhAB
B & C & EARTH_FLT	Release PhBC	No release	Release PhBC	Release PhBC	Release PhBC
C & A & EARTH_FLT	Release PhCA	No release	Release PhCA	Release PhCA	Release PhCA

Impedance protection zones

DSTPDIS has three flexible and configurable impedance zones, which are Z1, Z2, Z3, and two additional impedance zones, ZAR1 and ZAR2, that can be applied for autoreclosing AR schemes, for example the local acceleration scheme.

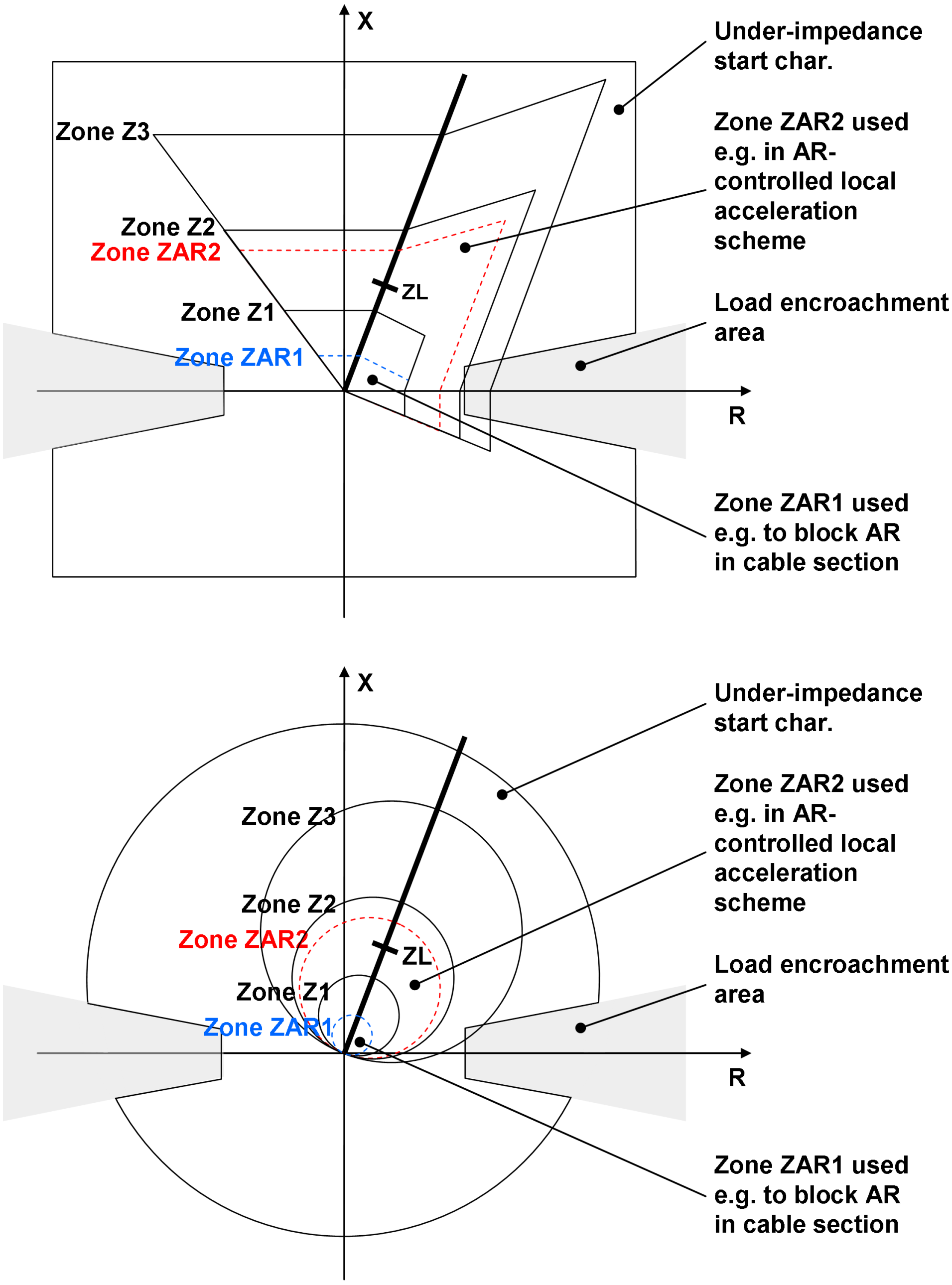


Figure 384: Zones of DSTPDIS function: ZAR1 and ZAR2

The AR-zones, ZAR1 and ZAR2, can be enabled only when the autorecloser function is included in the configuration and set to operate. In the configuration, the `AR_ZONES` group output from the AR-function is connected to the `AR_ZONES` group input of DSTPDIS.

Each zone in DSTPDIS provides three independent phase-to-earth and three phase-to-phase measuring elements. A three-phase fault is measured with a dedicated measuring element. Each measuring element is controlled by the faulted loop phase selection function. Based on the recognized fault type, the release-signals are given for the corresponding measuring elements.

DSTPDIS supports both fault detection dependent control of zone timers and zone dedicated timer control for maximum application flexibility. Zone dedicated timer control is enabled when *Zone timer mode* is set to “Independent”. In this case operate delay timers of protection zones are independent from each other and starts when fault is seen inside the particular protection zone. Fault detection dependent control of zone timers is enabled when *Zone timer mode* is set to “Common”. In this case operate delay timers of all protection zones starts simultaneously and immediately when the fault is seen by the GFC. The operation of a particular zone is given after the set *Operate delay time* (considering the fault type), is detected. The actual operate time is the value calculated from the initial fault detection and it is not affected, for example, in case the fault moves between zones.

The general indication of fault for each zone is given in the START_Zx (x = 1...3, AR1, AR2) binary output. The faulted phase information can be found from the STARTS_Zx (x = 1...3, AR1, AR2) integer type output signal.

Table 778: Enumeration values for integer output signal ***STARTS_Zx*** *(x = 1...3, AR1, AR2)*

Enumeration name	Value
No starts	0
Start PhA	1
Start PhB	2
Start PhA, PhB	3
Start PhC	4
Start PhC, PhA	5
Start PhB, PhC	6
Start PhA, PhB, PhC	7

The operate signal from each zone is the OPERATE_Zx (x = 1...3, AR1, AR2) binary output signal.

The output from each zones can be blocked and the timers are also reset with the BLOCK_Zx (x = 1...3 AR1, AR2) binary input signal. The start outputs can be blocked with the BLK_ST_Zx (x = 1...3, AR1, AR2) binary input signal and the operate output can be blocked with the BLK_OP_Zx (x = 1...3, AR1, AR2) binary input signal. The timers of phase-to-earth and phase-to-phase fault measuring elements can be stopped with the FR_T_PE_Zx (x = 1...3, AR1, AR2) and FR_T_PP_Zx (x = 1...3, AR1, AR2) binary input signals.

The CONFLICT_Zx (x = 1...3, AR1, AR2) output data is an assisting integer type output which supervises the validity of a tilt angle of quadrilateral characteristics so that the characteristics always produces a closed boundary. It can have the values: No conflict, PhE angle tilt, PhPh angle tilt and PhE,PhPh tilt. If the actual value for

Angle tilt Zx (x = 1...3, AR1, AR2) is not valid, the value of *Angle tilt Zx* is forced to zero.

Impedance measurement

The impedance measurement is based on a full cycle DFT-filtered current and voltage phasors providing the operating time for approximately two to three cycles.

DSTPDIS provides three independent phase-to-earth, phase-to-phase measuring elements per zone and the three-phase fault is measured with a dedicated measurement element.

The impedance measurement is done similarly regardless of the zone shape. The operation is based on impedance mapping approach where the fault loop impedance is first calculated and then compared with the zone boundaries. If impedance is recognized inside the operation zone, the corresponding operate output is activated after the operate time has elapsed.

Phase-to-earth impedance measuring elements

The phase-to-earth impedance measuring elements provide the basic earth-fault protection in direct or low impedance earthed networks. The earth-fault protection is enabled with the *Op Mod Gnd loops Znx* (x = 1...3, AR1, AR2) = "Enabled" setting. The enabling requires that all three phase-to-earth voltages are measured. Otherwise, the release of the earth-fault measuring elements is automatically blocked.

The reach of phase-to-earth measuring elements is based on loop impedance

$$\underline{Z}1 + \underline{Z}N + RF = (R1 + (R0 - R1)/3) + j \cdot (X1 + (X0 - X1)/3) + RF$$

(Equation 133)

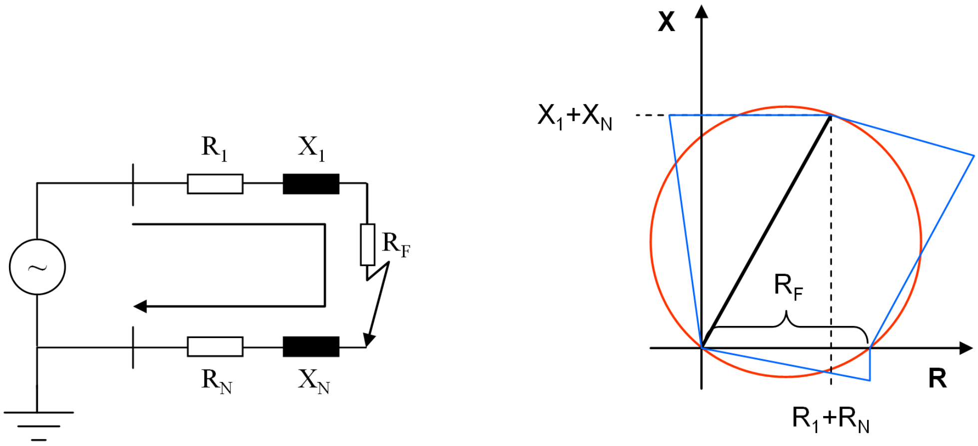


Figure 385: The fault loop impedance model for phase-to-earth impedance measuring elements

R_1 Positive sequence resistance from measuring point to fault location

X_1 Positive sequence reactance from measuring point to fault location

R_N Earth return path resistance = $(R_0 - R_1)/3$ from measuring point to fault loaction

X_N Earth return path reactance = $(X_0 - X_1)/3$ from measuring point to fault location

R_0 Zero sequence resistance from measuring point to fault location

X_0 Zero sequence reactance from measuring point to fault location

R_F Physical fault resistance between phase and earth (includes arc and earthing resistances)

Considering the load in case of a single line to earth fault, conventional distance protection might overreach at the exporting end and underreach at the importing end. DSTPDIS has a load compensation functionality which increases the security in such applications. The load compensation is enabled with the *Load Com zone x* (x = 1...3, AR1, AR2) setting.

The load compensation is only used with single phase-to-earth faults. Load compensation is not used if multiple phases are included into fault (more than one single earth fault releases).

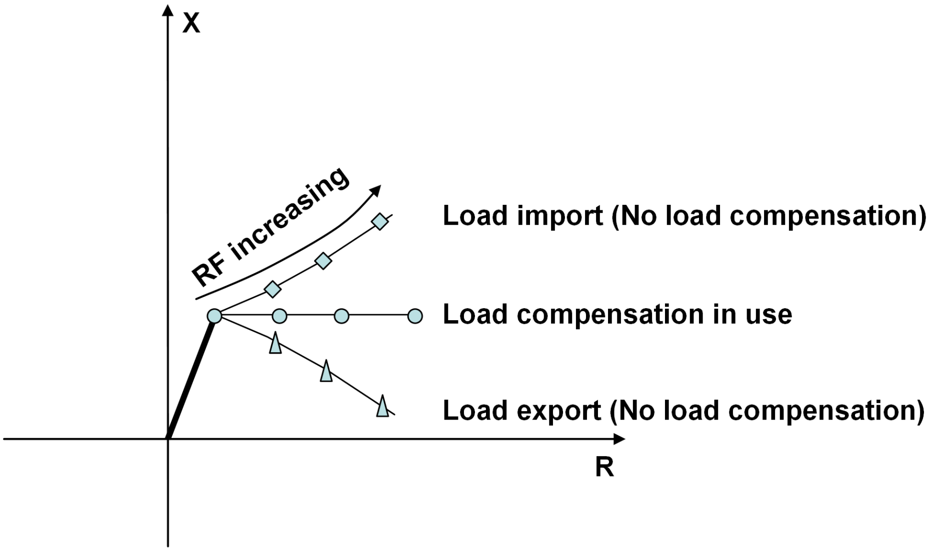


Figure 386: Operation principle of load compensation functionality

When three-phase feeders are placed close to each other, a mutual inductive zero sequence coupling of the current path exists. This has an impact during earth faults. If no special measures are taken, this will lead to errors in the impedance calculation. The residual current of the parallel line induces a voltage in the protection line and changes the measured voltage at the IED location. The influence depends on the system configuration, that is, the magnitude and polarity of the residual current in a parallel line. The phase-to-earth impedance measuring elements in DSTPDIS take the zero-sequence mutual coupling into account in impedance calculation. The compensation is enabled and set with the *Par line Com zone x, Mutual R0 zone* and *Mutual X0 zone x* (x = 1...3, AR1, AR2) settings. It is required that the residual current of the parallel line is available and connected to the `I3P_PAR` input. The earth-current balance logic is implemented to prevent malfunctioning of the IED on the healthy parallel line. This means that the parallel compensation functionality is internally blocked when the ratio between residual current of the parallel line and protected lines exceeds the *Fact EF current Bal* setting.

The parallel line compensation functionality is only used with single phase-to-earth faults. Parallel line compensation is not used if multiple phases are included into fault (more than one single earth fault releases).

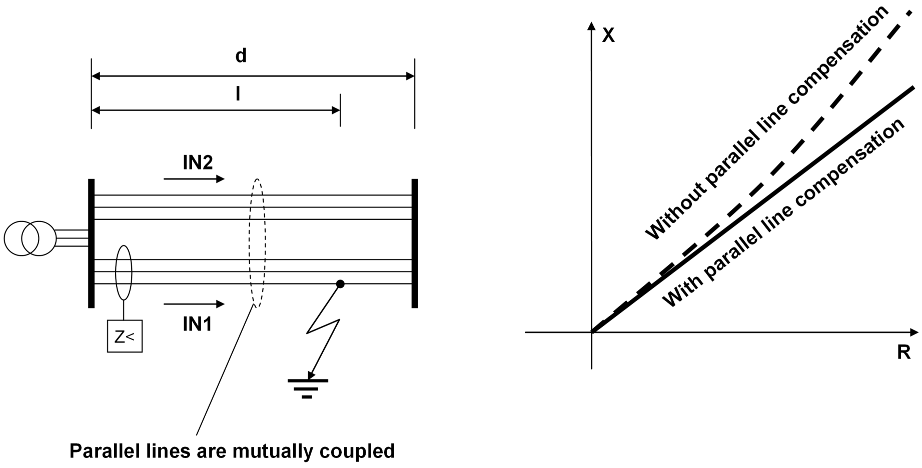


Figure 387: Operation principle of parallel line compensation functionality

The time delay of operation is defined with the *Gnd operate Dl Znx* (x = 1...3, AR1, AR2) setting. The timer can be disabled with the *Gnd Op Dl mode Znx* = "Disable" setting. This blocks the `OPERATE_Zx` (x = 1...3, AR1, AR2) output of the phase-to-earth measuring elements.

Phase-to-phase impedance measuring elements

The phase-to-phase distance protection is suitable as a basic protection function against two-phase short circuit faults in all kinds of networks, regardless of the treatment of the neutral point. The short circuit fault protection is enabled with the *Op Mod PP loops Znx* (x = 1...3, AR1, AR2) = "Enabled" setting.

The reach of the phase-to-phase measuring elements is based on the loop impedance

$$\underline{Z}_1 + \frac{R_F}{2} = R_1 + j \cdot X_1 + \frac{R_F}{2}$$

(Equation 134)

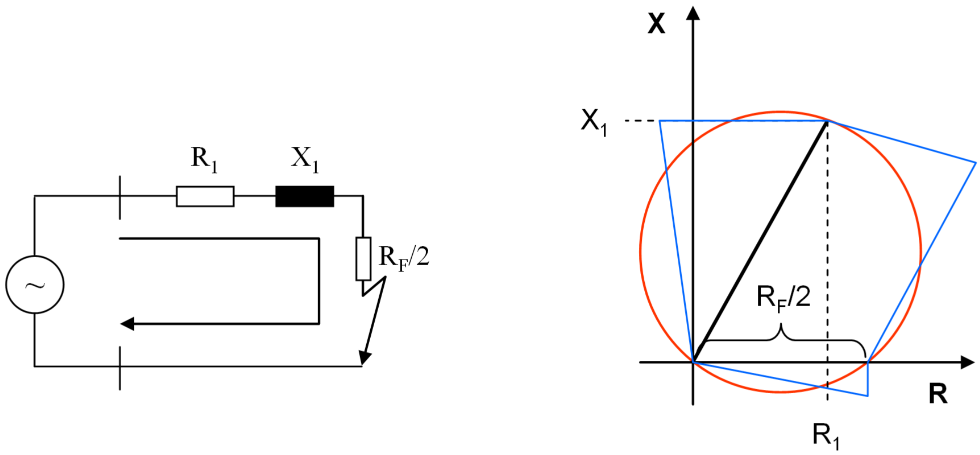


Figure 388: The fault loop impedance model for phase-to-phase impedance measuring elements

R_1 Positive-sequence resistance from measuring point to fault location

X_1 Positive-sequence reactance from measuring point to fault location

R_F Physical fault resistance between phases, for example, arc resistance

The phase-to-phase impedance measuring elements measure only half of the physical fault resistance between phases. This must be taken into account when the resistive reach of the phase-to-phase elements is set (that is, setting the value of 5 ohm corresponds 5+5=10 ohm of physical arc resistance between phases).

The resistive reach setting is common for phase-to-phase and three-phase impedance measuring elements.

The time delay of operation is defined with the *PP operate delay Znx* (x = 1...3, AR1, AR2) setting. The timer can be disabled with the *PP Op delay Mod Znx* = "Disabled" setting. This blocks the `OPERATE_Zx` (x = 1...3, AR1, AR2) output of the phase-to-phase measuring elements.

Three-phase impedance measuring element

DSTPDIS has a dedicated measuring element for three-phase short-circuit fault for each zone. The three-phase measuring element utilizes the positive sequence quantities for a fault loop impedance estimation which increases the accuracy by reducing the influence of line parameter asymmetry. This is advantageous especially in case of non-transposed, asymmetrical lines. The three-phase impedance measuring element is enabled together with the phase-to-phase impedance elements by the *OP Mod PP loops Znx* (x = 1...3, AR1, AR2) = "Enabled" setting.

The reach of three-phase measuring element is based on the loop impedance:

$$\text{Three-phase measuring element reach} = Z_1 + R_F = R_1 + j\,X_1 + R_F$$

(Equation 135)

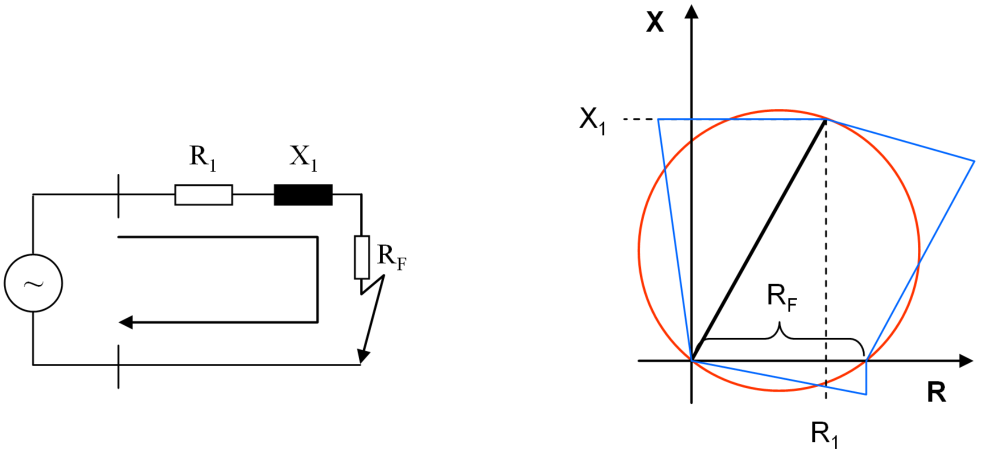


Figure 389: The fault loop impedance model for three-phase impedance measuring element

R_1 Positive sequence resistance from measuring point to fault location

X_1 Positive sequence reactance from measuring point to fault location

R_F Physical fault resistance per phase, for example, arc resistance

The three-phase impedance measuring element measures the physical fault resistance per phase. The resistive reach setting is common for three-phase and phase-to-phase impedance measuring elements.

The time delay of operation is defined with the *PP operate delay Znx* (x = 1...3, AR1, AR2) setting. The timer can be disabled with the *PP Op delay Mod znx* = "Disabled" setting. This will block the `OPERATE_Zx` (x = 1...3, AR1, AR2) output of the three-phase measuring elements.

Entering the line reach

The line reach is entered in primary ohms. The impedance format is selected with the *Impedance mode Zn* = "Rectangular" for the vectors R, X and "Polar" for the magnitude and angle.

Impedance mode Zn = Rectangular

In case of phase-to-phase or three-phase impedance measuring elements, the line reach is defined with:

- Resistive reach: *R1 zone x* (x = 1...3, AR1, AR2)
- Reactive reach: *X1 zone x* (x = 1...3, AR1, AR2).

In case of non-directional characteristics, the reactive reach in reverse direction is defined with the *X1 reverse zone x* (x = 1...3, AR1, AR2) setting. The characteristic line angle, denoted as α, is the same for both forward and reverse direction.

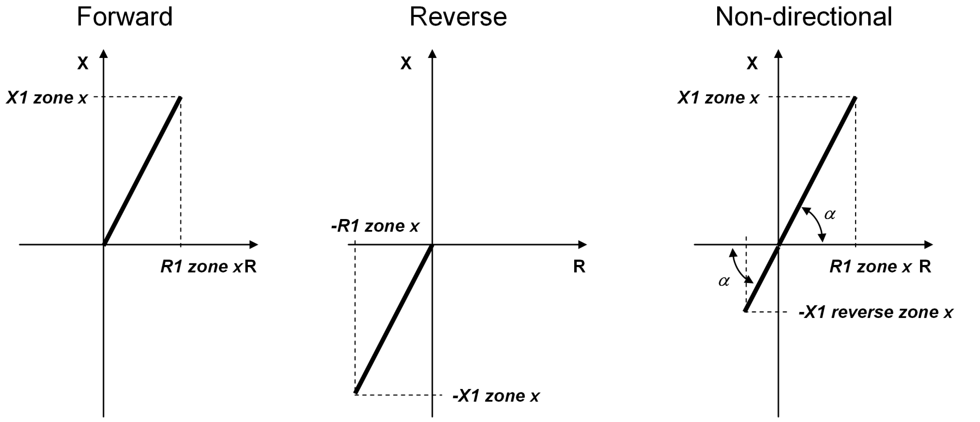


Figure 390: Settings which define the line reach for phase-to-phase or three phase impedance measuring elements in case of Impedance mode Zn = "Rectangular"

In case of phase-to-earth impedance measuring elements, the line reach is defined with:

- Resistive reach :(2**R1 zone x* + *R0 zone x*)/3, (x = 1...3, AR1, AR2)
- Reactive reach : (2**X1 zone x* + *X0 zone x*)/3, (x = 1...3, AR1, AR2).

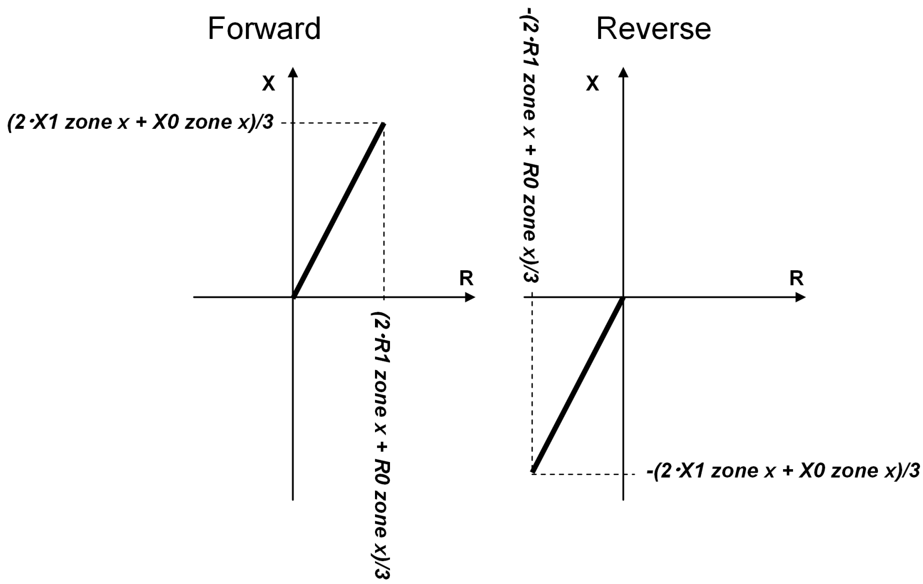


Figure 391: Settings which define line reach for phase-to-earth impedance measuring elements in case of Impedance mode Zn = "Rectangular" and forward or reverse directionality

In case of non-directional characteristics, the reactive reach in reverse direction is defined with the *X1 reverse zone x* (x = 1...3, AR1, AR2) setting. The total reactive reach in reverse direction includes a part which is common to both forward and reverse direction. This part is automatically calculated based on the values of *R1 zone x, R0 zone 0, X1 zone x* and *X0 zone x* settings. The characteristic line angle, denoted as α, is the same for forward and reverse direction.

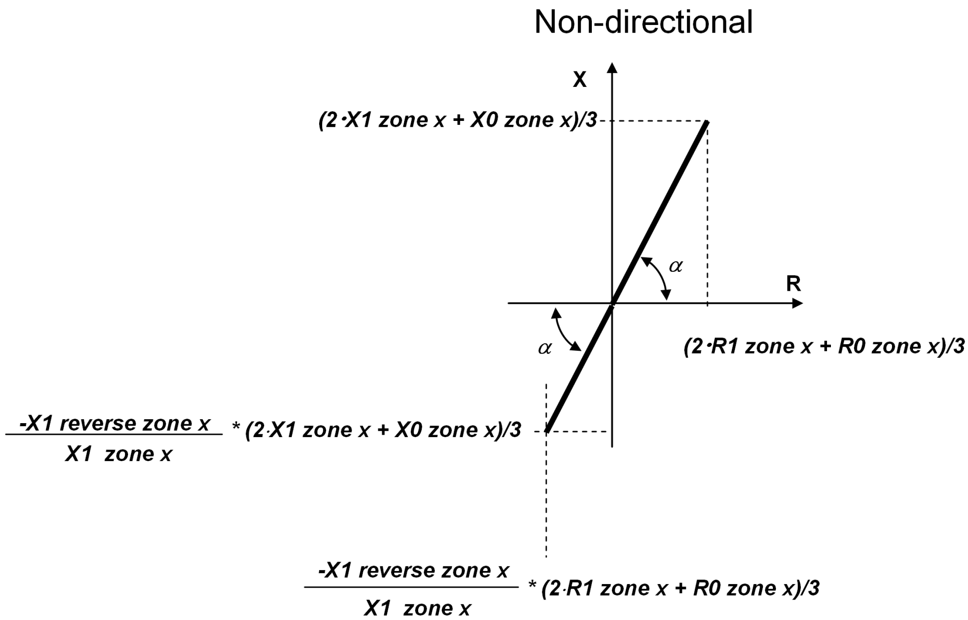


Figure 392: Settings which define the line reach for phase-to-earth impedance measuring elements in case of Impedance mode Zn = "Rectangular" and non-directional directionality

Impedance mode Zn = Polar

In case of phase-to-phase or three-phase impedance measuring elements, the line reach is defined with:

- *Z1 zone x* (x = 1...3, AR1, AR2)
- *Z1 angle zone x* (x = 1...3 AR1, AR2)

In case of non-directional characteristics, the reactive reach magnitude in reverse direction is defined with the *Z1 reverse zone x* (x = 1...3, AR1, AR2) setting. The characteristic line angle, *Z1 angle zone x*, is the same for forward and reverse direction.

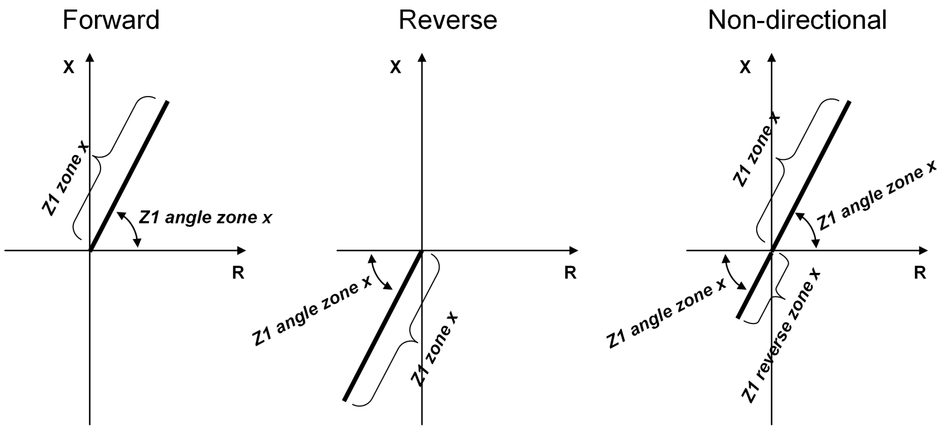


Figure 393: Settings which define line reach for phase-to-phase or three-phase impedance measuring elements in case of Impedance mode Zn = "Polar"

In case of phase-to-earth impedance measuring elements, the line reach is defined with:

- *Z1 zone x* (x = 1...3, AR1, AR2)
- *Z1 angle zone x* (x = 1...3 AR1, AR2)
- *Factor K0 zone x* (x = 1...3 AR1, AR2)
- *Factor K0 angle Znx* (x = 1...3, AR1, AR2)

The reach magnitude and angle are:

$$Magnitude = abs(\underline{Z}1 + \underline{Z}1 \times \underline{K}_N)$$

(Equation 136)

$$Angle = angle(\underline{Z}1 + \underline{Z}1\underline{K}_N)$$

(Equation 137)

$$\underline{Z}_1 = Z1\ zone\ x(\cos(Z1 angle\ zone\ x) + j\sin(Z1 angle\ zone\ x))$$

$$\underline{K}_N = Factor\ K0\ zone\ x(\cos(Factor\ K0 angle\ znx) + j\sin(Factor\ K0 angle\ znx))$$

In case of non-directional characteristics, the reactive reach in reverse direction is defined with the *Z1 reverse zone x* (x = 1...3, AR1, AR2) setting.

$$\underline{Z}_{1R} = Z1 reverse\ zone\ x(\cos(Z1 angle\ zone\ x) + j\sin(Z1 angle\ zone\ x))$$

(Equation 138)

The total reactive reach in reverse direction includes a part which is defined by the residual compensation factor $\underline{K}_N$. The characteristic line angle, denoted as α, is the same for forward and reverse direction.

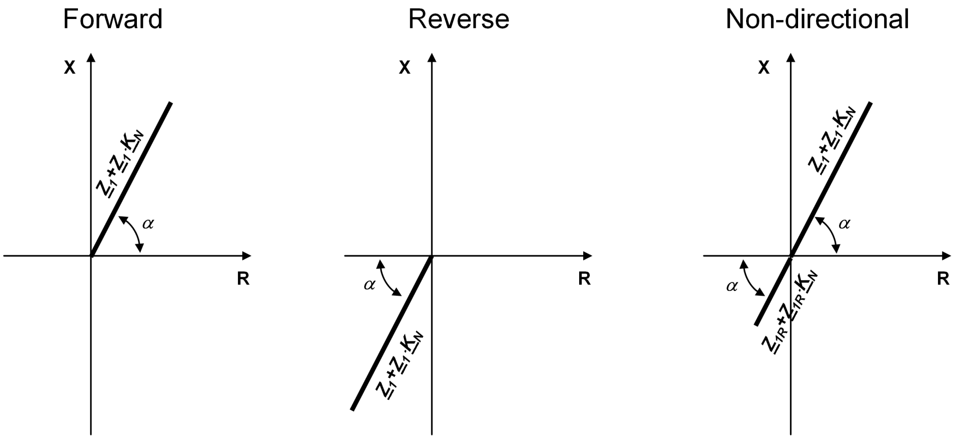


Figure 394: Settings which define line reach for phase-to-earth impedance measuring elements in case of Impedance mode Zn = "Polar"

Protection zone characteristics

DSTPDIS has both “Quadrilateral” and “Mho (circular)” characteristics available for the protection zones and they can be combined also with the bullet characteristic. The shape of a tripping characteristic can be set independently for phase-to-earth and for phase-to-phase or three-phase impedance elements. The zone shape is defined with the *Impedance Chr Gnd Zn* setting for phase-to-earth impedance elements, and with the *Impedance Chr PP Zn* setting for phase-to-phase/three-phase impedance elements. The alternatives are "Quadrilateral", "Mho (circular)", "Mho dir line", "Offset dir line" and "Bullet (combi)".

All impedance values defining the zone shape is entered in primary ohms. Angles are given in degrees.

Quadrilateral characteristic

If the zone has the "Quadrilateral" shape, DSTPDIS has a polygonal tripping characteristic.

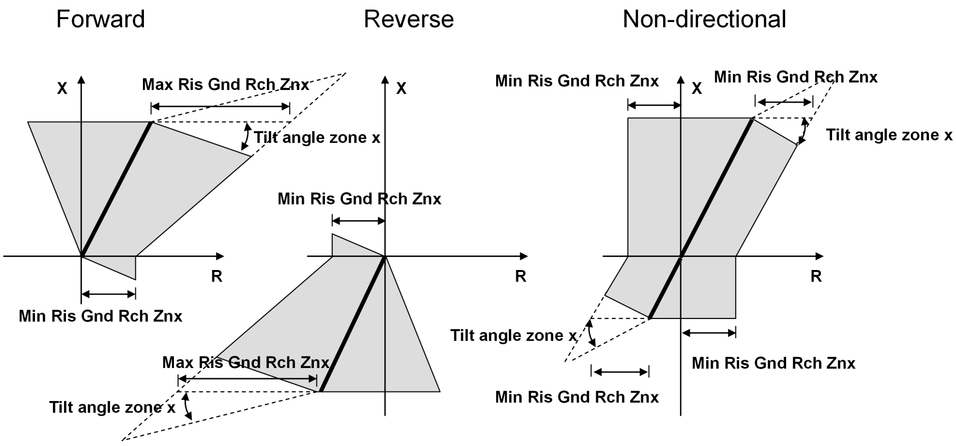


Figure 395: Tripping characteristic for phase-to-earth impedance elements in case the zone shape is quadrilateral. The tilt angle is set to compensate for possible under or overreaching.

The reach in the reactive direction is defined by the line reach independently for phase-to-earth and for phase-to-phase/three-phase elements. The resistive reach is defined at the minimum and maximum reactive reach with the *Min Ris Gnd Rch Znx, Max Ris Gnd Rch Znx, Min Ris PP Rch Znx, Max Ris PP Rch Znx* (x = 1...3, AR1, AR2) settings. In case of a non-directional zone, only the *Min Ris Gnd Rch Znx, Min Ris PP Rch Znx* (x = 1...3, AR1, AR2) settings are valid. The resistive reach can be set independently for phase-to-earth and for phase-to-phase or three-phase elements.

In case of phase-to-earth impedance elements, the resistive reach value corresponds to the physical fault resistance between phase and earth including arc and earthing resistance.

In case of phase-to-phase impedance elements, the resistive reach value corresponds to the half of the physical fault resistance between the phases. If there is a three-phase impedance element, the resistive reach value corresponds to the physical fault resistance per phase.

The directionality of the quadrilateral zone is defined with two independent directional boundary lines. See chapter Directional lines for details.

The reactive reach can be adjusted by tilting the top reactance boundary line by an angle with *Tilt angle zone x* (x = 1...3, AR1, AR2). The negative value decreases the tripping zone area while the positive value increases the tripping area. The negative value is used in case of underreaching zones to compensate a possible overreaching. The positive value is used in case of overreaching zones to compensate a possible underreaching.

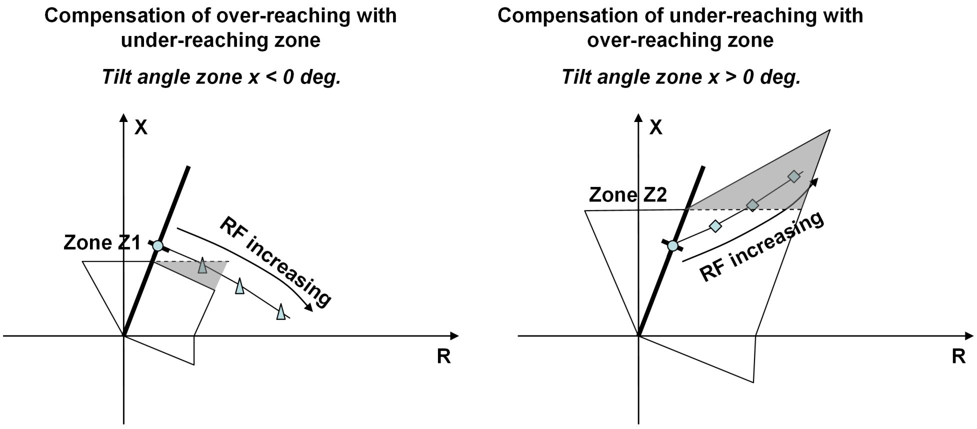


Figure 396: Operation principle of top reactance line tilting

The CONFLICT_Zx (x = 1...3, AR1, AR2) output data is an assisting integer-type output which supervises the validity of the tilt angle. It can have the values: No conflict, PhE angle tilt, PhPh angle tilt and PhE, PhPh tilt. If the actual value for *Tilt angle zone x* (x = 1...3, AR1, AR2) is not valid, which means that the polygon boundaries do not form a close loop, the value of *Tilt angle zone x* is forced to zero.

Directional lines

The direction of a zone is defined with the *Directional mode Znx* = "Non-directional", "Forward" or "Reverse" setting. The directionality of each zone can be set independently from other zones. For example, zones Z1 and Z2 can be set in the "Forward" direction and Z3 set in the "Reverse" direction.

The directionality of a quadrilateral zone is defined with two independent directional lines. The directional lines can be included into the mho characteristics to secure the directionality or to transform the non-directional mho characteristic into a directional one.

The directional lines are adjusted with the *Min phase angle zone* and *Max phase angle zone* settings. These settings are common for all the zones. The angles are given in degrees.

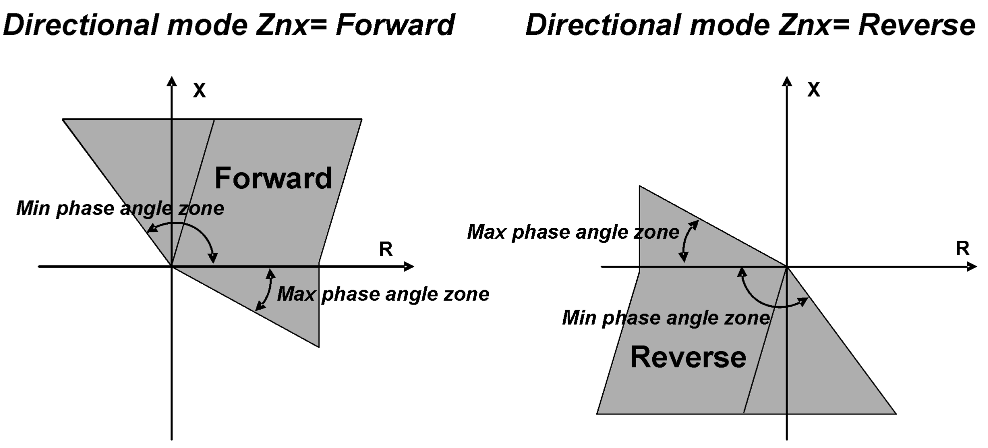


Figure 397: Settings that adjust directional lines in case of quadrilateral characteristics

If there is no fault present, the calculated direction of the fault or load current is indicated in the `DIRECTION` = "Unknown", "Forward", "Reverse" or "Both" output. The direction is based on the measurement of the three-phase impedance element.

Voltage memory

The directional lines are polarized with a positive sequence voltage for all impedance measuring elements. The memory voltage is used with three-phase impedance measurement elements if the positive sequence voltage is too low. This assures the correct directional measurement in case of close-in three-phase faults, where the voltages on all three phases are close to zero. The memory voltage is calculated using the positive-sequence voltage measured before the fault occurred. The memory function enables the function to operate up to a maximum of three seconds after a total loss of voltage. This time can be set with the *Voltage Mem time* setting.

Switch onto fault function (CVRSOF) is recommended to be used together with distance protection. CVRSOF accelerates and secures the operation of the protection, in case a close-in three-phase fault is detected immediately after circuit breaker closing.

Voltage memory functionality for close-in three phase faults supports AR sequences up to 300 seconds.

Mho circular characteristic

When the zone characteristic is "Mho (circular)", the distance protection has a circular tripping characteristic. The zone reach is defined independently by the line reach for phase-to-earth and phase-to-phase/three-phase elements. The resistive reach of the tripping characteristic depends on the selected polarization method defined with the *Pol quantity zone* setting (*Pol quantity zone* = "Cross Pol", "Pos seq Pol"). The non-directional mho characteristics is an exception being independent from the selected polarization method. It is always explicitly defined by the reach settings and thus fixed in the impedance plane.

Table 779: Polarization methods and corresponding polarization voltages

Fault loop	"Cross Pol"	"Pos seq Pol"
Z_A	$j \cdot \underline{U}_{L23}/\sqrt{3}$	$\underline{U}_1$
Z_B	$j \cdot \underline{U}_{L31}/\sqrt{3}$	$\underline{U}_1 \cdot 1\angle{-120°}$
Z_C	$j \cdot \underline{U}_{L12}/\sqrt{3}$	$\underline{U}_1 \cdot 1\angle{120°}$
Z_{AB}	$j \cdot (\underline{U}_{L23}-\underline{U}_{L31})/\sqrt{3}$	$\underline{U}_1 \cdot \sqrt{3} \cdot 1\angle{30°}$
Z_{BC}	$j \cdot (\underline{U}_{L31}-\underline{U}_{L12})/\sqrt{3}$	$\underline{U}_1 \cdot \sqrt{3} \cdot 1\angle{-90°}$
Z_{CA}	$j \cdot (\underline{U}_{L12}-\underline{U}_{L23})/\sqrt{3}$	$\underline{U}_1 \cdot \sqrt{3} \cdot 1\angle{150°}$
Z_{ABC}	U_1 1)	

1) Regardless of the selected polarization method, the three-phase fault measuring element always uses a positive sequence voltage for polarization. Memory voltage is included in the polarization voltage to secure directionality in case the positive sequence voltage becomes too small.

In case of cross-polarization "Cross Pol", the polarization voltages is in theory quadrature to the fault loop voltage. The phase angle of the polarization voltage is rotated 90 degrees to match the original fault loop voltage. The cross-polarization expands the tripping characteristic according to the prevailing system conditions. In case of short-circuit faults, the circle expands as a function of the source impedance magnitude $\underline{Z}_{1source}$. In case of an earth fault, the circle expands as a function of the source impedance $\underline{Z}_{1source}$, $\underline{Z}_{0source}$ and earthing impedance magnitude $\underline{Z}_E$ as $(2*\underline{Z}_{1source} + \underline{Z}_{0source})/3 + \underline{Z}_E$.

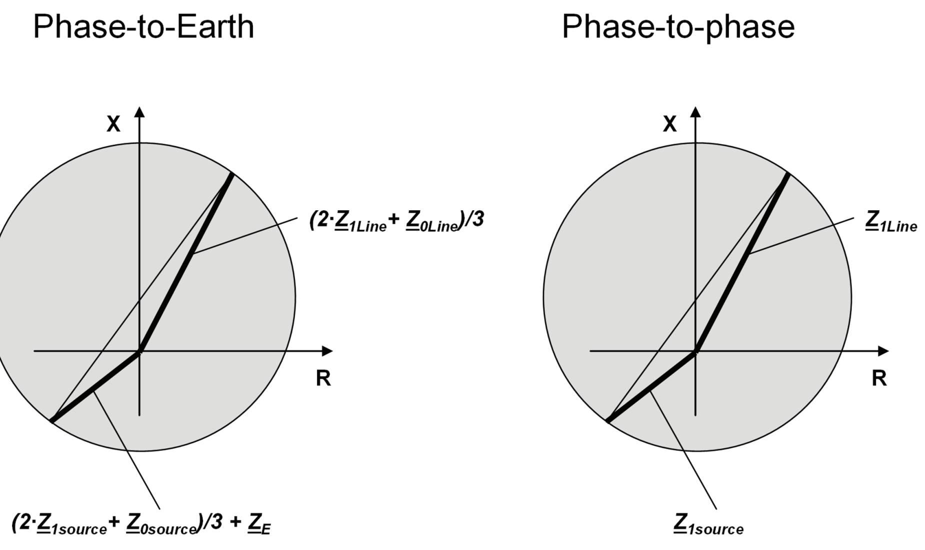


Figure 398: Tripping characteristic in case the zone characteristic is "Mho (circular)" and Pol quantity zone is "Cross Pol"

In case of positive-sequence polarization "Pos seq Pol", the polarization voltage is the positive-sequence voltage. The voltage phase angle is rotated to match the original fault loop voltage. The positive-sequence polarization expands the tripping characteristic according to the prevailing system conditions. In case of short-circuit faults, the circle expands as a function of the source impedance magnitude $\underline{Z}_{1source}/2$. In case of an earth fault, the circle expands as a function of source impedance and earthing impedance magnitude:$(\underline{Z}_{1source} + \underline{Z}_{0source})/3 + \underline{Z}_{E}$.

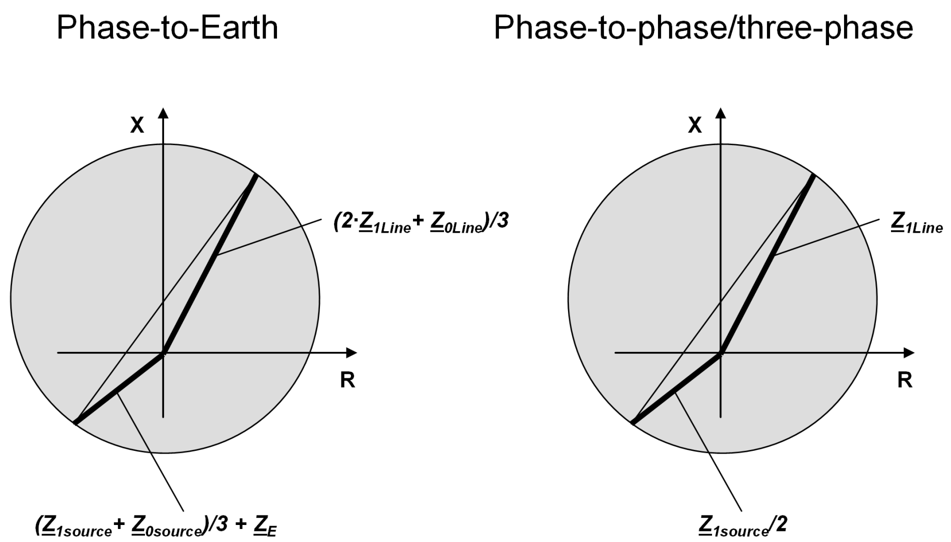


Figure 399: Tripping characteristic in case the zone characteristic is "Mho (circular)" and Pol quantity zone is "Pos seq Pol"

In case of cross and positive-sequence polarization, the expansion of the mho circle is a positive feature as the fault resistance coverage is increased. The reach of the zone is not affected by the expansion. The greatest expansion is obtained with cross-polarization.

The shape of the off-set mho (non-directional mho) characteristic is independent from the selected polarization method. The off-set mho is selected with the *Imp zone shape* and *Directional mode Znx* settings (*Imp zone shape* = "Mho (circular)" and *Directional mode Znx* = "Non-directional"). It is always explicitly defined by the reach settings and thus fixed in the impedance plane.

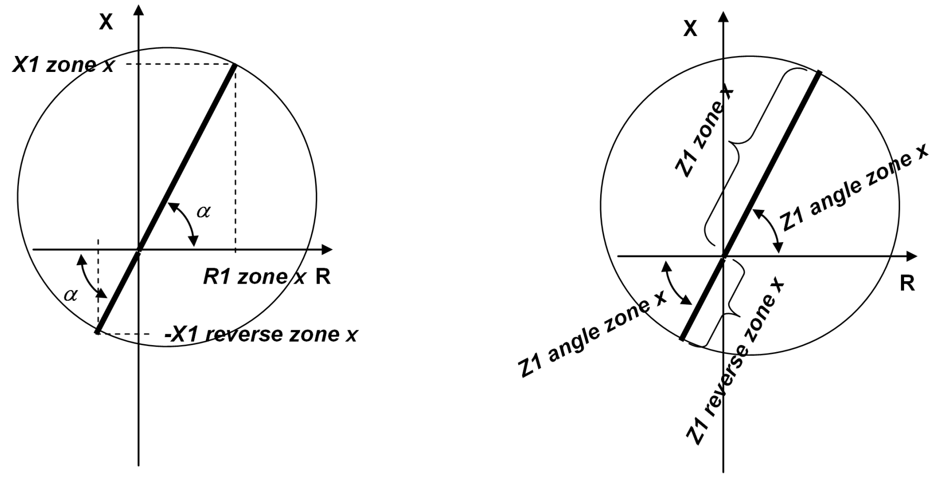


Figure 400: Tripping characteristic for phase-to-phase or three-phase impedance measuring elements in case Imp zone shape is "Mho (circular)" and Directional mode Znx is "Non-directional". On the left, the Impedance mode Zn is "Rectangular". On the right, Impedance mode Zn is "Polar".

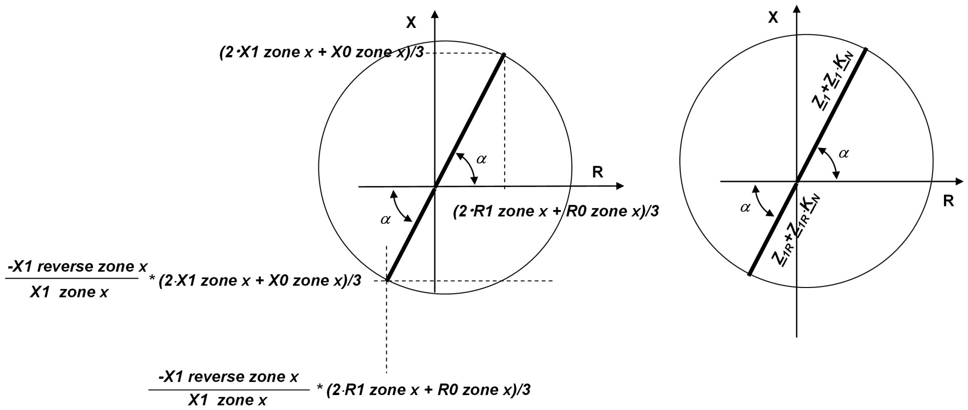


Figure 401: Tripping characteristic for phase-to-earth impedance measuring elements in case Imp zone shape is "Mho (circular)" and Directional mode Znx is "Non-directional". On the left, the Impedance mode Zn is "Rectangular". On the right, Impedance mode Zn is "Polar".

Adding directional lines into circular mho charateristic

Directional lines which are always included in the directional quadrilateral characteristic can also be included in the mho characteristics to secure the directionality or to transform the non-directional mho characteristics into a directional one.

Directional lines with mho are available only when the zone is set to directional, that is, *Directional mode Znx* is "Forward" or "Reverse".

The directionality of the directional mho characteristic is secured with directional lines by setting the impedance zone shape to "Mho dir line". The directional mho characteristic can also be created by adding directional lines in the offset mho characteristic. This is done by selecting the impedance zone shape as "Offset dir line".

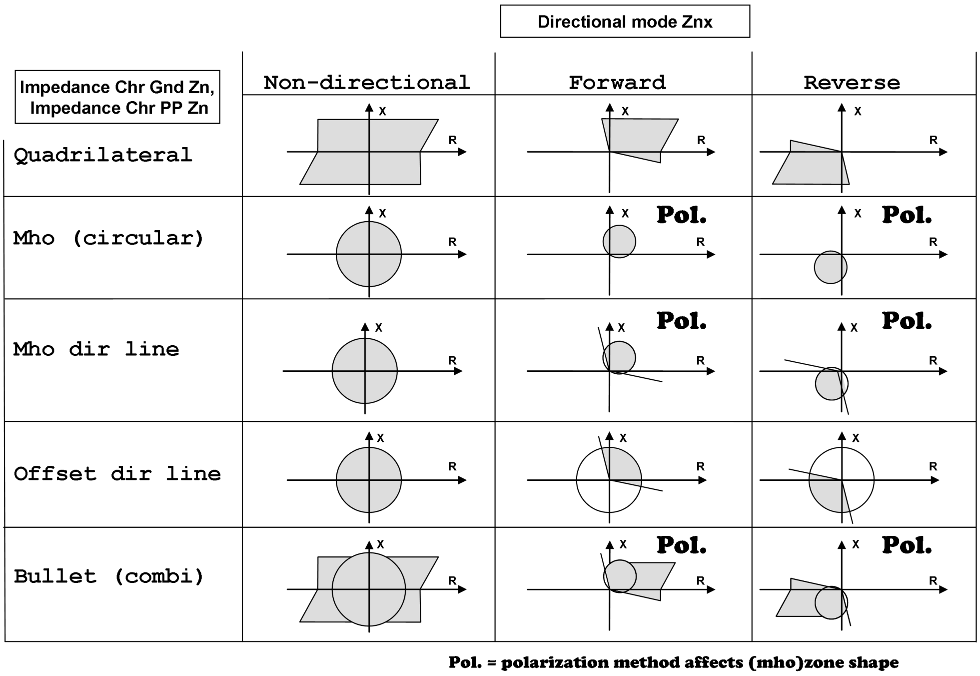


Figure 402: Possible combinations of the Directional mode Zx and zone characteristics settings. Pol. in the figure means that the shape of the characteristic is affected by the selected polarization method of the mho circle, Pol quantity zone = "Cross Pol" and "Pos Seq Pol"

Bullet combi characteristic

In case the impedance zone shape equals to "Bullet (combi)", the distance protection has a tripping characteristic which is a combination of the quadrilateral and mho. All settings relevant to the quadrilateral and mho are applicable. The shape of the "Bullet (combi)" characteristic is affected by the selected polarization method of the mho circle (*Pol quantity zone* = "Cross Pol", "Pos seq Pol").

The directionality of the "Bullet (combi)" characteristic is defined by the directional lines when *Directional mode Zx* is "Forward" or "Reverse".

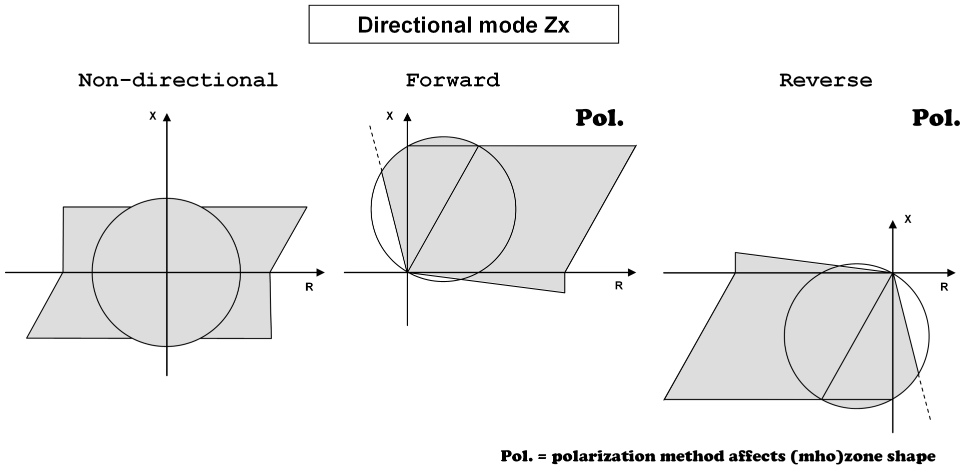


Figure 403: Bullet combi tripping characteristic. Pol, in the figure means the shape of the characteristic is affected by the selected polarization method of the mho circle, Pol quantity zone = "Cross Pol", "Pos seq Pol"

4.7.1.5 Base values

In this function block, some of the settings are set in per unit (p.u). These p.u. values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "Phase Grp 1", "Phase Grp 2" and "Phase Grp 3". Similarly, "Residual Grp 1", "Residual Grp 2" and "Residual Grp 3" are supported for the residual current or voltage-related settings. One of the groups to be used with the *Base value Sel phase* or *Base value Sel Res* settings must be selected.

4.7.1.6 Recorded data

The required information for later fault analysis is recorded when the recording function of DSTPDIS is triggered. The triggering can either be internal or external. Internal triggering occurs every time a zone is operating.

Table 780: Recorded data for the phase selection function

Parameter name	Description
n Recording time GFC	Recording date
n RELEASE_PE GFC	Release signals for PE-loops, GFC
n RELEASE_PP GFC	Release signals for PP/3P-loops, GFC
n EARTH_FLT GFC	Indication of a single-phase earth-fault, GFC
n XC_FLT GFC	Indication of a cross-country fault (high imp. earthed), GFC
n DIR_E_FLT GFC	Earth-fault direction (low imp. earthed), GFC
n DIRECTION	Direction of fault or load
n Zones OPERATE	Operate signals of all zones

The direction of the fault is indicated with the parameter *n DIRECTION* ("Unknown", "Forward", "Reverse" or "Both"). In case of a no-fault condition, the direction of the load current seen by a three-phase fault measuring element is indicated.

The parameter *n Zones OPERATE* can have the values (0...31):

:

Table 781: Enumeration values and names for the parameter n Zones OPERATE

Enumerator value	Enumerator name
0	No Zn operates
1	Zn1
2	Zn2
3	Zn1,2
4	Zn3
5	Zn1,3
6	Zn2,3
7	Zn1,2,3
8	AR1
9	Zn1,AR1
10	Zn2,AR1
11	Zn1,2,AR1
12	Zn3,AR1
13	Zn1,3,AR1
14	Zn2,3,AR1
15	Zn1,2,3,AR1
16	AR2
17	Zn1,AR2
18	Zn2,AR2
19	Zn1,2,AR2
20	Zn3,AR2
21	Zn1,3,AR2
22	Zn2,3,AR2
23	Zn1,2,3,AR2
24	AR1,AR2
25	Zn1,AR1,AR2
26	Zn2,AR1,AR2
27	Zn1,2,AR1,AR2
28	Zn3,AR1,AR2
29	Zn1,3,AR1,AR2
30	Zn2,3,AR1,AR2
31	Zn1,2,3,AR1,AR2

Additionally, the zone which has operated generates a data record.

Table 782: Parameter names and respective functions

Parameter name	Description
n Recording time Zx	Recording date
n DIR_LOOP_R Zx	direction resistance, Zone Zx
n DIR_LOOP_X Zx	direction reactance, Zone Zx
n FLTLOOP_RFST Zx	PE-loop resistance (1st), Zone Zx
n FLTLOOP_XFST Zx	PE-loop reactance (1st), Zone Zx
n FLTLOOP_RSND Zx	PE-loop resistance (2nd), Zone Zx
n FLTLOOP_XSND Zx	PE-loop reactance (2nd), Zone Zx
n FLTLOOP_RPP Zx	PP-loop resistance, Zone Zx
n FLTLOOP_XPP Zx	PP-loop reactance, Zone Zx
n FLTPH_X	PE-phase reactance, Zone 1

n DIR_LOOP_R Zx and *n DIR_LOOP_X Zx* are the loop resistance and reactance from the impedance calculation used in directional discrimination for the zones. Depending on the released fault loops, the calculated fault loop impedance can be read from the parameters *n FLTLOOP_RFST Zx*, *n FLTLOOP_XFST Zx* and *n FLTLOOP_RPP Zx*, *n FLTLOOP_XPP Zx*. In case two phase-to-earth loops are released simultaneously for measurement, the second phase-to-earth impedance can be found from the parameters *n FLTLOOP_RSND Zx* and *n FLTLOOP_XSND Zx*. The corresponding positive sequence phase to earth-fault reactance can be found from parameters *n FLTPH_X*.

The impedances are shown in primary ohms.

During external triggering (input signal `TRIGG_REC`), the recorded data of all zones and the phase selection function are recorded.

There are a total of three sets of recorded data which are saved in data banks 1, 2 and 3. The data bank 1 holds the most recent recorded data and the older data are moved into the following banks (1->2 and 2->3) when triggering occurs. When all three banks have data and a new triggering occurs, the latest data is placed into bank 1 and the data in bank 3 becomes overwritten by the data from bank 2.

4.7.1.7 Application

DSTPDIS provides a fast and reliable protection for overhead lines and power cables. DSTPDIS is applied in distribution and sub-transmission networks where three-phase tripping is allowed for all kinds of faults.

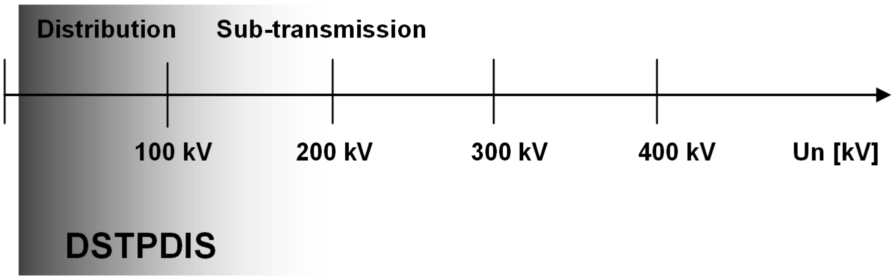


Figure 404: Application scope of DSTPDIS

Typically these networks are operated in ring or meshed type of configurations. It is also characteristic for these networks that the switching state is changed frequently due to daily operation and load flow considerations. The networks also include varying capacities of distributed generation. This makes it impossible to apply simple overcurrent based schemes. In these kind of networks, DSTPDIS is used to provide a fast and selective protection for overhead lines and power cables. It can also be applied for radial feeders to increase the sensitivity of the protection, especially if the short circuit power of the source is low or it is changing due to network operation.

From selectivity point of view, it is advantageous that in the protection chain all functions in different positions operate according to the same measuring principle. Therefore, DSTPDIS can also be applied for the backup protection of main transformers and buses. This way the selectivity with the distance protection of the outgoing lines is easier to achieve.

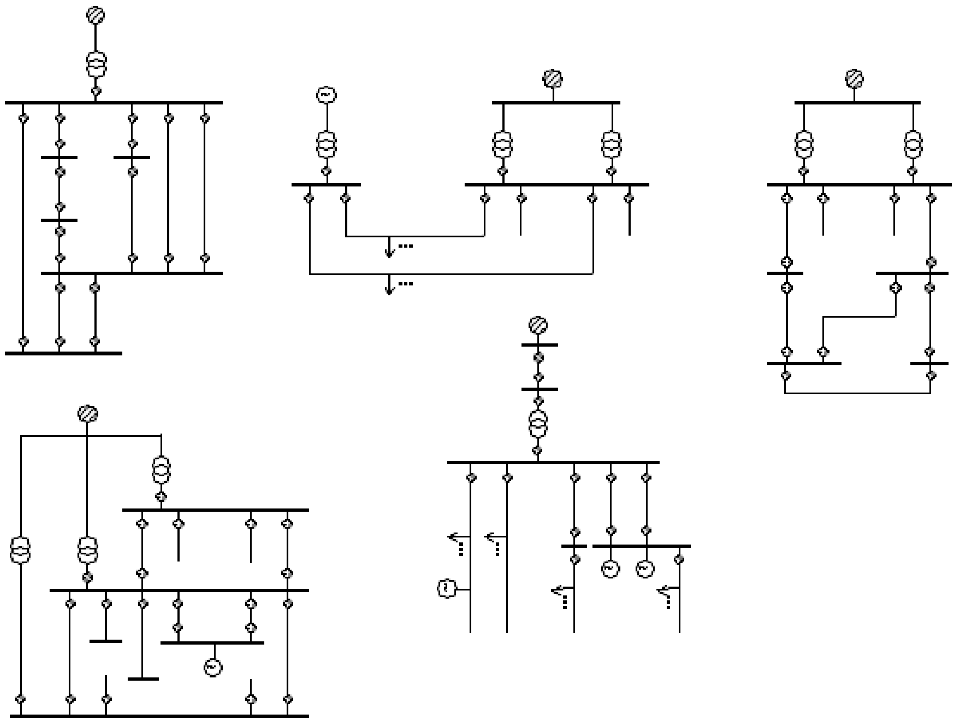


Figure 405: Typical network configurations for DSTPDIS application

DSTPDIS has three flexible configurable impedance zones for protection (Z1, Z2 and Z3) and two impedance zones for autoreclosing schemes (ZAR1 and ZAR2). ZAR1 can be used in a local acceleration scheme and ZAR2 to block autoreclosure in the cable section of a feeder. The autoreclosing related zones can be enabled only when the autoreclosing function is included in the configuration and it is set operational.

Phase-to-earth distance protection serves as a basic earth-fault protection in solidly or low impedance earthed networks. Together with the phase preference logic, it also serves as a selective protection function at cross-country faults in isolated or Petersen coil compensated networks. In certain applications system earthing is changed during operation from high impedance to low impedance earthed system due to fault location procedures. It is possible to use DSTPDIS during such an application by setting *System grounding GFC* to ""From input"" and by providing information about the type of earthing though binary input `SYS_EARTHING`. Low `SYS_EARTHING` input indicates low impedance earthing system.

DSTPDIS is suitable as a basic protection function against two and three-phase faults in all kinds of networks, regardless of the treatment of the neutral point. The independent setting of the reach in the reactive and the resistive direction makes it possible to create a fast and selective short circuit protection in many applications.

4.7.1.8 Signals

Table 783: DSTPDIS Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for phase and measured or virtual Io currents
I3P_PAR	GROUP SIGNAL	-	Group signal for measured Io current from parallel line
I3P_REF	GROUP SIGNAL	-	Group signal for Io current for polarization or EF detection
U3P	GROUP SIGNAL	-	Group signal for voltages and virtual or measured Uo
BLOCK	BOOLEAN	0	Block all outputs (includes timer reset)
SYS_EARTHING	BOOLEAN	0	Network earthing method
TRIGG_REC	BOOLEAN	0	External triggering for all recorded data
AR_ZONES	GROUP SIGNAL	-	Enabling connection from autorecloser for AR zones
BLOCK_GFC	BOOLEAN	0	Block all outputs (includes timer reset), GFC
BLK_OP_GFC	BOOLEAN	0	Block operate output, GFC
BLK_ST_GFC	BOOLEAN	0	Block start outputs, GFC
FR_T_GFC	BOOLEAN	0	Freeze timers of all fault loops, GFC
BLOCK_Z1	BOOLEAN	0	Block all outputs (includes timer reset), Zone Z1
BLK_OP_Z1	BOOLEAN	0	Block operate output, Zone Z1
BLK_ST_Z1	BOOLEAN	0	Block start outputs, Zone Z1
FR_T_PE_Z1	BOOLEAN	0	Freeze timers of PE-loops, Zone Z1
FR_T_PP_Z1	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone Z1
BLOCK_Z2	BOOLEAN	0	Block all outputs (includes timer reset), Zone Z2
BLK_OP_Z2	BOOLEAN	0	Block operate output, Zone Z2
BLK_ST_Z2	BOOLEAN	0	Block start outputs, Zone Z2
FR_T_PE_Z2	BOOLEAN	0	Freeze timers of PE-loops, Zone Z2
FR_T_PP_Z2	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone Z2
BLOCK_Z3	BOOLEAN	0	Block all outputs (includes timer reset), Zone Z3
BLK_OP_Z3	BOOLEAN	0	Block operate output, Zone Z3
BLK_ST_Z3	BOOLEAN	0	Block start outputs, Zone Z3
FR_T_PE_Z3	BOOLEAN	0	Freeze timers of PE-loops, Zone Z3
FR_T_PP_Z3	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone Z3
BLOCK_ZAR1	BOOLEAN	0	Block all outputs (includes timer reset), Zone AR1
BLK_OP_ZAR1	BOOLEAN	0	Block operate output, Zone AR1
BLK_ST_ZAR1	BOOLEAN	0	Block start outputs, Zone AR1
FR_T_PE_ZAR1	BOOLEAN	0	Freeze timers of PE-loops, Zone AR1
FR_T_PP_ZAR1	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone AR1
BLOCK_ZAR2	BOOLEAN	0	Block all outputs (includes timer reset), Zone AR2
BLK_OP_ZAR2	BOOLEAN	0	Block operate output, Zone AR2

Table continues on next page

Name	Type	Default	Description
BLK_ST_ZAR2	BOOLEAN	0	Block start outputs, Zone AR2
FR_T_PE_ZAR2	BOOLEAN	0	Freeze timers of PE-loops, Zone AR2
FR_T_PP_ZAR2	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone AR2
RESET	BOOLEAN	0	Input signal for resetting registers

Table 784: DSTPDIS Output signals

Name	Type	Description
OPERATE_GFC	BOOLEAN	Time delayed operate-signal, GFC
START_GFC	BOOLEAN	General start-signal, GFC
STARTS_GFC	INTEGER	Start-signals for phases A, B and C, GFC
RELEASE_PE	INTEGER	Release signals for PE-loops, GFC
RELEASE_PP	INTEGER	Release signals for PP/3P-loops, GFC
EARTH_FLT	BOOLEAN	Indication of a single phase earth-fault, GFC
XC_FLT	BOOLEAN	Indication of a cross-country-fault (high imp. earthed), GFC
DIR_E_FLT	INTEGER	Earth-fault direction (low imp. earthed), GFC
OPERATE_Z1	BOOLEAN	Time delayed operate signal, Zone Z1
START_Z1	BOOLEAN	General start-signal, Zone Z1
STARTS_Z1	INTEGER	Start signals for phases A, B and C, Zone Z1
OPERATE_Z2	BOOLEAN	Time delayed operate signal, Zone Z2
START_Z2	BOOLEAN	General start-signal, Zone Z2
STARTS_Z2	INTEGER	Start signals for phases A, B and C, Zone Z2
OPERATE_Z3	BOOLEAN	Time delayed operate signal, Zone Z3
START_Z3	BOOLEAN	General start-signal, Zone Z3
STARTS_Z3	INTEGER	Start signals for phases A, B and C, Zone Z3
OPERATE_ZAR1	BOOLEAN	Time delayed operate signal, Zone AR1
START_ZAR1	BOOLEAN	General start-signal, Zone AR1
STARTS_ZAR1	INTEGER	Start signals for phases A, B and C, Zone AR1
OPERATE_ZAR2	BOOLEAN	Time delayed operate signal, Zone AR2
START_ZAR2	BOOLEAN	General start-signal, Zone AR2
STARTS_ZAR2	INTEGER	Start signals for phases A, B and C, Zone AR2
DIRECTION	INTEGER	Direction of fault or load
DIR_LOOP_R	REAL	Real part of the impedance used in dir. evaluation, Zone Z1
DIR_LOOP_X	REAL	Imaginary part of the impedance used in dir. eval., Zone Z1
FLTLOOP_RFST	REAL	Real part of the first PE-loop impedance, Zone Z1
FLTLOOP_XFST	REAL	Imaginary part of the first PE-loop impedance, Zone Z1
FLTLOOP_RSND	REAL	Real part of the second PE-loop impedance, Zone Z1

Table continues on next page

Name	Type	Description
FLTLOOP_XSND	REAL	Imaginary part of the second PE-loop impedance, Zone Z1
FLTLOOP_RPP	REAL	Real part of the PP/3P-loop impedance, Zone Z1
FLTLOOP_XPP	REAL	Imaginary part of PP/3P-loop impedance, Zone Z1
FLTPH_X	REAL	Phase to earth reactance in phase domain, Zone 1

4.7.1.9 Settings

Table 785: DSTPDIS Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Phase Sel mode GFC	Overcurrent Voltdep overcur Under impedance	-	-	Overcurrent	Phase selection method
EF detection Mod GFC	Io Io OR Uo Io AND Uo Io AND Ioref	-	-	Io	Earth-fault (EF) detection method
Operate delay GFC	0.100 - 60.000	s	0.001	3.000	Time delay to operate, GFC
Ph Str A Ph Sel GFC	0.10 - 10.00	pu	0.01	2.00	Phase current start value, PSL
Ph Lo A Ph Sel GFC	0.10 - 10.00	pu	0.01	0.80	Phase current start value, voltage dep. over current, PSL
Ph V Ph Sel GFC	0.10 - 1.00	pu	0.01	0.80	PE-voltage start value, voltage dep. over current, PSL
PP V Ph Sel GFC	0.10 - 1.00	pu	0.01	0.80	PP-voltage start value, voltage dep. over current, PSL
Z Chr Mod Ph Sel GFC	Quadrilateral Mho (circular)	-	-	Quadrilateral	Impedance characteristic, underimpedance, PSL
Load Dsr mode GFC	Off On	-	-	Off	Enable load discrimination, underimpedance, PSL
X Gnd Fwd reach GFC	0.01 - 3000.00	ohm	0.01	40.00	React. reach in fwd. dir. for PE-loops, underimpedance, PSL
X Gnd Rv reach GFC	0.01 - 3000.00	ohm	0.01	40.00	React. reach in rev. dir. for PE-loops, underimpedance, PSL
Ris Gnd Rch GFC	0.01 - 500.00	ohm	0.01	100.00	Resistive reach for PE-loops, underimpedance, PSL
X PP Fwd reach GFC	0.01 - 3000.00	ohm	0.01	40.00	React. reach in fwd. dir. for PP-loops, underimpedance, PSL
X PP Rv reach GFC	0.01 - 3000.00	ohm	0.01	40.00	React. reach in rev. dir. for PP-loops, underimpedance, PSL
Resistive PP Rch GFC	0.01 - 100.00	ohm	0.01	30.00	Resistive reach for PP-loops, underimpedance, PSL
Ris reach load GFC	1.00 - 3000.00	ohm	0.01	80.00	Resistive reach for load discrimination, underimpedance, PSL
Angle load area GFC	5 - 45	Deg	1	25	Load discrimination angle, underimpedance, PSL
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
Gnd Op current GFC	0.01 - 10.00	pu	0.01	0.10	Basic start value for residual curr., EF-detection function
Gnd Op A Ref GFC	0.01 - 10.00	pu	0.01	0.10	Transformer neutral curr. start val., EF-detection function
Gnd Str voltage GFC	0.02 - 1.00	pu	0.01	0.15	Residual voltage start value, EF-detection function
Gnd Op A XC GFC	0.10 - 10.00	pu	0.01	0.20	Residual current start value, XC-fault detection function
PP voltage XCF GFC	0.10 - 1.00	pu	0.01	0.80	PP-voltage start value, XC-fault detection function
Directional mode Zn1	Non-directional Forward Reverse	-	-	Forward	Directional mode, Zone Z1
Op Mod PP loops Zn1	Disabled Enabled	-	-	Enabled	Enable PP/3P-loop measurement, Zone Z1
PP Op delay Mod Zn1	Disabled Enabled	-	-	Enabled	Enable operate timer for PP/3P-loops, Zone Z1
R1 zone 1	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence resistive zone reach, Zone Z1
X1 zone 1	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence reactive zone reach, Zone Z1
X1 reverse zone 1	0.01 - 3000.00	ohm	0.01	40.00	Pos. seq. reactive zone reach in rev. dir., non-dir. Zone Z1
Z1 zone 1	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone Z1
Z1 angle zone 1	15 - 90	Deg	1	45	Positive sequence line angle, Zone Z1
Z1 reverse zone 1	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach in rev. dir., non-dir. Zone Z1
Min Ris PP Rch Zn1	0.01 - 100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, Zone Z1
Max Ris PP Rch Zn1	0.01 - 100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, Zone Z1
PP operate delay Zn1	0.040 - 60.000	s	0.001	0.040	Time delay to operate of PP/3P-loops, Zone Z1
Op Mod Gnd loops Zn1	Disabled Enabled	-	-	Enabled	Enable PE-loop measurement, Zone Z1
Gnd Op Dl mode Zn1	Disabled Enabled	-	-	Enabled	Enable operate timer for PE-loops, Zone Z1
Load Com zone 1	Disabled Enabled	-	-	Enabled	Enable load compensation for PE-loops, Zone Z1
R0 zone 1	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence resistive zone reach, Zone Z1
X0 zone 1	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence reactive zone reach, Zone Z1
Factor K0 zone 1	0.0 - 4.0	-	0.1	1.0	Residual compensation factor, magnitude, Zone Z1
Factor K0 angle Zn1	-135 - 135	Deg	1	0	Residual compensation factor, angle, Zone Z1
Min Ris Gnd Rch Zn1	0.01 - 500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, Zone Z1

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Max Ris Gnd Rch Zn1	0.01 - 500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, Zone Z1
Gnd operate Dl Zn1	0.040 - 60.000	s	0.001	0.040	Time delay to operate of PE-loops, Zone Z1
Directional mode Zn2	Non-directional Forward Reverse	-	-	Forward	Directional mode, Zone Z2
Op Mod PP loops Zn2	Disabled Enabled	-	-	Disabled	Enable PP/3P-loop measurement, Zone Z2
PP Op delay Mod Zn2	Disabled Enabled	-	-	Enabled	Enable operate timer for PP/3P-loops, Zone Z2
R1 zone 2	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence resistive zone reach, Zone Z2
X1 zone 2	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence reactive zone reach, Zone Z2
X1 reverse zone 2	0.01 - 3000.00	ohm	0.01	40.00	Pos. seq. reactive zone reach in rev. dir., non-dir. Zone Z2
Z1 zone 2	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone Z2
Z1 angle zone 2	15 - 90	Deg	1	45	Positive sequence line angle, Zone Z2
Z1 reverse zone 2	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach in rev. dir., non-dir. Zone Z2
Min Ris PP Rch Zn2	0.01 - 100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, Zone Z2
Max Ris PP Rch Zn2	0.01 - 100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, Zone Z2
PP operate delay Zn2	0.040 - 60.000	s	0.001	0.200	Time delay to operate of PP/3P-loops, Zone Z2
Op Mod Gnd loops Zn2	Disabled Enabled	-	-	Disabled	Enable PE-loop measurement, Zone Z2
Gnd Op Dl mode Zn2	Disabled Enabled	-	-	Enabled	Enable operate timer for PE-loops, Zone Z2
Load Com zone 2	Disabled Enabled	-	-	Enabled	Enable load compensation for PE-loops, Zone Z2
R0 zone 2	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence resistive zone reach, Zone Z2
X0 zone 2	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence reactive zone reach, Zone Z2
Factor K0 zone 2	0.0 - 4.0	-	0.1	1.0	Residual compensation factor, magnitude, Zone Z2
Factor K0 angle Zn2	-135 - 135	Deg	1	0	Residual compensation factor, angle, Zone Z2
Min Ris Gnd Rch Zn2	0.01 - 500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, Zone Z2
Max Ris Gnd Rch Zn2	0.01 - 500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, Zone Z2
Gnd operate Dl Zn2	0.040 - 60.000	s	0.001	0.200	Time delay to operate of PE-loops, Zone Z2
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
Directional mode Zn3	Non-directional Forward Reverse	-	-	Forward	Directional mode, Zone Z3
Op Mod PP loops Zn3	Disabled Enabled	-	-	Disabled	Enable PP/3P-loop measurement, Zone Z3
PP Op delay Mod Zn3	Disabled Enabled	-	-	Enabled	Enable operate timer for PP/3P-loops, Zone Z3
R1 zone 3	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence resistive zone reach, Zone Z3
X1 zone 3	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence reactive zone reach, Zone Z3
X1 reverse zone 3	0.01 - 3000.00	ohm	0.01	40.00	Pos. seq. reactive zone reach in rev. dir., non-dir. Zone Z3
Z1 zone 3	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone Z3
Z1 angle zone 3	15 - 90	Deg	1	45	Positive sequence line angle, Zone Z3
Z1 reverse zone 3	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach in rev. dir., non-dir. Zone Z3
Min Ris PP Rch Zn3	0.01 - 100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, Zone Z3
Max Ris PP Rch Zn3	0.01 - 100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, Zone Z3
PP operate delay Zn3	0.040 - 60.000	s	0.001	0.400	Time delay to operate of PP/3P-loops, Zone Z3
Op Mod Gnd loops Zn3	Disabled Enabled	-	-	Disabled	Enable PE-loop measurement, Zone Z3
Gnd Op Dl mode Zn3	Disabled Enabled	-	-	Enabled	Enable operate timer for PE-loops, Zone Z3
Load Com zone 3	Disabled Enabled	-	-	Enabled	Enable load compensation for PE-loops, Zone Z3
R0 zone 3	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence resistive zone reach, Zone Z3
X0 zone 3	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence reactive zone reach, Zone Z3
Factor K0 zone 3	0.0 - 4.0	-	0.1	1.0	Residual compensation factor, magnitude, Zone Z3
Factor K0 angle Zn3	-135 - 135	Deg	1	0	Residual compensation factor, angle, Zone Z3
Min Ris Gnd Rch Zn3	0.01 - 500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, Zone Z3
Max Ris Gnd Rch Zn3	0.01 - 500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, Zone Z3
Gnd operate Dl Zn3	0.040 - 60.000	s	0.001	0.400	Time delay to operate of PE-loops, Zone Z3
Directional mode AR1	Non-directional Forward Reverse	-	-	Forward	Directional mode, Zone AR1
Op Mod PP loops AR1	Disabled Enabled	-	-	Disabled	Enable PP/3P-loop measurement, Zone AR1
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
PP Op delay Mod AR1	Disabled Enabled	-	-	Enabled	Enable operate timer for PP/3P-loops, Zone AR1
R1 AR1	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence resistive zone reach, Zone AR1
X1 AR1	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence reactive zone reach, Zone AR1
X1 reverse AR1	0.01 - 3000.00	ohm	0.01	40.00	Pos. seq. reactive zone reach in rev. dir, non-dir. Zone AR1
Z1 AR1	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone AR1
Z1 angle AR1	15 - 90	Deg	1	45	Positive sequence line angle, Zone AR1
Z1 reverse AR1	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach in rev. dir., non-dir. Zone AR1
Min Ris PP Rch AR1	0.01 - 100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, Zone AR1
Max Ris PP Rch AR1	0.01 - 100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, Zone AR1
PP operate delay AR1	0.040 - 60.000	s	0.001	0.050	Time delay to operate of PP/3P-loops, Zone AR1
Op Mod Gnd loops AR1	Disabled Enabled	-	-	Disabled	Enable PE-loop measurement, Zone AR1
Gnd Op Dl mode AR1	Disabled Enabled	-	-	Enabled	Enable operate timer for PE-loops, Zone AR1
Load Com AR1	Disabled Enabled	-	-	Enabled	Enable load compensation for PE-loops, Zone AR1
R0 AR1	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence resistive zone reach, Zone AR1
X0 AR1	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence reactive zone reach, Zone AR1
Factor K0 AR1	0.0 - 4.0	-	0.1	1.0	Residual compensation factor, magnitude, Zone AR1
Factor K0 angle AR1	-135 - 135	Deg	1	0	Residual compensation factor, angle, Zone AR1
Min Ris Gnd Rch AR1	0.01 - 500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, Zone AR1
Max Ris Gnd Rch AR1	0.01 - 500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, Zone AR1
Gnd operate Dl AR1	0.040 - 60.000	s	0.001	0.050	Time delay to operate of PE-loops, Zone AR1
Directional mode AR2	Non-directional Forward Reverse	-	-	Forward	Directional mode, Zone AR2
Op Mod PP loops AR2	Disabled Enabled	-	-	Disabled	Enable PP/3P-loop measurement, Zone AR2
PP Op delay Mod AR2	Disabled Enabled	-	-	Enabled	Enable operate timer for PP/3P-loops, Zone AR2
R1 AR2	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence resistive zone reach, Zone AR2

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
X1 AR2	0.01 - 3000.00	ohm	0.01	40.00	Positive sequence reactive zone reach, Zone AR2
X1 reverse AR2	0.01 - 3000.00	ohm	0.01	40.00	Pos. seq. reactive zone reach in rev. dir, non-dir. Zone AR2
Z1 AR2	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone AR2
Z1 angle AR2	15 - 90	Deg	1	45	Positive sequence line angle, Zone AR2
Z1 reverse AR2	0.01 - 3000.00	ohm	0.01	56.57	Positive sequence zone reach in rev. dir., non-dir. Zone AR2
Min Ris PP Rch AR2	0.01 - 100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, Zone AR2
Max Ris PP Rch AR2	0.01 - 100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, Zone AR2
PP operate delay AR2	0.040 - 60.000	s	0.001	0.050	Time delay to operate of PP/3P-loops, Zone AR2
Op Mod Gnd loops AR2	Disabled Enabled	-	-	Disabled	Enable PE-loop measurement, Zone AR2
Gnd Op Dl mode AR2	Disabled Enabled	-	-	Enabled	Enable operate timer for PE-loops, Zone AR2
Load Com AR2	Disabled Enabled	-	-	Enabled	Enable load compensation for PE-loops, Zone AR2
R0 AR2	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence resistive zone reach, Zone AR2
X0 AR2	0.01 - 3000.00	ohm	0.01	160.00	Zero sequence reactive zone reach, Zone AR2
Factor K0 AR2	0.0 - 4.0	-	0.1	1.0	Residual compensation factor, magnitude, Zone AR2
Factor K0 angle AR2	-135 - 135	Deg	1	0	Residual compensation factor, angle, Zone AR2
Min Ris Gnd Rch AR2	0.01 - 500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, Zone AR2
Max Ris Gnd Rch AR2	0.01 - 500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, Zone AR2
Gnd operate Dl AR2	0.040 - 60.000	s	0.001	0.050	Time delay to operate of PE-loops, Zone AR2

Table 786: DSTPDIS Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Gnd Op current 2 GFC	0.10 - 10.00	pu	0.01	1.00	Res. curr. start value for slope 2, EF-detection function
Stab slope 1 GFC	0.00 - 0.30	-	0.01	0.10	Slope 1 for res. curr. stabilization, EF-detection function
Stab slope 2 GFC	0.00 - 1.00	-	0.01	1.00	Slope 2 for res. current stab., EF-detection function
A Ph Stab value GFC	1.00 - 10.00	pu	0.01	2.00	Phase current start value for slope 2, EF-detection function
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
Dir mode EF GFC	Non-directional Forward Reverse	-	-	Non-directional	Directional mode, earth-fault directional function
Pol quantity GFC	Zro vol.OR cur. Zero seq. cur. Zero seq. volt. Neg. seq. volt.	-	-	Zero seq. volt.	Polarization method, earth-fault directional function
Chr angle GFC	-179 - 180	Deg	1	75	Characteristic angle, earth-fault directional function
Max phase angle GFC	0 - 90	Deg	1	88	Right hand side angle, earth-fault directional function
Min phase angle GFC	0 - 90	Deg	1	88	Left hand side angle, earth-fault directional function
Cross-country Dl GFC	0.00 - 10.00	s	0.01	0.10	Time delay for residual current, XC-fault detection function
Tilt angle zone 1	-45 - 45	Deg	1	0	Tilt angle (positive value increases Zone area), Zone Z1
Par line Com zone 1	Disabled Enabled	-	-	Disabled	Enable parallel line compensation for PE-loops, Zone Z1
Mutual R0 zone 1	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, Zone Z1
Mutual X0 zone 1	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, Zone Z1
Tilt angle zone 2	-45 - 45	Deg	1	0	Tilt angle (positive value increases Zone area), Zone Z2
Par line Com zone 2	Disabled Enabled	-	-	Disabled	Enable parallel line compensation for PE-loops, Zone Z2
Mutual R0 zone 2	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, Zone Z2
Mutual X0 zone 2	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, Zone Z2
Tilt angle zone 3	-45 - 45	Deg	1	0	Tilt angle (positive value increases Zone area), Zone Z3
Par line Com zone 3	Disabled Enabled	-	-	Disabled	Enable parallel line compensation for PE-loops, Zone Z3
Mutual R0 zone 3	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, Zone Z3
Mutual X0 zone 3	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, Zone Z3
Tilt angle AR1	-45 - 45	Deg	1	0	Tilt angle (positive value increases Zone area), Zone AR1
Par line Com AR1	Disabled Enabled	-	-	Disabled	Enable parallel line compensation for PE-loops, Zone AR1
Mutual R0 AR1	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, Zone AR1
Mutual X0 AR1	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, Zone AR1
Tilt angle AR2	-45 - 45	Deg	1	0	Tilt angle (positive value increases Zone area), Zone AR2

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Par line Com AR2	Disabled Enabled	-	-	Disabled	Enable parallel line compensation for PE-loops, Zone AR2
Mutual R0 AR2	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, Zone AR2
Mutual X0 AR2	0.01 - 3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, Zone AR2

Table 787: DSTPDIS Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Phase voltage Meas	Accurate PP without Uo	-	-	Accurate	Phase voltage measurement principle
System grounding GFC	High impedance Low impedance From input	-	-	Low impedance	Network neutral earthing method
Ph Prf mode Hi Z GFC	No filter No preference Cyc A-B-C-A Cyc A-C-B-A Acyc A-B-C Acyc A-C-B Acyc B-A-C Acyc B-C-A Acyc C-A-B Acyc C-B-A	-	-	No filter	Phase preference mode for high impedance earthed network
Ph Prf mode Lo Z GFC	All loops PE only PP only BLK leading PE BLK lagging PE	-	-	All loops	Loop selection mode for low impedance earthed network
Impedance mode Zn	Rectangular Polar	-	-	Rectangular	Impedance format, Zones
Impedance Chr Gnd Zn	Quadrilateral Mho (circular) Mho dir line Offset dir line Bullet (combi)	-	-	Quadrilateral	Impedance characteristic for PE-loops, Zones
Impedance Chr PP Zn	Quadrilateral Mho (circular) Mho dir line Offset dir line Bullet (combi)	-	-	Quadrilateral	Impedance characteristic for PP/3P-loops, Zones
Max phase angle zone	0 - 45	Deg	1	15	Angle from R-axis to right hand side directional line
Min phase angle zone	90 - 135	Deg	1	115	Angle from R-axis to left hand side directional line
Pol quantity zone	Pos. seq. volt. Cross Pol	-	-	Pos. seq. volt.	Mho polarization method for zones

Table 788: DSTPDIS Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Base Val Sel Res Ref	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 2	Base value selector for reference residual current
EF Det neutral A GFC	Measured Virtual	-	-	Measured	Residual current meas. principle, EF-detection function
Fact EF current Bal	1.000 - 2.000	-	0.001	1.200	Residual current ratio for parallel line compensation
Zone timer mode	Independent Common	-	-	Independent	Operate timer start mode, Zones
Voltage Mem time	100 - 3000	ms	10	400	Voltage memory time

4.7.1.10 Measured values

Table 789: DSTPDIS Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Amplitude of the phase A current
I_AMPL_B	REAL	0	Amplitude of the phase B current
I_AMPL_C	REAL	0	Amplitude of the phase C current
I0_AMPL	REAL	0	Amplitude of the residual current
I0_ANGL	REAL	0	Angle of the residual current
I0_AMPL_VIR	REAL	0	Amplitude of residual current, virtual
I0_AMPL_REF	REAL	0	Amplitude of transformer neutral current
I0_ANGL_REF	REAL	0	Angle of the transformer neutral current
I1_AMPL	REAL	0	Amplitude of the positive-sequence current
I2_AMPL	REAL	0	Amplitude of the negative-sequence current
I2_ANGL	REAL	0	Angle of the negative-sequence current
U_AMPL_A	REAL	0	Amplitude of the phase A voltage
U_AMPL_B	REAL	0	Amplitude of the phase B voltage
U_AMPL_C	REAL	0	Amplitude of the phase C voltage
U_AMPL_AB	REAL	0	Amplitude of the phase-to-phase AB voltage
U_AMPL_BC	REAL	0	Amplitude of the phase-to-phase BC voltage
U_AMPL_CA	REAL	0	Amplitude of the phase-to-phase CA voltage
U0_AMPL	REAL	0	Amplitude of the residual voltage
U0_ANGL	REAL	0	Angle of the residual voltage
U1_AMPL	REAL	0	Amplitude of the positive-sequence voltage
U1_ANGL	REAL	0	Angle of the positive-sequence voltage
Table continues on next page			

Name	Type	Default	Description
U2_AMPL	REAL	0	Amplitude of the negative-sequence voltage
U2_ANGL	REAL	0	Angle of the negative-sequence voltage
BLOCK	BOOLEAN	0	Block all outputs (includes timer reset)
SYS_EARTHING	BOOLEAN	0	Network earthing method
TRIGG_REC	BOOLEAN	0	External triggering for all recorded data
AR_ZONES	BOOLEAN	0	Configuration allows AR-zones to be enabled
BLOCK_GFC	BOOLEAN	0	Block all outputs (includes timer reset), GFC
BLK_OP_GFC	BOOLEAN	0	Block operate output, GFC
BLK_ST_GFC	BOOLEAN	0	Block start outputs, GFC
FR_T_GFC	BOOLEAN	0	Freeze timers of all fault loops, GFC
BLOCK_Z1	BOOLEAN	0	Block all outputs (includes timer reset), Zone Z1
BLK_OP_Z1	BOOLEAN	0	Block operate output, Zone Z1
BLK_ST_Z1	BOOLEAN	0	Block start outputs, Zone Z1
FR_T_PE_Z1	BOOLEAN	0	Freeze timers of PE-loops, Zone Z1
FR_T_PP_Z1	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone Z1
BLOCK_Z2	BOOLEAN	0	Block all outputs (includes timer reset), Zone Z2
BLK_OP_Z2	BOOLEAN	0	Block operate output, Zone Z2
BLK_ST_Z2	BOOLEAN	0	Block start outputs, Zone Z2
FR_T_PE_Z2	BOOLEAN	0	Freeze timers of PE-loops, Zone Z2
FR_T_PP_Z2	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone Z2
BLOCK_Z3	BOOLEAN	0	Block all outputs (includes timer reset), Zone Z3
BLK_OP_Z3	BOOLEAN	0	Block operate output, Zone Z3
BLK_ST_Z3	BOOLEAN	0	Block start outputs, Zone Z3
FR_T_PE_Z3	BOOLEAN	0	Freeze timers of PE-loops, Zone Z3
FR_T_PP_Z3	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone Z3
BLOCK_ZAR1	BOOLEAN	0	Block all outputs (includes timer reset), Zone AR1
BLK_OP_ZAR1	BOOLEAN	0	Block operate output, Zone AR1
BLK_ST_ZAR1	BOOLEAN	0	Block start outputs, Zone AR1
FR_T_PE_ZAR1	BOOLEAN	0	Freeze timers of PE-loops, Zone AR1
FR_T_PP_ZAR1	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone AR1
BLOCK_ZAR2	BOOLEAN	0	Block all outputs (includes timer reset), Zone AR2
BLK_OP_ZAR2	BOOLEAN	0	Block operate output, Zone AR2
BLK_ST_ZAR2	BOOLEAN	0	Block start outputs, Zone AR2
FR_T_PE_ZAR2	BOOLEAN	0	Freeze timers of PE-loops, Zone AR2
FR_T_PP_ZAR2	BOOLEAN	0	Freeze timers of PP/3P-loops, Zone AR2
RESET	BOOLEAN	0	Input signal for resetting registers

4.7.1.11 Monitored data

Table 790: DSTPDIS Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE_GFC	BOOLEAN	0=FALSE 1=TRUE	-	Time delayed operate-signal, GFC
START_GFC	BOOLEAN	0=FALSE 1=TRUE	-	General start-signal, GFC
STARTS_GFC	INTEGER	0=No starts 1=Start PhA 2=Start PhB 3=Start PhA, PhB 4=Start PhC 5=Start PhC, PhA 6=Start PhB, PhC 7=St PhA,PhB,PhC	-	Start-signals for phases A, B and C, GFC
RELEASE_PE	INTEGER	0=No releases 1=Release PhA 2=Release PhB 3=Release PhA,PhB 4=Release PhC 5=Release PhC,PhA 6=Release PhB,PhC 7=Release PhA,B,C	-	Release signals for PE-loops, GFC
RELEASE_PP	INTEGER	0=No releases 1=Release PhAB 2=Release PhBC 3=Rel PhAB,PhBC 4=Release PhCA 5=Rel PhAB,PhCA 6=Rel PhBC,PhCA 7=PhAB,PhBC,PhCA 8=Release PhABC 9=Rel PhAB,PhABC 10=Rel PhBC,PhABC 11=PhAB,PhBC,PhABC 12=Rel PhCA,PhABC 13=PhAB,PhCA,PhABC 14=PhBC,PhCA,PhABC 15=PhAB,BC,CA,ABC	-	Release signals for PP/3P-loops, GFC
EARTH_FLT	BOOLEAN	1=Yes 0=No	-	Indication of a single phase earth-fault, GFC

Table continues on next page

Name	Type	Values (Range)	Unit	Description
XC_FLT	BOOLEAN	1=Yes 0=No	-	Indication of a cross-country-fault (high imp. earthed), GFC
DIR_E_FLT	INTEGER	3=Both 0=Unknown 1=Forward 2=Reverse	-	Earth-fault direction (low imp. earthed), GFC
CONFLICT_GFC	BOOLEAN	1=Yes 0=No	-	Conflict with PSL-function and voltage measuring principle
OPERATE_Z1	BOOLEAN	0=FALSE 1=TRUE	-	Time delayed operate signal, Zone Z1
START_Z1	BOOLEAN	0=FALSE 1=TRUE	-	General start-signal, Zone Z1
STARTS_Z1	INTEGER	0=No starts 1=Start PhA 2=Start PhB 3=Start PhA, PhB 4=Start PhC 5=Start PhC, PhA 6=Start PhB, PhC 7=St PhA,PhB,PhC	-	Start signals for phases A, B and C, Zone Z1
CONFLICT_Z1	INTEGER	0=No conflict 1=PhE angle tilt 2=PhPh angle tilt 3=PhE,PhPh tilt	-	Tilt angle validity check, Zone Z1
OPERATE_Z2	BOOLEAN	0=FALSE 1=TRUE	-	Time delayed operate signal, Zone Z2
START_Z2	BOOLEAN	0=FALSE 1=TRUE	-	General start-signal, Zone Z2
STARTS_Z2	INTEGER	0=No starts 1=Start PhA 2=Start PhB 3=Start PhA, PhB 4=Start PhC 5=Start PhC, PhA 6=Start PhB, PhC 7=St PhA,PhB,PhC	-	Start signals for phases A, B and C, Zone Z2
CONFLICT_Z2	INTEGER	0=No conflict 1=PhE angle tilt 2=PhPh angle tilt 3=PhE,PhPh tilt	-	Tilt angle validity check, Zone Z2
OPERATE_Z3	BOOLEAN	0=FALSE 1=TRUE	-	Time delayed operate signal, Zone Z3
START_Z3	BOOLEAN	0=FALSE 1=TRUE	-	General start-signal, Zone Z3

Table continues on next page

Name	Type	Values (Range)	Unit	Description
STARTS_Z3	INTEGER	0=No starts 1=Start PhA 2=Start PhB 3=Start PhA, PhB 4=Start PhC 5=Start PhC, PhA 6=Start PhB, PhC 7=St PhA,PhB,PhC	-	Start signals for phases A, B and C, Zone Z3
CONFLICT_Z3	INTEGER	0=No conflict 1=PhE angle tilt 2=PhPh angle tilt 3=PhE,PhPh tilt	-	Tilt angle validity check, Zone Z3
OPERATE_ZAR1	BOOLEAN	0=FALSE 1=TRUE	-	Time delayed operate signal, Zone AR1
START_ZAR1	BOOLEAN	0=FALSE 1=TRUE	-	General start-signal, Zone AR1
STARTS_ZAR1	INTEGER	0=No starts 1=Start PhA 2=Start PhB 3=Start PhA, PhB 4=Start PhC 5=Start PhC, PhA 6=Start PhB, PhC 7=St PhA,PhB,PhC	-	Start signals for phases A, B and C, Zone AR1
CONFLICT_ZAR1	INTEGER	0=No conflict 1=PhE angle tilt 2=PhPh angle tilt 3=PhE,PhPh tilt	-	Tilt angle validity check, Zone AR1
OPERATE_ZAR2	BOOLEAN	0=FALSE 1=TRUE	-	Time delayed operate signal, Zone AR2
START_ZAR2	BOOLEAN	0=FALSE 1=TRUE	-	General start-signal, Zone AR2
STARTS_ZAR2	INTEGER	0=No starts 1=Start PhA 2=Start PhB 3=Start PhA, PhB 4=Start PhC 5=Start PhC, PhA 6=Start PhB, PhC 7=St PhA,PhB,PhC	-	Start signals for phases A, B and C, Zone AR2
CONFLICT_ZAR2	INTEGER	0=No conflict 1=PhE angle tilt 2=PhPh angle tilt 3=PhE,PhPh tilt	-	Tilt angle validity check, Zone AR2
DIRECTION	INTEGER	3=Both 0=Unknown 1=Forward 2=Reverse	-	Direction of fault or load
DIR_LOOP_R	REAL	-	Ohm	Real part of the impedance used in dir. evaluation, Zone Z1

Table continues on next page

Name	Type	Values (Range)	Unit	Description
DIR_LOOP_X	REAL	-	Ohm	Imaginary part of the impedance used in dir. eval., Zone Z1
FLTLOOP_RFST	REAL	-	Ohm	Real part of the first PE-loop impedance, Zone Z1
FLTLOOP_XFST	REAL	-	Ohm	Imaginary part of the first PE-loop impedance, Zone Z1
FLTLOOP_RSND	REAL	-	Ohm	Real part of the second PE-loop impedance, Zone Z1
FLTLOOP_XSND	REAL	-	Ohm	Imaginary part of the second PE-loop impedance, Zone Z1
FLTLOOP_RPP	REAL	-	Ohm	Real part of the PP/3P-loop impedance, Zone Z1
FLTLOOP_XPP	REAL	-	Ohm	Imaginary part of PP/3P-loop impedance, Zone Z1
FLTPH_X	REAL	-	Ohm	Phase to earth reactance in phase domain, Zone 1
1 Recording time GFC	INTEGER	-	-	Record data of bank 1 for fault time stamp, GFC
1 RELEASE_PE GFC	INTEGER	0=No releases 1=Release PhA 2=Release PhB 3=Release PhA,PhB 4=Release PhC 5=Release PhC,PhA 6=Release PhB,PhC 7=Release PhA,B,C	-	Record data of bank 1 for release PE-loops, GFC

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 RELEASE_PP GFC	INTEGER	0=No releases 1=Release PhAB 2=Release PhBC 3=Rel PhAB,PhBC 4=Release PhCA 5=Rel PhAB,PhCA 6=Rel PhBC,PhCA 7=PhAB,PhBC,PhCA 8=Release PhABC 9=Rel PhAB,PhABC 10=Rel PhBC,PhABC 11=PhAB,PhBC,PhABC 12=Rel PhCA,PhABC 13=PhAB,PhCA,PhABC 14=PhBC,PhCA,PhABC 15=PhAB,BC,CA,ABC	-	Record data of bank 1 for release PP-loops, GFC
1 EARTH_FLT GFC	BOOLEAN	1=Yes 0=No	-	Record data of bank 1 for earth-fault, GFC
1 XC_FLT GFC	BOOLEAN	1=Yes 0=No	-	Record data of bank 1 for cross country fault, GFC
1 DIR_E_FLT GFC	INTEGER	3=Both 0=Unknown 1=Forward 2=Reverse	-	Record data of bank 1 for EF-direction, GFC
1 DIRECTION	INTEGER	3=Both 0=Unknown 1=Forward 2=Reverse	-	Record data of bank 1 for direction

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 Zones OPERATE	INTEGER	0=No Zn operates 1=Zn1 2=Zn2 4=Zn3 3=Zn1,2 5=Zn1,3 6=Zn2,3 7=Zn1,2,3 8=AR1 9=Zn1,AR1 10=Zn2,AR1 11=Zn1,2,AR1 12=Zn3,AR1 13=Zn1,3,AR1 14=Zn2,3,AR1 15=Zn1,2,3,AR1 16=AR2 17=Zn1,AR2 18=Zn2,AR2 19=Zn1,2,AR2 20=Zn3,AR2 21=Zn1,3,AR2 23=Zn1,2,3,AR2 22=Zn2,3,AR2 24=AR1,AR2 25=Zn1,AR1,AR2 26=Zn2,AR1,AR2 27=Zn1,2,AR1,AR2 28=Zn3,AR1,AR2 29=Zn1,3,AR1,AR2 30=Zn2,3,AR1,AR2 31=Zn1,2,3,AR1,AR2	-	Record data of bank 1 for operate signals of all zones
1 FLTPH_X	REAL	-	Ohm	Record data of bank 1 PE reactance in phase domain
2 Recording time GFC	INTEGER	-	-	Record data of bank 2 for fault time stamp, GFC
2 RELEASE_PE GFC	INTEGER	0=No releases 1=Release PhA 2=Release PhB 3=Release PhA,PhB 4=Release PhC 5=Release PhC,PhA 6=Release PhB,PhC 7=Release PhA,B,C	-	Record data of bank 2 for release PE-loops, GFC

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 RELEASE_PP GFC	INTEGER	0=No releases 1=Release PhAB 2=Release PhBC 3=Rel PhAB,PhBC 4=Release PhCA 5=Rel PhAB,PhCA 6=Rel PhBC,PhCA 7=PhAB,PhBC,PhCA 8=Release PhABC 9=Rel PhAB,PhABC 10=Rel PhBC,PhABC 11=PhAB,PhBC,PhABC 12=Rel PhCA,PhABC 13=PhAB,PhCA,PhABC 14=PhBC,PhCA,PhABC 15=PhAB,BC,CA,ABC	-	Record data of bank 2 for release PP-loops, GFC
2 EARTH_FLT GFC	BOOLEAN	1=Yes 0=No	-	Record data of bank 2 for earth-fault, GFC
2 XC_FLT GFC	BOOLEAN	1=Yes 0=No	-	Record data of bank 2 for cross country fault, GFC
2 DIR_E_FLT GFC	INTEGER	3=Both 0=Unknown 1=Forward 2=Reverse	-	Record data of bank 2 for EF-direction, GFC
2 DIRECTION	INTEGER	3=Both 0=Unknown 1=Forward 2=Reverse	-	Record data of bank 2 for direction

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 Zones OPERATE	INTEGER	0=No Zn operates 1=Zn1 2=Zn2 4=Zn3 3=Zn1,2 5=Zn1,3 6=Zn2,3 7=Zn1,2,3 8=AR1 9=Zn1,AR1 10=Zn2,AR1 11=Zn1,2,AR1 12=Zn3,AR1 13=Zn1,3,AR1 14=Zn2,3,AR1 15=Zn1,2,3,AR1 16=AR2 17=Zn1,AR2 18=Zn2,AR2 19=Zn1,2,AR2 20=Zn3,AR2 21=Zn1,3,AR2 23=Zn1,2,3,AR2 22=Zn2,3,AR2 24=AR1,AR2 25=Zn1,AR1,AR2 26=Zn2,AR1,AR2 27=Zn1,2,AR1,AR2 28=Zn3,AR1,AR2 29=Zn1,3,AR1,AR2 30=Zn2,3,AR1,AR2 31=Zn1,2,3,AR1,AR2	-	Record data of bank 2 for operate signals of all zones
2 FLTPH_X	REAL	-	Ohm	Record data of bank 2 PE reactance in phase domain
3 Recording time GFC	INTEGER	-	-	Record data of bank 3 for fault time stamp, GFC
3 RELEASE_PE GFC	INTEGER	0=No releases 1=Release PhA 2=Release PhB 3=Release PhA,PhB 4=Release PhC 5=Release PhC,PhA 6=Release PhB,PhC 7=Release PhA,B,C	-	Record data of bank 3 for release PE-loops, GFC
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
3 RELEASE_PP GFC	INTEGER	0=No releases 1=Release PhAB 2=Release PhBC 3=Rel PhAB,PhBC 4=Release PhCA 5=Rel PhAB,PhCA 6=Rel PhBC,PhCA 7=PhAB,PhBC,PhCA 8=Release PhABC 9=Rel PhAB,PhABC 10=Rel PhBC,PhABC 11=PhAB,PhBC,PhABC 12=Rel PhCA,PhABC 13=PhAB,PhCA,PhABC 14=PhBC,PhCA,PhABC 15=PhAB,BC,CA,ABC	-	Record data of bank 3 for release PP-loops, GFC
3 EARTH_FLT GFC	BOOLEAN	1=Yes 0=No	-	Record data of bank 3 for earth-fault, GFC
3 XC_FLT GFC	BOOLEAN	1=Yes 0=No	-	Record data of bank 3 for cross country fault, GFC
3 DIR_E_FLT GFC	INTEGER	3=Both 0=Unknown 1=Forward 2=Reverse	-	Record data of bank 3 for EF-direction, GFC
3 DIRECTION	INTEGER	3=Both 0=Unknown 1=Forward 2=Reverse	-	Record data of bank 3 for direction

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3 Zones OPERATE	INTEGER	0=No Zn operates 1=Zn1 2=Zn2 4=Zn3 3=Zn1,2 5=Zn1,3 6=Zn2,3 7=Zn1,2,3 8=AR1 9=Zn1,AR1 10=Zn2,AR1 11=Zn1,2,AR1 12=Zn3,AR1 13=Zn1,3,AR1 14=Zn2,3,AR1 15=Zn1,2,3,AR1 16=AR2 17=Zn1,AR2 18=Zn2,AR2 19=Zn1,2,AR2 20=Zn3,AR2 21=Zn1,3,AR2 23=Zn1,2,3,AR2 22=Zn2,3,AR2 24=AR1,AR2 25=Zn1,AR1,AR2 26=Zn2,AR1,AR2 27=Zn1,2,AR1,AR2 28=Zn3,AR1,AR2 29=Zn1,3,AR1,AR2 30=Zn2,3,AR1,AR2 31=Zn1,2,3,AR1,AR2	-	Record data of bank 3 for operate signals of all zones
3 FLTPH_X	REAL	-	Ohm	Record data of bank 3 PE reactance in phase domain
1 Recording time Z1	INTEGER	-	-	Record data of bank 1 for fault time stamp, Zone 1
1 DIR_LOOP_R Z1	REAL	-	Ohm	Record data of bank 1 for direction resistance, Zone Z1
1 DIR_LOOP_X Z1	REAL	-	Ohm	Record data of bank 1 for direction reactance, Zone Z1
1 FLTLOOP_RFST Z1	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (1st), Zone Z1

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 FLTLOOP_XFST Z1	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (1st), Zone Z1
1 FLTLOOP_RSND Z1	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (2nd), Zone Z1
1 FLTLOOP_XSND Z1	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (2nd), Zone Z1
1 FLTLOOP_RPP Z1	REAL	-	Ohm	Record data of bank 1 for PP-loop resistance, Zone Z1
1 FLTLOOP_XPP Z1	REAL	-	Ohm	Record data of bank 1 for PP-loop reactance, Zone Z1
2 Recording time Z1	INTEGER	-	-	Record data of bank 2 for fault time stamp, Zone 1
2 DIR_LOOP_R Z1	REAL	-	Ohm	Record data of bank 2 for direction resistance, Zone Z1
2 DIR_LOOP_X Z1	REAL	-	Ohm	Record data of bank 2 for direction reactance, Zone Z1
2 FLTLOOP_RFST Z1	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (1st), Zone Z1
2 FLTLOOP_XFST Z1	REAL	-	Ohm	Record data of bank 2 for PE-loop reactance (1st), Zone Z1
2 FLTLOOP_RSND Z1	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (2nd), Zone Z1
2 FLTLOOP_XSND Z1	REAL	-	Ohm	Record data of bank 2 for PE-loop reactance (2nd), Zone Z1
2 FLTLOOP_RPP Z1	REAL	-	Ohm	Record data of bank 2 for PP-loop resistance, Zone Z1

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 FLTLOOP_XPP Z1	REAL	-	Ohm	Record data of bank 2 for PP-loop reactance, Zone Z1
3 Recording time Z1	INTEGER	-	-	Record data of bank 3 for fault time stamp, Zone 1
3 DIR_LOOP_R Z1	REAL	-	Ohm	Record data of bank 3 for direction resistance, Zone Z1
3 DIR_LOOP_X Z1	REAL	-	Ohm	Record data of bank 3 for direction reactance, Zone Z1
3 FLTLOOP_RFST Z1	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (1st), Zone Z1
3 FLTLOOP_XFST Z1	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (1st), Zone Z1
3 FLTLOOP_RSND Z1	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (2nd), Zone Z1
3 FLTLOOP_XSND Z1	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (2nd), Zone Z1
3 FLTLOOP_RPP Z1	REAL	-	Ohm	Record data of bank 3 for PP-loop resistance, Zone Z1
3 FLTLOOP_XPP Z1	REAL	-	Ohm	Record data of bank 3 for PP-loop reactance, Zone Z1
1 Recording time Z2	INTEGER	-	-	Record data of bank 1 for fault time stamp, Zone 2
1 DIR_LOOP_R Z2	REAL	-	Ohm	Record data of bank 1 for direction resistance, Zone Z2
1 DIR_LOOP_X Z2	REAL	-	Ohm	Record data of bank 1 for direction reactance, Zone Z2

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 FLTLOOP_RFST Z2	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (1st), Zone Z2
1 FLTLOOP_XFST Z2	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (1st), Zone Z2
1 FLTLOOP_RSND Z2	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (2nd), Zone Z2
1 FLTLOOP_XSND Z2	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (2nd), Zone Z2
1 FLTLOOP_RPP Z2	REAL	-	Ohm	Record data of bank 1 for PP-loop resistance, Zone Z2
1 FLTLOOP_XPP Z2	REAL	-	Ohm	Record data of bank 1 for PP-loop reactance, Zone Z2
2 Recording time Z2	INTEGER	-	-	Record data of bank 2 for fault time stamp, Zone 2
2 DIR_LOOP_R Z2	REAL	-	Ohm	Record data of bank 2 for direction resistance, Zone Z2
2 DIR_LOOP_X Z2	REAL	-	Ohm	Record data of bank 2 for direction reactance, Zone Z2
2 FLTLOOP_RFST Z2	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (1st), Zone Z2
2 FLTLOOP_XFST Z2	REAL	-	Ohm	Record data of bank 2 for PE-loop reactance (1st), Zone Z2
2 FLTLOOP_RSND Z2	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (2nd), Zone Z2
2 FLTLOOP_XSND Z2	REAL	-	Ohm	Record data of bank 2 for PE-loop reactance (2nd), Zone Z2

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 FLTLOOP_RPP Z2	REAL	-	Ohm	Record data of bank 2 for PP-loop resistance, Zone Z2
2 FLTLOOP_XPP Z2	REAL	-	Ohm	Record data of bank 2 for PP-loop reactance, Zone Z2
3 Recording time Z2	INTEGER	-	-	Record data of bank 3 for fault time stamp, Zone 2
3 DIR_LOOP_R Z2	REAL	-	Ohm	Record data of bank 3 for direction resistance, Zone Z2
3 DIR_LOOP_X Z2	REAL	-	Ohm	Record data of bank 3 for direction reactance, Zone Z2
3 FLTLOOP_RFST Z2	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (1st), Zone Z2
3 FLTLOOP_XFST Z2	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (1st), Zone Z2
3 FLTLOOP_RSND Z2	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (2nd), Zone Z2
3 FLTLOOP_XSND Z2	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (2nd), Zone Z2
3 FLTLOOP_RPP Z2	REAL	-	Ohm	Record data of bank 3 for PP-loop resistance, Zone Z2
3 FLTLOOP_XPP Z2	REAL	-	Ohm	Record data of bank 3 for PP-loop reactance, Zone Z2
1 Recording time Z3	INTEGER	-	-	Record data of bank 1 for fault time stamp, Zone 3
1 DIR_LOOP_R Z3	REAL	-	Ohm	Record data of bank 1 for direction resistance, Zone Z3

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 DIR_LOOP_X Z3	REAL	-	Ohm	Record data of bank 1 for direction reactance, Zone Z3
1 FLTLOOP_RFST Z3	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (1st), Zone Z3
1 FLTLOOP_XFST Z3	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (1st), Zone Z3
1 FLTLOOP_RSND Z3	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (2nd), Zone Z3
1 FLTLOOP_XSND Z3	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (2nd), Zone Z3
1 FLTLOOP_RPP Z3	REAL	-	Ohm	Record data of bank 1 for PP-loop resistance, Zone Z3
1 FLTLOOP_XPP Z3	REAL	-	Ohm	Record data of bank 1 for PP-loop reactance, Zone Z3
2 Recording time Z3	INTEGER	-	-	Record data of bank 2 for fault time stamp, Zone 3
2 DIR_LOOP_R Z3	REAL	-	Ohm	Record data of bank 2 for direction resistance, Zone Z3
2 DIR_LOOP_X Z3	REAL	-	Ohm	Record data of bank 2 for direction reactance, Zone Z3
2 FLTLOOP_RFST Z3	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (1st), Zone Z3
2 FLTLOOP_XFST Z3	REAL	-	Ohm	Record data of bank 2 for PE-loop reactance (1st), Zone Z3
2 FLTLOOP_RSND Z3	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (2nd), Zone Z3

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 FLTLOOP_XSND Z3	REAL	-	Ohm	Record data of bank 2 for PE-loop reactance (2nd), Zone Z3
2 FLTLOOP_RPP Z3	REAL	-	Ohm	Record data of bank 2 for PP-loop resistance, Zone Z3
2 FLTLOOP_XPP Z3	REAL	-	Ohm	Record data of bank 2 for PP-loop reactance, Zone Z3
3 Recording time Z3	INTEGER	-	-	Record data of bank 3 for fault time stamp, Zone 3
3 DIR_LOOP_R Z3	REAL	-	Ohm	Record data of bank 3 for direction resistance, Zone Z3
3 DIR_LOOP_X Z3	REAL	-	Ohm	Record data of bank 3 for direction reactance, Zone Z3
3 FLTLOOP_RFST Z3	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (1st), Zone Z3
3 FLTLOOP_XFST Z3	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (1st), Zone Z3
3 FLTLOOP_RSND Z3	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (2nd), Zone Z3
3 FLTLOOP_XSND Z3	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (2nd), Zone Z3
3 FLTLOOP_RPP Z3	REAL	-	Ohm	Record data of bank 3 for PP-loop resistance, Zone Z3
3 FLTLOOP_XPP Z3	REAL	-	Ohm	Record data of bank 3 for PP-loop reactance, Zone Z3
1 Recording time AR1	INTEGER	-	-	Record data of bank 1 for fault time stamp, Zone AR1

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 DIR_LOOP_R AR1	REAL	-	Ohm	Record data of bank 1 for direction resistance, Zone AR1
1 DIR_LOOP_X AR1	REAL	-	Ohm	Record data of bank 1 for direction reactance, Zone AR1
1 FLTLOOP_RFST AR1	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (1st), Zone AR1
1 FLTLOOP_XFST AR1	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (1st), Zone AR1
1 FLTLOOP_RSND AR1	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (2nd), Zone AR1
1 FLTLOOP_XSND AR1	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (2nd), Zone AR1
1 FLTLOOP_RPP AR1	REAL	-	Ohm	Record data of bank 1 for PP-loop resistance, Zone AR1
1 FLTLOOP_XPP AR1	REAL	-	Ohm	Record data of bank 1 for PP-loop reactance, Zone AR1
2 Recording time AR1	INTEGER	-	-	Record data of bank 2 for fault time stamp, Zone AR1
2 DIR_LOOP_R AR1	REAL	-	Ohm	Record data of bank 2 for direction resistance, Zone AR1
2 DIR_LOOP_X AR1	REAL	-	Ohm	Record data of bank 2 for direction reactance, Zone AR1
2 FLTLOOP_RFST AR1	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (1st), Zone AR1
2 FLTLOOP_XFST AR1	REAL	-	Ohm	Record data of bank 2 for PE-loop reactance (1st), Zone AR1

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 FLTLOOP_RSND AR1	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (2nd), Zone AR1
2 FLTLOOP_XSND AR1	REAL	-	Ohm	Record data of bank 2 for PE-loop reactance (2nd), Zone AR1
2 FLTLOOP_RPP AR1	REAL	-	Ohm	Record data of bank 2 for PP-loop resistance, Zone AR1
2 FLTLOOP_XPP AR1	REAL	-	Ohm	Record data of bank 2 for PP-loop reactance, Zone AR1
3 Recording time AR1	INTEGER	-	-	Record data of bank 3 for fault time stamp, Zone AR1
3 DIR_LOOP_R AR1	REAL	-	Ohm	Record data of bank 3 for direction resistance, Zone AR1
3 DIR_LOOP_X AR1	REAL	-	Ohm	Record data of bank 3 for direction reactance, Zone AR1
3 FLTLOOP_RFST AR1	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (1st), Zone AR1
3 FLTLOOP_XFST AR1	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (1st), Zone AR1
3 FLTLOOP_RSND AR1	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (2nd), Zone AR1
3 FLTLOOP_XSND AR1	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (2nd), Zone AR1
3 FLTLOOP_RPP AR1	REAL	-	Ohm	Record data of bank 3 for PP-loop resistance, Zone AR1
3 FLTLOOP_XPP AR1	REAL	-	Ohm	Record data of bank 3 for PP-loop reactance, Zone AR1

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 Recording time AR2	INTEGER	-	-	Record data of bank 1 for fault time stamp, Zone AR2
1 DIR_LOOP_R AR2	REAL	-	Ohm	Record data of bank 1 for direction resistance, Zone AR2
1 DIR_LOOP_X AR2	REAL	-	Ohm	Record data of bank 1 for direction reactance, Zone AR2
1 FLTLOOP_RFST AR2	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (1st), Zone AR2
1 FLTLOOP_XFST AR2	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (1st), Zone AR2
1 FLTLOOP_RSND AR2	REAL	-	Ohm	Record data of bank 1 for PE-loop resistance (2nd), Zone AR2
1 FLTLOOP_XSND AR2	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (2nd), Zone AR2
1 FLTLOOP_RPP AR2	REAL	-	Ohm	Record data of bank 1 for PP-loop resistance, Zone AR2
1 FLTLOOP_XPP AR2	REAL	-	Ohm	Record data of bank 1 for PP-loop reactance, Zone AR2
2 Recording time AR2	INTEGER	-	-	Record data of bank 2 for fault time stamp, Zone AR2
2 DIR_LOOP_R AR2	REAL	-	Ohm	Record data of bank 2 for direction resistance, Zone AR2
2 DIR_LOOP_X AR2	REAL	-	Ohm	Record data of bank 2 for direction reactance, Zone AR2
2 FLTLOOP_RFST AR2	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (1st), Zone AR2
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
2 FLTLOOP_XFST AR2	REAL	-	Ohm	Record data of bank 1 for PE-loop reactance (1st), Zone AR2
2 FLTLOOP_RSND AR2	REAL	-	Ohm	Record data of bank 2 for PE-loop resistance (2nd), Zone AR2
2 FLTLOOP_XSND AR2	REAL	-	Ohm	Record data of bank 2 for PE-loop reactance (2nd), Zone AR2
2 FLTLOOP_RPP AR2	REAL	-	Ohm	Record data of bank 2 for PP-loop resistance, Zone AR2
2 FLTLOOP_XPP AR2	REAL	-	Ohm	Record data of bank 2 for PP-loop reactance, Zone AR2
3 Recording time AR2	INTEGER	-	-	Record data of bank 3 for fault time stamp, Zone AR2
3 DIR_LOOP_R AR2	REAL	-	Ohm	Record data of bank 3 for direction resistance, Zone AR2
3 DIR_LOOP_X AR2	REAL	-	Ohm	Record data of bank 3 for direction reactance, Zone AR2
3 FLTLOOP_RFST AR2	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (1st), Zone AR2
3 FLTLOOP_XFST AR2	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (1st), Zone AR2
3 FLTLOOP_RSND AR2	REAL	-	Ohm	Record data of bank 3 for PE-loop resistance (2nd), Zone AR2
3 FLTLOOP_XSND AR2	REAL	-	Ohm	Record data of bank 3 for PE-loop reactance (2nd), Zone AR2
3 FLTLOOP_RPP AR2	REAL	-	Ohm	Record data of bank 3 for PP-loop resistance, Zone AR2
3 FLTLOOP_XPP AR2	REAL	-	Ohm	Record data of bank 3 for PP-loop reactance, Zone AR2

4.7.1.12 Technical data

Table 791: DSTPDIS Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	Current: ±1.5% of the set value or ±0.003 × I_n Voltage: ±1.0% of the set value or ±0.003 × U_n Impedance: ±2.0% of the set value or ±0.01 Ω static accuracy Phase angle: ±2°
Start time 1)2) SIR3): 0.1...60	Typically 40...50 ms (±15 ms)
Transient overreach SIR = 0.1...60	<6%
Reset time	<65 ms
Reset ratio	Typically 0.95/1.05
Operate time accuracy	±1.0% of the set value or ±20 ms

1) Includes the delay of the signal output contact
2) Relates to start signals of the Zone Z1–Zone ZAR2
3) SIR = Source impedance ratio

4.7.1.13 Technical revision history

Table 792: DSTPDIS technical revision history

Technical revision	Change
B	*Voltage Mem time* setting is added. Information related to fault time stamp (*x Recording time xxx*) is made available in recorded data.
C	Voltage memory functionality for close-in three-phase faults supports AR up to 300 s. Output `FLTPH_X` is added. Selection “Self Pol” is removed from setting *Pol quantity zone.* Selection “Overcur/underZ” is removed from setting *Phase Sel mode GFC*. Minimum setting value changed from 0.050 ms to 0.040 ms for *Gnd operate Dl Zn1*, *PP operate delay Zn1*, *Gnd operate Dl Zn2*, *PP operate delay Zn2*, *Gnd operate Dl Zn3*, *PP operate delay Zn3*, *Gnd operate Dl AR1*, *PP operate delay AR1*, *Gnd operate Dl AR2*, and *PP operate delay AR2.* Default setting for *Gnd operate Dl Zn1* and *PP operate delay Zn1* changed from 0.050 ms to 0.040 ms. Support for other faulty phase detection in XC fault. Added setting *Zone timer mode.*

4.7.2 Three-phase underexitation protection UEXPDIS

4.7.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase underexcitation protection	UEXPDIS	X<	40

4.7.2.2 Function block

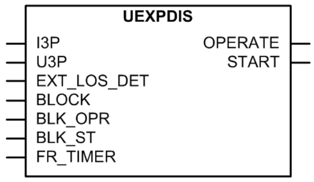


Figure 406: Function block

4.7.2.3 Functionality

The three-phase underexcitation protection UEXPDIS is used to protect the synchronous machine against the underexcitation or loss of excitation condition.

The protection is based on the offset-mho circular characteristics on the impedance plane. The function calculates the apparent impedance from the machine terminal voltages and currents. If the impedance vector enters the offset-mho circle, the function gives the operating signal after a set definite time. The operating time characteristics are according to definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, timer or the function itself, if desired.

4.7.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the three-phase underexcitation protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

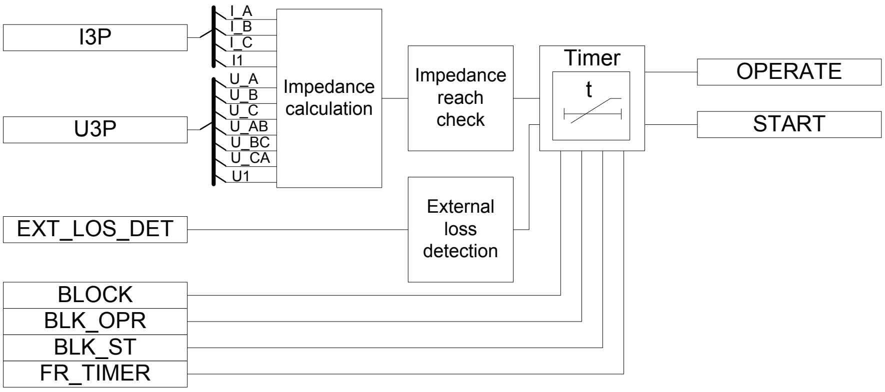


Figure 407: Functional module diagram

Impedance calculation

This module calculates the apparent impedance based on the selected voltages and currents. The *Measurement mode* and *Phase Sel for Z Clc* settings determine which voltages and currents are to be used. If the *Measurement mode* is set to "1Phase-earth" or "1Phase-phase", the *Phase Sel for Z Clc* setting is needed for determining which phase or phase-phase voltages ("A or AB", "B or BC" and "C or CA") and currents should be used for calculating the impedance.

Table 793: Voltages and currents used in impedance calculation

Measurement mode	Phase Sel for Z Clc	Voltages and currents
1Phase-earth	A or AB	U_A, I_A
1Phase-earth	B or BC	U_B, I_B
1Phase-earth	C or CA	U_C, I_C
1Phase-phase	A or AB	U_AB, I_A, I_B
1Phase-phase	B or BC	U_BC, I_B, I_C
1Phase-phase	C or CA	U_CA, I_C, I_A
3Phase-earth	N/A	U_A, U_B, U_C, I_A, I_B, I_C
3Phase-phase	N/A	U_AB, U_BC, U_CA, I_A, I_B, I_C
Pos seqn	N/A	{ U_A,U_B,U_C } or { U_AB,U_BC,U_CA } and I_A, I_B, I_C

If all three phase voltages and phase currents are fed to the IED, the positive-sequence alternative is recommended.

If the polarity of the voltage signals is opposite to the normal polarity, the correction can be done by setting *Voltage reversal* to "Yes", which rotates the impedance vector by 180 degrees.

If the magnitude of the voltage is less than 0.05 × U_N, the calculated impedance is not reliable and the impedance calculation is disabled. U_N is the rated phase-to-phase voltage.

The calculated impedance magnitudes and angles are available in the monitored data view. The impedance angles are provided between -180 to 180 degrees.

The calculated apparent impedance is converted to pu impedance as the operating characteristics are defined with the pu settings.

Impedance reach check

The operating characteristic is a circular offset mho on the impedance plane. The operating characteristics are defined with the *Offset*, *Diameter* and *Displacement* settings. If the calculated impedance value enters the circle in the impedance plane, the module sends an enabling signal to start the timer.

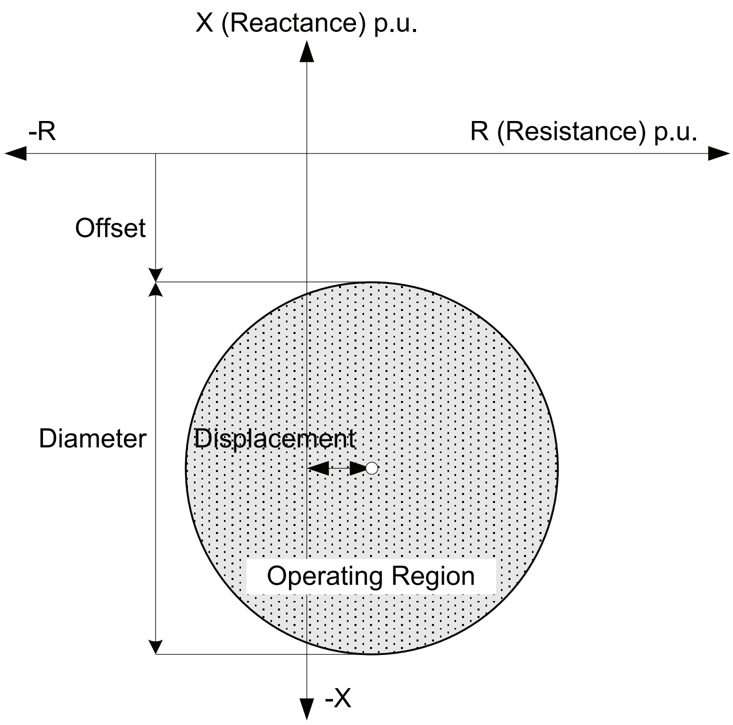


Figure 408: Operating region of the impedance mho circle

A fault in Automatic Voltage Regulator (AVR) or in the excitation system may cause a total loss of excitation. A short circuit on the slip rings reduces the excitation voltage to zero. This causes a gradual reduction of the excitation current and eventually a loss of excitation. An open circuit in the field circuit also causes a loss of excitation. These are the typical examples which cause underexcitation in synchronous machines. This module detects the underexcitation condition for the above cases when the calculated impedance enters the operating characteristics.

External loss detection

This module checks the status information of the excitation system. The module is activated when the *External Los Det Ena* setting is set to "Enable". The total loss of excitation current or a failure in the excitation system is indicated by connecting the external binary signal to the `EXT_LOS_DET` input. The timer is enabled immediately when the `EXT_LOS_DET` input is activated.

Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the duration of the underexcitation exceeds the set definite *Operate delay time*, the `OPERATE` output is activated. If the impedance locus moves out of the offset-mho operating characteristics before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operating timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time (DT). The value is available in the monitored data view.

The activation of the `BLOCK` input deactivates all the binary outputs and resets the internal timers. The `BLK_ST` binary input can be used to block the `START` signal. The `BLK_OPR` binary input can be used to block the `OPERATE` signal. The operation timer counting can be frozen on the prevailing value by activating the `FR_TIMER` input.

The angle values available at the input monitor data view are in radians.

4.7.2.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.7.2.6 Application

There are limits for the underexcitation of a synchronous machine. A reduction of the excitation current weakens the coupling between the rotor and the external power system. The machine may lose the synchronism and starts to operate like an induction machine, which increases the consumption of the reactive power. Even if the machine does not lose synchronism, it may not be acceptable to operate in this state for a long time. The underexcitation causes excessive heating in the end region of the stator winding. This can damage the insulation of the stator winding and even the iron core.

The underexcitation also causes the generator to operate in the asynchronous mode. This increases the rotor speed, which causes heating in the rotor iron and damps the windings. A high intake of the reactive power from the network during underexcitation causes problems in the network like voltage dip, stability and power swings. The power swings stress the prime mover, causing turbine blade cavitations and mechanical stress in the gearbox, for example.

The capability curve of a synchronous generator describes the underexcitation capability of the machine. An excessive capacitive load on the synchronous machine causes it to drop out-of-step. The reason is the steady-state stability limit as defined by the load angle being 90°, which can only be reached when the unit is underexcited.

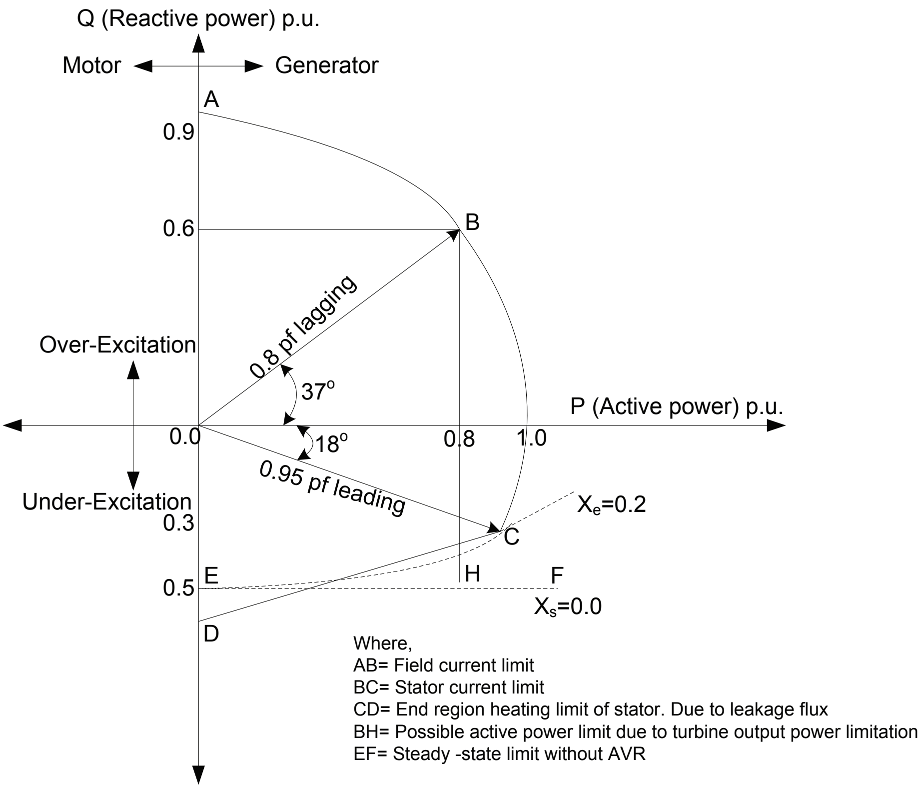


Figure 409: Capability curve of a synchronous generator

UEXPDIS protects the synchronous machines against an unstable operation due to loss of excitation. A partial or total loss of excitation causes a reactive power intake from the network to the machine, and the reactance of the system viewed from the machine terminals turns negative. This kind of drop-of-reactance condition can be detected by measuring the impedance of the system.

The operating characteristic is an offset-mho circle in the impedance plane, and the circle is parameterized with the *Offset*, *Diameter* and *Displacement* setting values.

Table 794: Parameters of the circle

Setting values	Description
Offset	Distance of the top of the circle from the R-axis. This is usually set equal to –x_d'/2, where x_d' is the transient reactance of the machine. The sign of the setting value determines the top of the circle regarding the R-axis. If the sign is negative, the circle lies below the R-axis.
Diameter	Normally set equal to the machine's synchronous reactance x_d, which determines the size of the impedance circle.
Displacement	Displacement of the center of the circle from the reactance axis or the R–coordinate of the center. The setting can be used to adjust the sensitivity of the underexcitation protection. If the sign of the setting is positive, the circle is shifted to the right, that is, closer to the normal operating point. Respectively, if the sign is negative, the circle is shifted to the left and thus moves away from the normal operating point.

The setting parameters of the off-set mho circle are to be given in pu values. The base impedance (Z_N) in ohms is:

$$Z_N = \left| \frac{U_N^{\ 2}}{S_N} \right|$$

U_N the rated (phase-to-phase) voltage in kV

S_N the rated power of the protected machine in MVA

The corresponding calculation to convert ohms to pu values is:

$$X_{pu} = \frac{X_{ohm}}{Z_N}$$

X_{pu} the pu value

X_{ohm} the reactance in ohms

Z_N the base impedance

Example of impedance locus in underexcitation

In an example of a typical impedance locus, once the impedance locus enters the relay operation characteristics, the relay operates after a settable definite time.

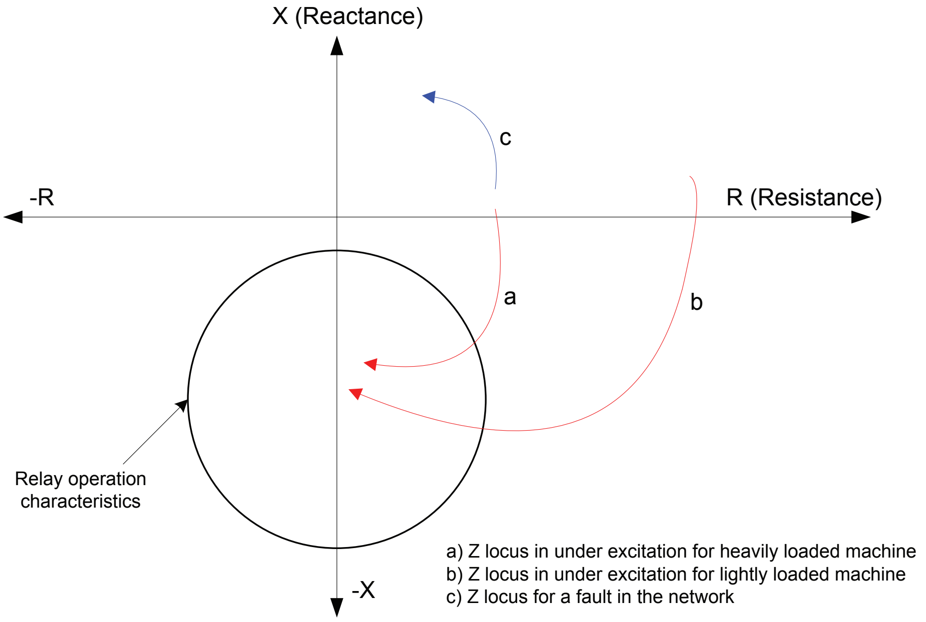


Figure 410: Typical impedance locus in underexcitation: a) heavy load b) light load c) fault in the network

4.7.2.7 Signals

Table 795: UEXPDIS Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timer
EXT_LOS_DET	BOOLEAN	0	External signal for excitation loss detection

Table 796: UEXPDIS Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started

4.7.2.8 Settings

Table 797: UEXPDIS Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Diameter	1 - 6000	% Zb	1	200	Diameter of the impedance mho circle
Offset	-1000 - 1000	% Zb	1	-10	Offset of top of the impedance circle from the R-axis
Displacement	-1000 - 1000	% Zb	1	0	Displacement of impedance circle centre from the X-axis
Operate delay time	0.06 - 200.00	s	0.01	5.00	Operate delay time

Table 798: UEXPDIS Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Measurement mode	1Phase-earth 1Phase-phase 3Phase-earth 3Phase-phase Pos Seqn	-	-	Pos Seqn	Select voltage/current signals for Z calculation
Phase Sel for Z Clc	A or AB B or BC C or CA	-	-	A or AB	Select ph/ ph-ph voltages and currents for Z calculation

Table 799: UEXPDIS Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On
External Los Det Ena	Disable Enable	-	-	Enable	Enable external excitation loss detection

Table 800: UEXPDIS Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Reset delay time	0.00 - 60.00	s	0.01	3.00	Time delay to reset timer
Voltage reversal	No Yes	-	-	No	Rotate voltage signals by 180 degrees

4.7.2.9 Measured values

Table 801: UEXPDIS Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0.0	Current amplitude (DFT) phase A
I_AMPL_B	REAL	0.0	Current amplitude (DFT) phase B
I_AMPL_C	REAL	0.0	Current amplitude (DFT) phase C
I_ANGL_A	REAL	0.0	Current phase angle phase A
I_ANGL_B	REAL	0.0	Current phase angle phase B
I_ANGL_C	REAL	0.0	Current phase angle phase C
I1_AMPL	REAL	0.0	Positive sequence current amplitude
I1_ANGL	REAL	0.0	Positive sequence current angle
U_AMPL_A	REAL	0.0	Phase A-to-ground voltage amplitude
U_AMPL_B	REAL	0.0	Phase B-to-ground voltage amplitude
U_AMPL_C	REAL	0.0	Phase C-to-ground voltage amplitude
U_ANGL_A	REAL	0.0	Phase A-to-ground voltage phase angle
U_ANGL_B	REAL	0.0	Phase B-to-ground voltage phase angle
U_ANGL_C	REAL	0.0	Phase C-to-ground voltage phase angle
U_AMPL_AB	REAL	0.0	Phase-to-phase A-B voltage amplitude
U_AMPL_BC	REAL	0.0	Phase-to-phase B-C voltage amplitude
U_AMPL_CA	REAL	0.0	Phase-to-phase C-A voltage amplitude
U_ANGL_AB	REAL	0.0	Phase-to-phase A-B voltage phase angle
U_ANGL_BC	REAL	0.0	Phase-to-phase B-C voltage phase angle
U_ANGL_CA	REAL	0.0	Phase-to-phase C-A voltage phase angle
U1_AMPL	REAL	0.0	Positive sequence voltage amplitude
U1_ANGL	REAL	0.0	Positive sequence voltage phase angle
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timer
EXT_LOS_DET	BOOLEAN	0	External signal for excitation loss detection

4.7.2.10 Monitored data

Table 802: UEXPDIS Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
Z_AMPL_A	REAL	-	pu	Impedance amplitude phase A
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
Z_AMPL_B	REAL	-	pu	Impedance amplitude phase B
Z_AMPL_C	REAL	-	pu	Impedance amplitude phase C
Z_ANGLE_A	REAL	-	deg	Impedance phase angle phase A
Z_ANGLE_B	REAL	-	deg	Impedance phase angle phase B
Z_ANGLE_C	REAL	-	deg	Impedance phase angle phase C
Z_AMPL_AB	REAL	-	pu	Phase-to-phase A-B impedance amplitude
Z_AMPL_BC	REAL	-	pu	Phase-to-phase B-C impedance amplitude
Z_AMPL_CA	REAL	-	pu	Phase-to-phase C-A impedance amplitude
Z_ANGLE_AB	REAL	-	deg	Phase-to-phase A-B impedance phase angle
Z_ANGLE_BC	REAL	-	deg	Phase-to-phase B-C impedance phase angle
Z_ANGLE_CA	REAL	-	deg	Phase-to-phase C-A impedance phase angle
Z1_AMPL	REAL	-	pu	Positive sequence impedance amplitude
Z1_ANGLE	REAL	-	deg	Positive sequence impedance phase angle
START_DUR	REAL	-	%	Ratio of start time / operate time

4.7.2.11 Technical data

Table 803: UEXPDIS Technical data

Characteristic	Value
Operation accuracy[1)]	At the frequency $f = f_n$
	±3.0% of the set value or ±0.2% Zb
Start time[2)3)]	Typically 45 ms (±15 ms)
Reset time	<50 ms
Reset ratio	Typically 1.04
Retardation time	Total retardation time when the impedance returns from the operating circle <40 ms
Operate time accuracy in definite-time mode	±1.0% of the set value of ±20 ms

1) Adaptive DFT measurement used
2) f_n = 50 Hz, results based on statistical distribution of 1000 measurements
3) Includes the delay of the signal output contact

4.7.3 Three-phase underimpedance protection UZPDIS

4.7.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase underimpedance protection	UZPDIS	Z< GT	21GT

4.7.3.2 Function block

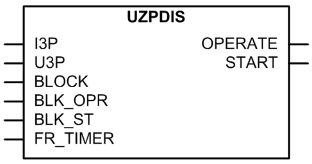


Figure 411: Function block

4.7.3.3 Functionality

The three-phase underimpedance protection UZPDIS is generally applied as a backup protection for generators and transformers against short circuit faults.

The protection is based on the origin-centric circular characteristics on the impedance plane. The function calculates the impedance value from the voltage and current phasors. If the impedance vector enters the origin-centric circle, the function produces the operating signal after a set delay. The operating time characteristics are according to definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, reset timer or the function itself, if desired.

4.7.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the three-phase underimpedance protection can be described with a module diagram. All the modules in the diagram are explained in the next sections.

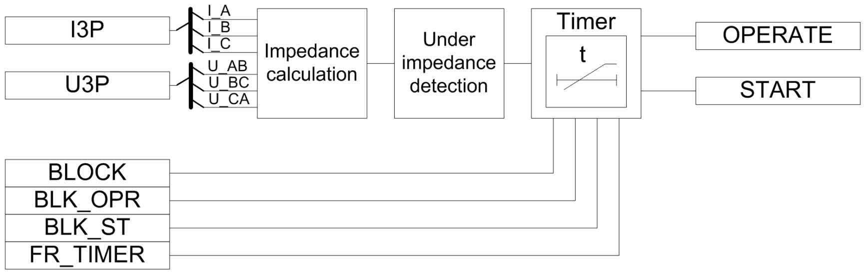


Figure 412: Functional module diagram

Impedance calculation

This module calculates the impedance based on the selected voltages and currents. The *Impedance Meas mode* and *Phase Sel for Z Clc* settings determine which voltages and currents are to be used. If *Impedance Meas mode* is set to "1Phase-phase", the *Phase Sel for Z Clc* setting is needed for determining which phase-phase voltages ("AB", "BC" and "CA") and currents should be used for calculating the impedance.

Table 804: Voltages and currents used in impedance calculation

Impedance Meas mode	*Phase Sel for Z Clc*	Voltages and currents used in impedance calculation
1Phase-phase	AB	$\overline{ZAB} = \frac{U\_AB}{I\_A - I\_B}$
1Phase-phase	BC	$\overline{ZBC} = \frac{U\_BC}{I\_B - I\_C}$
1Phase-phase	CA	$\overline{ZCA} = \frac{U\_CA}{I\_C - I\_A}$
3Phase-phase	N/A	$\overline{ZAB} = \frac{U\_AB}{I\_A - I\_B}$ $\overline{ZBC} = \frac{U\_BC}{I\_B - I\_C}$ $\overline{ZCA} = \frac{U\_CA}{I\_C - I\_A}$
The voltages and currents in the calculations are given in volts and amps.		

If all three phase or phase-phase voltages and phase currents are fed to the IED, the "3Phase-phase" mode is recommended.

The current measurement of the function is based on two alternative measurement modes, "DFT" and "Peak-To-Peak". The measurement mode is selected using the *Measurement mode* setting.

If the current magnitude is below 0.02 x I_N, where I_N is the nominal phase current, the impedance value is not evaluated and the maximum impedance value (99.999 pu) is shown in the monitored data view.

The calculated impedances are converted to a pu impedance as the operating characteristics are defined using the *Polar reach* setting in %Zb.

The calculated phase-phase impedance amplitudes ZAB_AMPL, ZBC_AMPL and ZCA_AMPL are available as pu values in the monitored data view.

Underimpedance detection

The operating characteristic is an origin-centric circle on the impedance plane. The origin-centric circular characteristic is defined using the *Polar reach* setting. If the calculated impedance value enters the circle in the impedance plane, the module sends an enabling signal to start the timer.

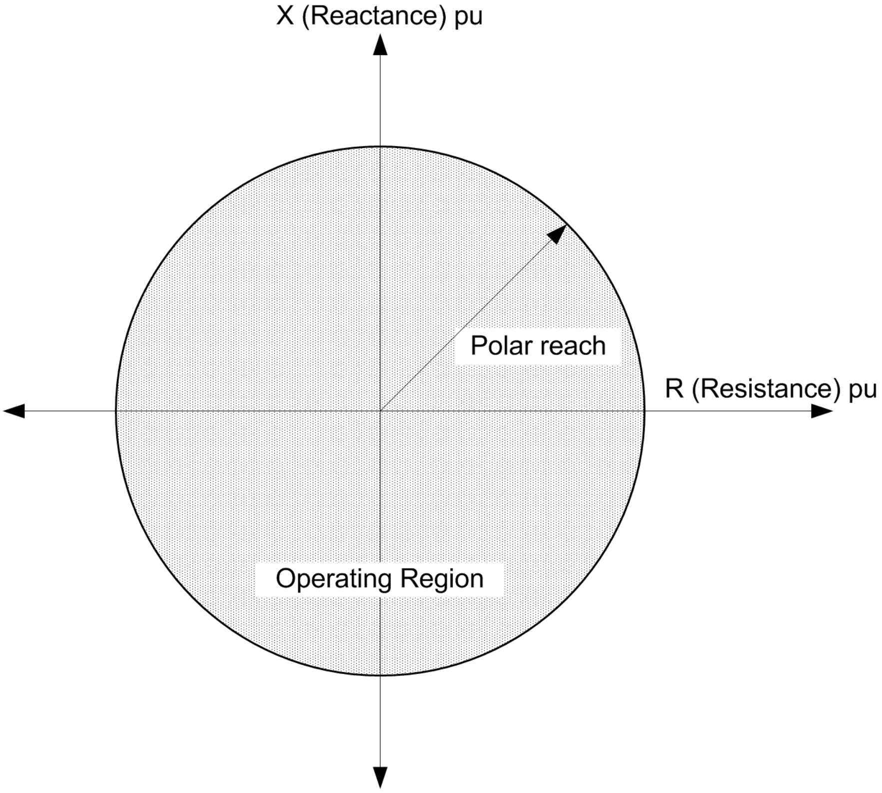


Figure 413: Origin-centric circular operating characteristics

More than one impedance value is available when *Impedance Meas mode* is set to "3Phase-phase", and the function considers the lowest impedance value for starting and operating.

Timer

Once activated, the timer activates `START` output. The time characteristic is according to DT. When the duration of the underimpedance condition exceeds the set definite *Operate delay time*, the `OPERATE` output is activated. If the impedance locus moves out of circular operating characteristics before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operating timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time (DT). The value is available in the monitored data view.

The activation of the `BLOCK` input deactivates all binary outputs and resets internal timers. The `BLK_ST` binary input can be used to block the `START` signal. The

BLK_OPR binary input can be used to block the OPERATE signal. The operation timer counting can be frozen on the prevailing value by activating the FR_TIMER input.

4.7.3.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.7.3.6 Application

The three-phase underimpedance protection is used as a backup protection against short circuit faults at the generator terminals or on the high-voltage side of a step-up transformer. This function can be used either instead of the definite time voltage-dependent overcurrent protection or to obtain a limited protection zone and the optimum operating time instead of the non-directional overcurrent protection.

Comparison between overcurrent and underimpedance protection

When a fault occurs at zero seconds in the phase current in a three-phase short circuit with an ordinary overcurrent IED having the current setting as 1.2 x I_n, the time setting should be less than 0.2 seconds because the short circuit current decays below the set value and the IED drops off with a higher value of time. The current setting can also be reduced to 1.1 x I_n, although this provides no substantial rise in the time setting. In some situations, either of the above current settings is appropriate, but if longer tripping times are required to maintain the time selectivity, the underimpedance protection is needed.

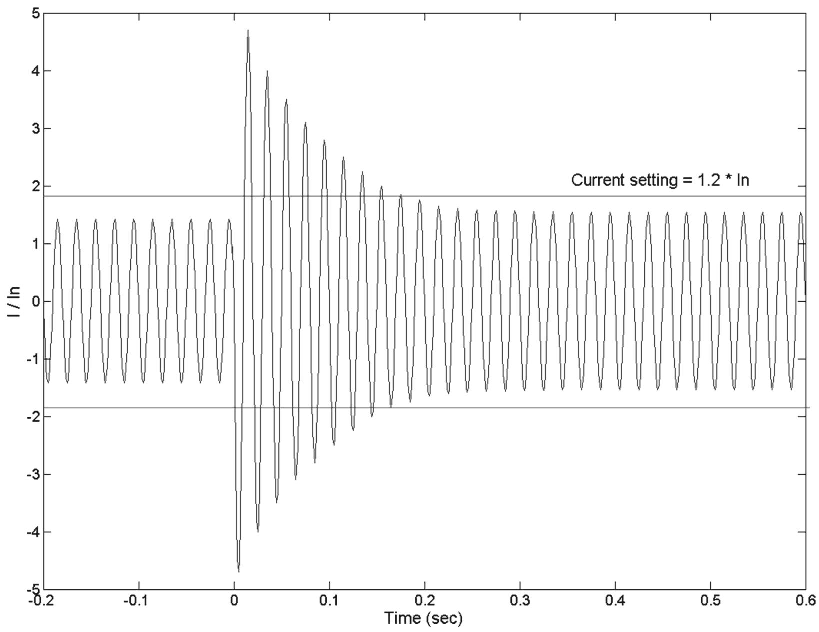


Figure 414: Short circuit current waveform, fault occurs at time 0 seconds (Current setting limit is multiplied by the square root of 2).

The phase voltage in a three-phase short circuit when a fault occurs at zero seconds is shown in Figure 415. The voltage drop caused by a three-phase fault provides more time for determining the fault by means of an underimpedance protection.

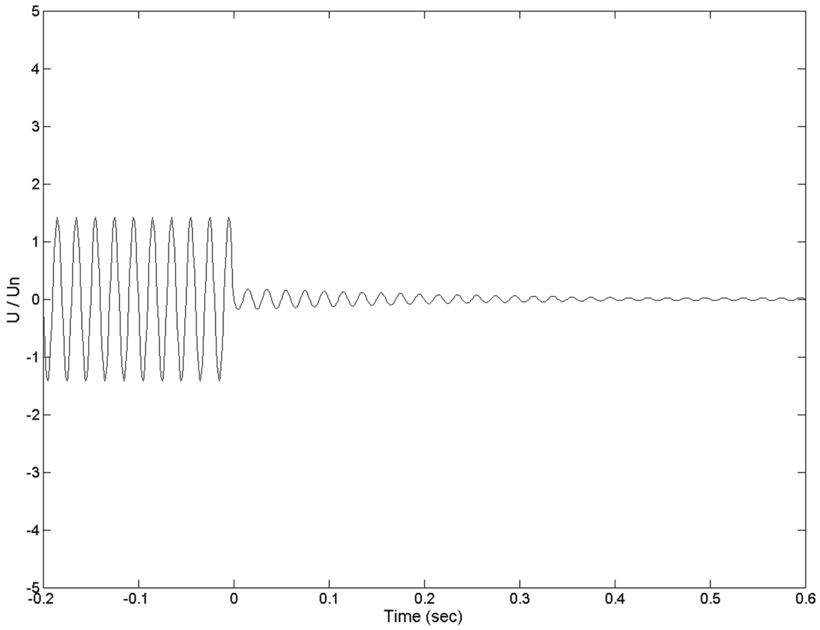


Figure 415: Short-circuit voltage waveform, fault occurs at time 0 seconds

In a typical impedance trajectory during a short circuit, the fault impedance remains inside the impedance circle for a longer time, in which case the underimpedance protection provides longer tripping delay times to maintain the time selectivity.

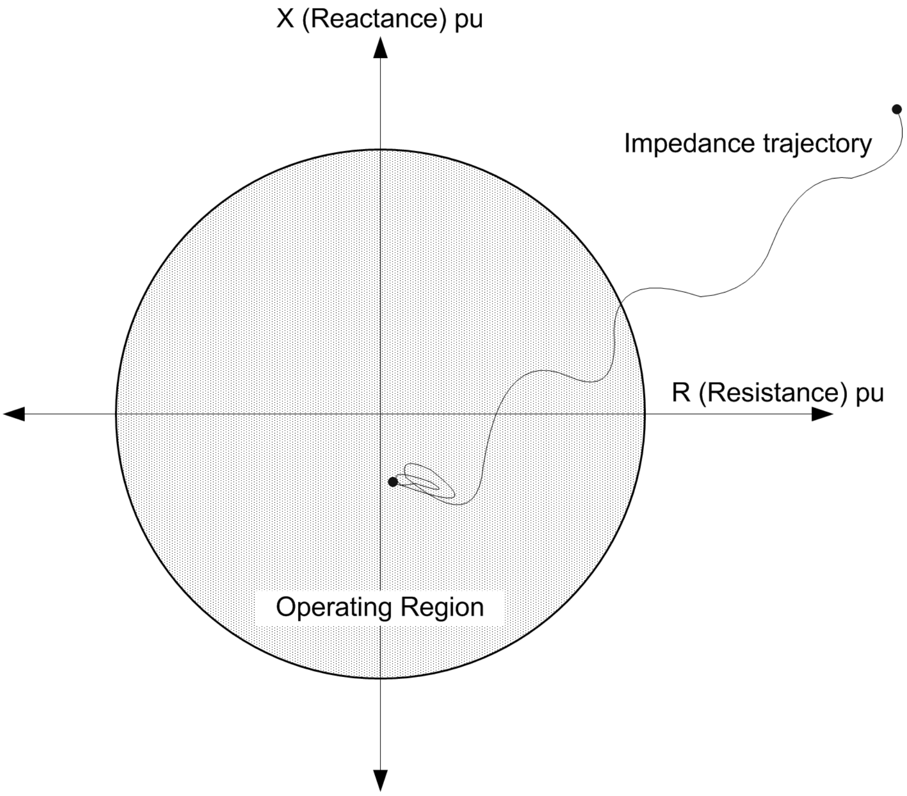


Figure 416: Typical impedance trajectory during a short circuit.

Underimpedance protection for transformers

The underimpedance function is used as a short circuit protection instead of the overcurrent protection. It is also used as a backup to the differential protection of transformers.

The voltage and current phasors are measured with the VTs and CTs connected on the HV side of the transformer.

The phase and current shifts due to transformer D/Y connections and other factors complicate the settings for the faults in the secondary winding (as seen from the IED), and detailed calculations are necessary for a good coverage.

The *Polar reach* setting is set to a value equal to 150 percent of the transformer short circuit impedance. The setting also provides a backup protection for the busbar and feeder faults on the HV side.

Underimpedance protection for generators

The underimpedance protection is set to protect the zone between the generator windings and the generator side windings of the step-up transformer. The function mainly protects the generator bus, the low-voltage part of the step-up transformer and a part of the stator winding against any short circuits.

The voltages should be measured from the generator terminals and the phase currents from the neutral point of the generator.

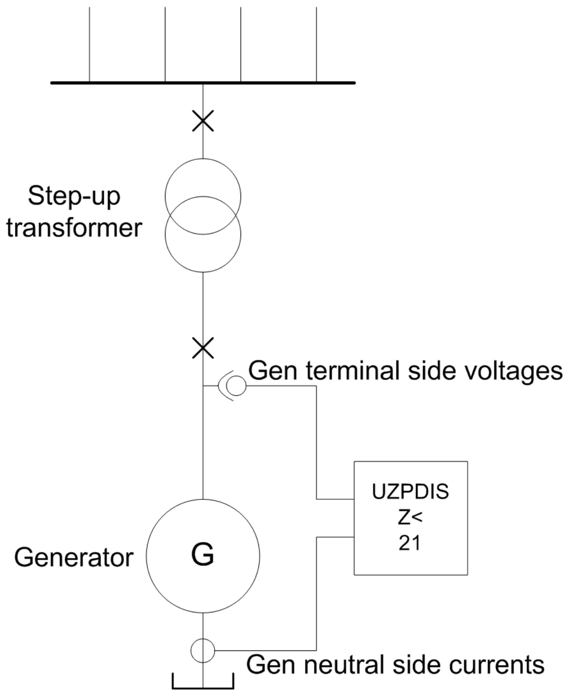


Figure 417: Current and voltage signals for underimpedance protection.

To prevent malfunctioning of the underimpedance protection in case of nearby faults, the *Polar reach* setting is set to a value equal to 70 percent of the step-up transformer short circuit impedance.

In directly connected machines where the impedance towards the network is limited only by the lines or bus bars, it must be secured that the function does not cause any selectivity problems. In such cases, it is recommended to use the voltage-dependent overcurrent protection instead of the underimpedance protection.

Function blocking guidelines

The operation of the underimpedance protection must be restrained if the voltage in one or more phases suddenly drops close to zero without any significant change in the current observed at the same time. This situation is considered as a fuse failure or a miniature circuit breaker operation in the voltage transformer secondary circuit. The voltage drop could cause an unwanted operation of the function block since the calculated impedance could fall below the set operating limit even if there is no actual fault in the primary system.

The blocking operation is provided by an external function block, the fuse failure supervision SEQRFUF, whose output is connected to the BLOCK input of UZPDIS.

4.7.3.7 Signals

Table 805: UZPDIS Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three-phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three-phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timer

Table 806: UZPDIS Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started

4.7.3.8 Settings

Table 807: UZPDIS Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Polar reach	1 - 6000	% Zb	1	7	Impedance start value, i.e. radius of impedance circle
Operate delay time	0.04 - 200.00	s	0.01	0.20	Operate delay time

Table 808: UZPDIS Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Impedance Meas mode	1Phase-phase 3Phase-phase	-	-	3Phase-phase	Select voltage and currents for impedance calculation
Phase Sel for Z Clc	AB BC CA	-	-	AB	Select ph/ ph-ph voltages for Impedance calculation

Table 809: UZPDIS Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On

Table 810: UZPDIS Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Measurement mode	DFT Peak-to-Peak	-	-	DFT	Selected measurement mode for phase currents
Reset delay time	0.00 - 60.00	s	0.01	0.02	Reset delay time

4.7.3.9 Measured values

Table 811: UZPDIS Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0.0	Current amplitude (DFT) phase A
I_AMPL_B	REAL	0.0	Current amplitude (DFT) phase B
I_AMPL_C	REAL	0.0	Current amplitude (DFT) phase C
I_PTOP_A	REAL	0.0	Current amplitude (PTOP) phase A
I_PTOP_B	REAL	0.0	Current amplitude (PTOP) phase B
I_PTOP_C	REAL	0.0	Current amplitude (PTOP) phase C
I_ANGL_A	REAL	0.0	Current phase angle phase A
I_ANGL_B	REAL	0.0	Current phase angle phase B
I_ANGL_C	REAL	0.0	Current phase angle phase C
U_AMPL_AB	REAL	0.0	Phase-to-phase A-B voltage amplitude
U_AMPL_BC	REAL	0.0	Phase-to-phase B-C voltage amplitude
U_AMPL_CA	REAL	0.0	Phase-to-phase C-A voltage amplitude
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate outputs
BLK_ST	BOOLEAN	0	Block signal for start outputs
FR_TIMER	BOOLEAN	0	Freeze signal for timer

4.7.3.10 Monitored data

Table 812: UZPDIS Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
Z_AMPL_AB	REAL	-	pu	Phase-to-phase A-B impedance amplitude
Z_AMPL_BC	REAL	-	pu	Phase-to-phase B-C impedance amplitude
Z_AMPL_CA	REAL	-	pu	Phase-to-phase C-A impedance amplitude
START_DUR	REAL	-	%	Ratio of start time / operate time (in %)

4.7.3.11 Technical data

Table 813: UZPDIS Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±3.0% of the set value or ±0.2% × Z_b
Start time	Typically 25 ms (±15 ms)
Reset time	<50 ms
Reset ratio	Typically 1.04
Retardation time	<40 ms
Operate time accuracy in definite-time mode 1)2)	±1.0% of the set value or ±20 ms

1) Fn = 50 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.7.3.12 Technical revision history

Table 814: UZPDIS technical revision history

Technical revision	Change
B	Inputs BLOCK, BLK_OPR, BLK_ST, FR_TIMER and outputs OPERATE and START are made visible in the Signal Matrix tool (SMT) of PCM600

4.8 Power protection

4.8.1 Reverse power/directional overpower protection DOPPDPR

4.8.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEE C37.2 device number
Reverse power/directional overpower protection	DOPPDPR	P>	32R/32O

4.8.1.2 Function block

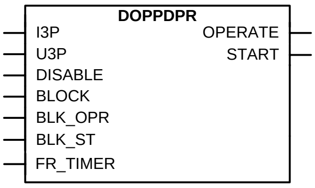


Figure 418: Function block

4.8.1.3 Functionality

The reverse power/directional overpower protection DOPPDPR can be used for generator protection against delivering an excessive power beyond the generator's capacity to the grid, against the generator running like a motor, against the motor running like a generator and protecting a motor which consumes more reactive power due to loss of field. DOPPDPR can also be used in feeder protection for indicating overload on the distribution system to indicate that a customer is supplying power into the grid and for protecting the transformer from delivering an excessive load.

DOPPDPR starts and operates when the measured power exceeds the set limit and in a specified direction. The operate time characteristics are according to definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, timer or the function itself, if desired.

4.8.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the reverse power/directional overpower protection protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

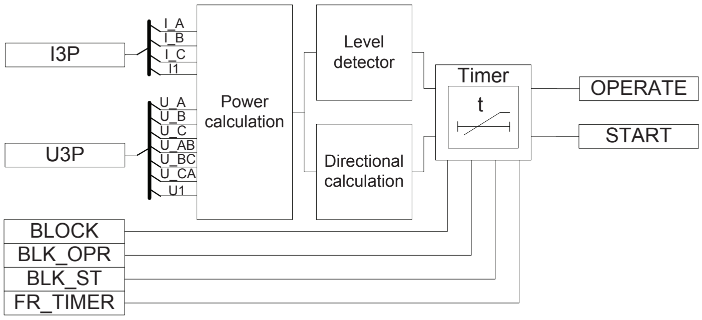


Figure 419: Functional module diagram

Power calculation

This module calculates the apparent power based on the selected voltages and currents. The *Measurement mode* setting determines which voltages and currents are used. It is also possible to use positive-sequence components for calculating the apparent power which makes the determination of power insensitive to a possible asymmetry in currents or voltages and corresponds to the real load on the prime mover of the generator.

Table 815: Voltages and currents used in apparent power calculation

Measurement mode	Voltages and currents used in power calculation
PhsA, PhsB, PhsC	U_A, U_B, U_C, I_A, I_B, I_C
Arone	U_AB, U_BC, I_A, I_C
Pos Seq	{ U_A, U_B, U_C } or { U_AB, U_BC, U_CA } and I_A, I_B, I_C
PhsAB	U_AB, I_A, I_B
PhsBC	U_BC, I_B, I_C
PhsCA	U_CA, I_C, I_A
PhsA	U_A, I_A
PhsB	U_B, I_B
PhsC	U_C, I_C

If all three phase voltages and phase currents are fed to the IED, the positive-sequence alternative is recommended.

The calculated powers S, P and Q and the power factor angle PF_ANGL are available in the monitored data view.

Level detector

The level detector compares the magnitude of the measured apparent power to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector sends an enabling signal to the timer module.

Directional calculation

The directional calculation module monitors the direction of the apparent power. When the apparent power flow is in the operating area, the module sends the enabling signal to the timer module. The directional operation can be selected with the combination of the settings *Directional mode* and *Power angle*. The selectable options for the *Directional mode* setting are "Forward" and "Reverse". The *Power angle* setting can be used to set the power direction between the reactive and active power.

A typical error is, for example, that the VT or CT poles are wrongly connected. This is seen as a power flow opposite to that of the intended direction. The *Pol Reversal* setting can be used to correct the situation. By setting the value to "Yes", the measured apparent power is turned 180 degrees.

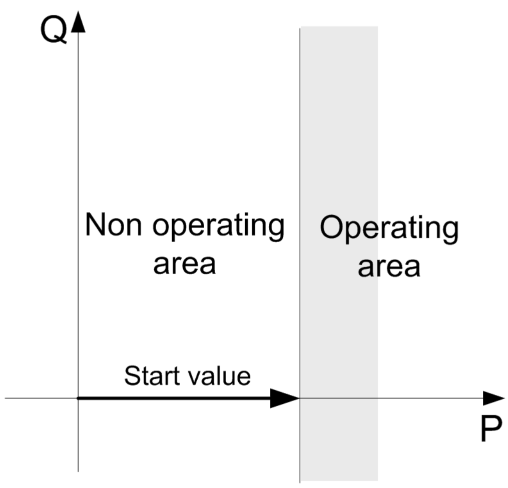


Figure 420: Operating characteristics with the Start Value setting, the Power angle setting being 0 and Directional mode "Forward"

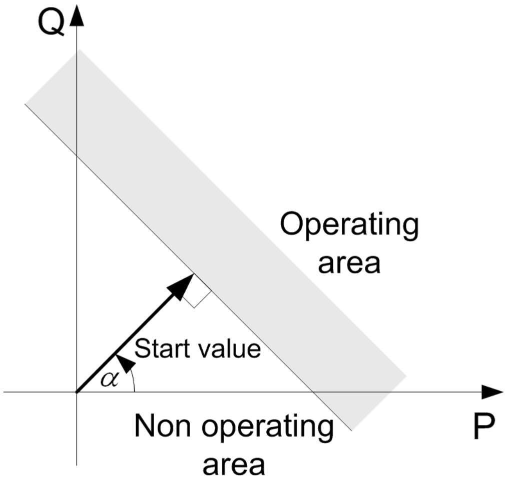


Figure 421: Operating characteristics with the Start Value setting, Power angle (α) being +45 and Directional mode "Forward"

Timer

Once activated, the timer activates the START output. The time characteristics are according to DT. When the operation timer has reached the value of *Operate delay time*, the OPERATE output is activated. If a drop-off situation happens, that is, the value of power drops below *Start value* before the operate delay is exceeded, the timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time (DT). The value is available in the monitored data view.

The binary input BLOCK can be used to block the module. The activation of the BLOCK input deactivates all the outputs and resets the internal timer. The binary input BLK_ST can be used to block the START output. The binary input BLK_OPR can be used to block the OPERATE output. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

The angle values available at the input monitor data view are in radians.

4.8.1.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.8.1.6 Application

DOPPDPR is used to provide protection against an excessive power flow in the set operating direction. Main application is the protection of generators and turbines. It can also be used in feeder protection applications, for example, the ring network.

DOPPDPR in the forward direction can be used to protect the generators or motors from delivering or consuming excess power. For example, the generator overpower protection can be used to shed a noncritical feeder load or to start parallel generators. A synchronous motor may start consuming more reactive power in case of loss of excitation, in which case the forward overpower protection is used to detect such condition.

The reverse power/directional overpower protection function has many applications when used as a reverse power protection. A generator in a power plant converts mechanical energy to electrical energy. Sometimes the mechanical power from a prime mover may decrease to a limit that it does not cover the internal losses. The synchronous generator becomes a synchronous motor and starts importing power from the system. The effect of a generator acting as a motor implies no risk to the machine but can cause damage to the prime mover. The extent of the damage depends on the type of the prime mover.

Steam turbines become overheated easily if the steam flow drops too low or if the steam ceases to flow through the turbine. The break of a main steam pipe, damage to one or more blades in the steam turbine or an inadvertent closing of the main stop valves are typical causes for the low steam flow. The steam turbines of turbo generators can be protected during a low steam flow with the overpower protection operating in reverse direction. Hydroturbines tolerate reverse power much better than steam turbines do. There is a risk that the turbine runner moves axially and touches stationary parts. They are not always strong enough to withstand the associated stresses.

A hydroturbine that rotates in water with the closed wicket gates draws about 10 percent of the rated power from the rest of the power system if the intake is blocked due to ice, snow, branches or leaves. A complete blockage of the intake may cause cavitations. If there is only air in the hydroturbine, the power demand drops to about 3 percent. The risk of damages to the hydroturbines can justify the reverse operation of the overpower protection in unattended plants.

Whenever a low value of the reverse power setting is required, an underpower protection should also be used in conjunction with DOPPDPR. The limit depends on the CT and VT accuracy.

Diesel engines should have overpower protection in reverse direction. The generator takes about 15 percent or more of its rated power from the system. A stiff engine may require 25 percent of the rated power to motor it. A well run engine may need no more than 5 percent. It is necessary to obtain information from the engine manufacturer and to measure the reverse power during commissioning.

Reverse overpower can also act as an alternative for an under excitation protection in case of small generators. If the field excitation is reduced, the generator may start importing the reactive power, making the generator run as an asynchronous generator. A synchronous generator is not designed to work asynchronously and may become damaged due to heating in the damper windings or heating in the rotor due to slip frequency current.

When operated in reverse power direction, it can be used as an alarm if the power flowing from the industry is feeding the grid, which may not be desired as per the rules and regulations of the utility owning the grid.

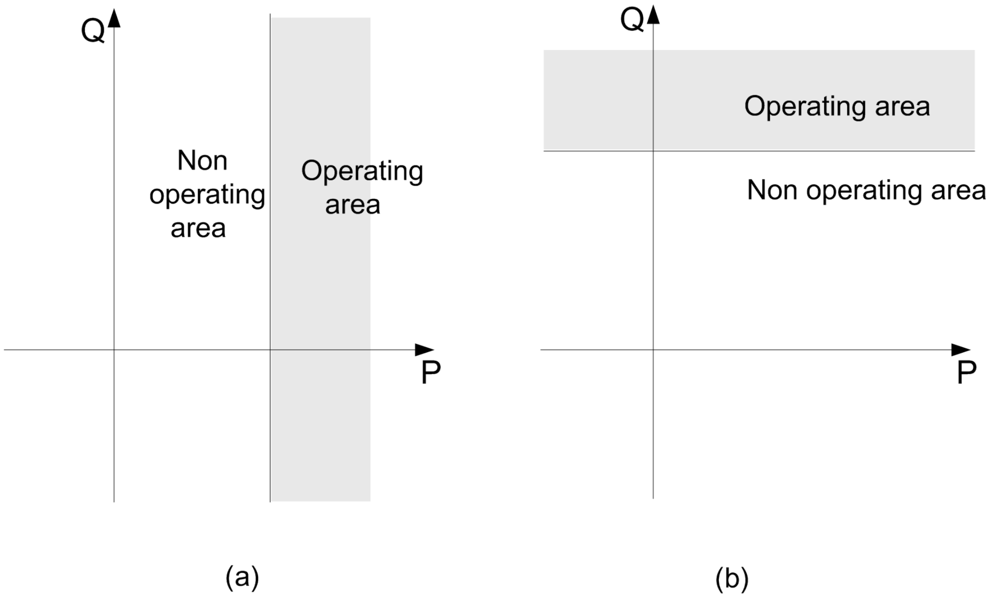


Figure 422: Forward active overpower characteristics and forward reactive overpower characteristics

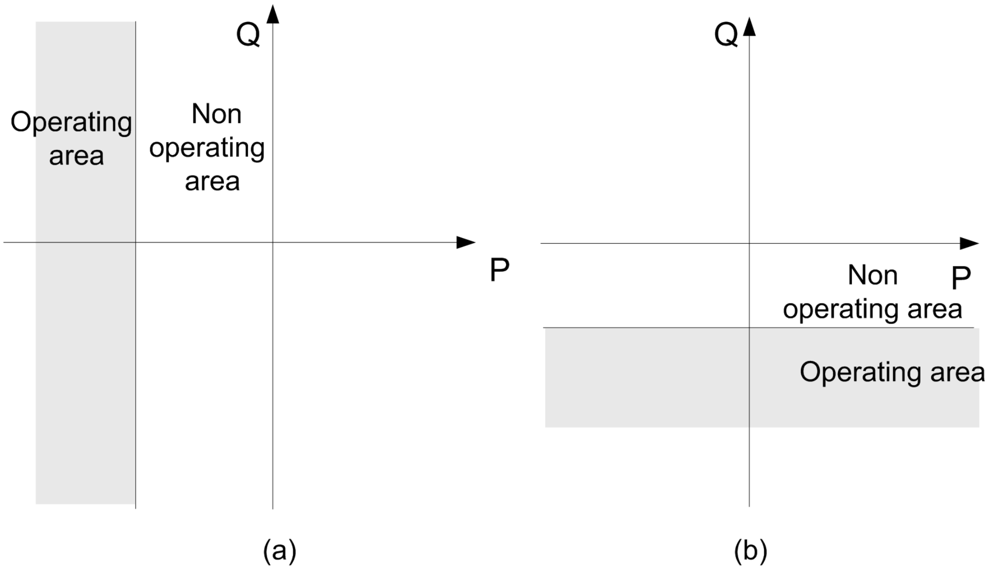


Figure 423: Reverse active overpower characteristics and reverse reactive overpower characteristics

4.8.1.7 Signals

Table 816: DOPPDPR Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
U3P	GROUP SIGNAL	-	Group signal for voltage inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timer

Table 817: DOPPDPR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started
S	REAL	Apparent power
P	REAL	Active power
Q	REAL	Reactive power
PF_ANGL	REAL	Angle between apparent power and active power

4.8.1.8 Settings

Table 818: DOPPDPR Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Directional mode	Forward Reverse	-	-	Forward	Directional mode
Start value	0.01 - 2.00	pu	0.01	1.00	Start value
Power angle	-90.00 - 90.00	Deg	0.01	0.00	Adjustable angle for power
Operate delay time	0.04 - 300.00	s	0.01	0.04	Operate delay time

Table 819: DOPPDPR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On

Table 820: DOPPDPR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Measurement mode	PhsA, PhsB, PhsC Arone Pos Seq PhsAB PhsBC PhsCA PhsA PhsB PhsC	-	-	Pos Seq	Selection of power calculation method
Reset delay time	0.00 - 60.00	s	0.01	0.02	Reset delay time
Pol reversal	No Yes	-	-	No	Reversing the definition of the positive power direction

4.8.1.9 Measured values

Table 821: DOPPDPR Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0.0	Current amplitude (DFT) phase A
I_AMPL_B	REAL	0.0	Current amplitude (DFT) phase B
I_AMPL_C	REAL	0.0	Current amplitude (DFT) phase C
I_ANGL_A	REAL	0.0	Current phase angle phase A
I_ANGL_B	REAL	0.0	Current phase angle phase B
I_ANGL_C	REAL	0.0	Current phase angle phase C
I1_AMPL	REAL	0.0	Positive sequence current amplitude
Table continues on next page			

Name	Type	Default	Description
I1_ANGL	REAL	0.0	Positive sequence current angle
U_AMPL_A	REAL	0.0	Phase A-to-earth voltage amplitude
U_AMPL_B	REAL	0.0	Phase B-to-earth voltage amplitude
U_AMPL_C	REAL	0.0	Phase C-to-earth voltage amplitude
U_ANGL_A	REAL	0.0	Phase A-to-earth voltage phase angle
U_ANGL_B	REAL	0.0	Phase B-to-earth voltage phase angle
U_ANGL_C	REAL	0.0	Phase C-to-earth voltage phase angle
U_AMPL_AB	REAL	0.0	Phase-to-phase A-B voltage amplitude
U_AMPL_BC	REAL	0.0	Phase-to-phase B-C voltage amplitude
U_AMPL_CA	REAL	0.0	Phase-to-phase C-A voltage amplitude
U_ANGL_AB	REAL	0.0	Phase-to-phase A-B voltage phase angle
U_ANGL_BC	REAL	0.0	Phase-to-phase B-C voltage phase angle
U_ANGL_CA	REAL	0.0	Phase-to-phase C-A voltage phase angle
U1_AMPL	REAL	0.0	Positive sequence voltage amplitude
U1_ANGL	REAL	0.0	Positive sequence voltage phase angle
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timer

4.8.1.10 Monitored data

Table 822: DOPPDPR Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
S	REAL	-	MVA	Apparent power
P	REAL	-	MW	Active power
Q	REAL	-	MVAr	Reactive power
PF_ANGL	REAL	-	deg	Angle between apparent power and active power
START_DUR	REAL	-	%	Ratio of start time / operate time

4.8.1.11 Technical data

Table 823: DOPPDPR Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±3% of the set value or ±0.002 × S_n
Start time[1)2)]	Typically 20 ms (±15 ms)
Reset time	<40 ms
Reset ratio	Typically 0.94
Retardation time	<45 ms
Operate time accuracy	±1.0% of the set value of ±20 ms

1) $U = U_n$, F_n = 50 Hz, results based on statistical distribution of 1000 measurements.
2) Includes the delay of the signal output contact.

4.8.1.12 Technical revision history

Table 824: DOPPDPR technical revision history

Technical revision	Change
B	Change in function IEC 60617 and ANSI symbol

4.8.2 Underpower protection DUPPDPR

4.8.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Underpower protection	DUPPDPR	P<	32U

4.8.2.2 Function block

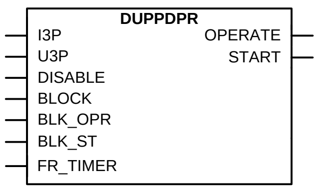


Figure 424: Function block

4.8.2.3 Functionality

The underpower protection DUPPDPR is used for protecting generators and prime movers against the effects of very low power outputs or reverse power condition.

DUPPDPR operates when the measured active power falls below the set value. The operating characteristics are according to definite time DT.

DUPPDPR contains a blocking functionality. It is possible to block the function outputs, timer or the function itself, if desired.

4.8.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the underpower protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

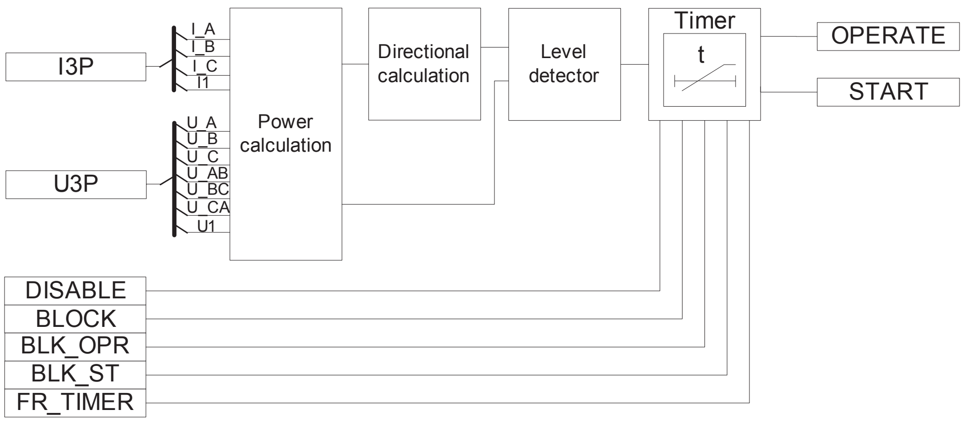


Figure 425: Functional module diagram

Power calculation

The power calculation calculates the apparent power based on the selected voltage and current measurements as described in Table 825. The *Measurement mode* setting determines which voltage and current measurements are to be used.

It is also possible to use positive-sequence components for calculating apparent power, which makes the determination of power insensitive to the possible asymmetry in currents or voltages and corresponds to the real load of the prime mover of the generator.

Table 825: Measured apparent power

Measurement mode setting	Voltages and currents used in power calculation
"PhsA", "PhsB", "PhsC"	U_A,U_B, U_C, I_A, I_B, I_C
"Arone"	U_AB, U_BC, I_A, I_C
"Pos Seq"	(U_A, U_B, U_C) or (U_AB, U_BC, U_CA) and I_A, I_B, I_C
"PhsAB"	U_AB, I_A, I_B
"PhsBC"	U_BC, I_B, I_C
"PhsCA"	U_CA, I_C, I_A
"PhsA"	U_A, I_A
"PhsB"	U_B, I_B
"PhsC"	U_C, I_C

If all three phase voltages and phase currents are fed to the IED, the positive-sequence alternative is recommended (default).

Depending on the set *Measurement mode*, the power calculation calculates active power, reactive power and apparent power values from the available set of measurements. The calculated powers S, P, Q and the power factor angle, PF_ANGL, are available in the monitored data.

Directional calculation

The directional calculation determines the direction of the measured power. The measured power is considered to be in the forward direction if the active power is positive, else it is considered to be in the reverse direction.

If the polarity of the measured power is opposite to normal, the correction can be done by the *Pol reversal* setting to "Yes", which rotates the apparent power by 180 degrees.

Level detector

The level detector compares the calculated value of the active power with a set *Start value*. If the calculated value of the active power falls below *Start value* in the forward direction or if the measured power is in the reverse direction, the level detector enables the timer module.

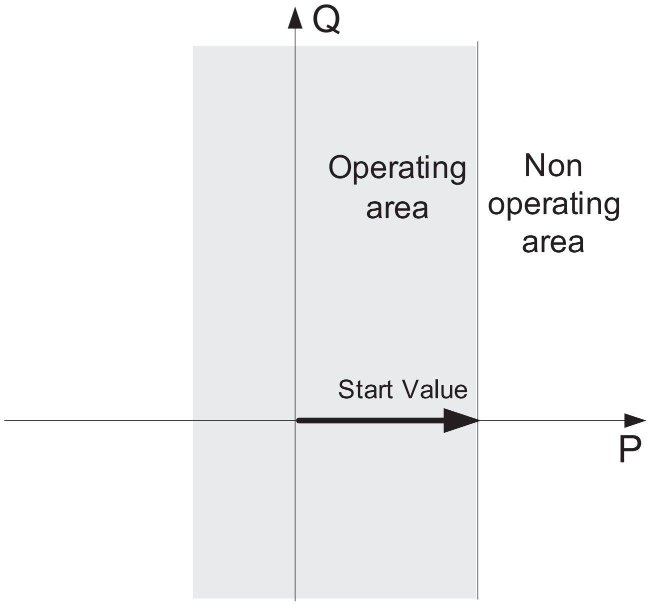


Figure 426: Operating characteristics of DUPPDPR with setting Start value

Timer

Once activated, the timer activates the START output. The time characteristics are according to DT. When the operation timer has reached the value of *Operate delay time*, the OPERATE output is activated. If a drop-off situation happens, that is, if the underpower condition disappears before the operation delay is exceeded, the timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

The timer calculates the START_DUR value which indicates the percentage of the time elapsed since the activation of the START output with respect to *Operate delay time*. The value is available in the monitored data.

The DISABLE input can be used to coordinate the correct operation during the generator startup situation. By activating the DISABLE signal, both the START and OPERATE outputs are blocked. Once the DISABLE signal is deactivated, the timer remains blocked for an additional time duration as set through the setting *Disable time*.

The binary input BLOCK can be used to block the module. The activation of the BLOCK input deactivates all binary outputs and reset the internal timer. The binary input BLK_ST can be used to block the START signal. The binary input BLK_OPR can be used to block the OPERATE signal. The operation timer counting can be frozen on the prevailing value by the activation of the FR_TIMER input.

4.8.2.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

4.8.2.6 Application

The task of a generator in a power plant is to convert mechanical energy into electrical energy. Sometimes the mechanical power from the prime mover may decrease so much that it does not cover the internal losses. The task of an underpower protection is to protect the generator from very low power output conditions.

Steam turbines easily become overheated if the steam flow becomes too low or if the steam ceases to flow through the turbine. Hydro turbine of the Kaplan type may be damaged due to the fact that the turbine blade surf on the water and set up axial pressure on the bearing. Diesel engines may be damaged due to insufficient lubrication.

If the generator size is very large, it is uneconomical to continue running it with low generated power. In the reverse power condition, large generators draw a considerable amount of power from the rest of the system to feed their internal losses. Hence, it is desirable to disconnect the generator in such situations.

In case of the parallel-connected generators, for example, the load of one generator may be so low that it is better to disconnect it and let the remaining generators feed the network.

Where a low value of power setting is required, for example less than 2%, the correction parameters should be used to compensate for the measuring errors. The manufacturer of the measuring devices is to be contacted for information on the measuring errors. If the measuring errors are not compensated for, the underpower setting should not be lower than the sum of the current-measuring and voltage-measuring errors.
For example, if the error of the current-measuring device is 2% and that of the voltage-measuring device is 1%, the minimum setting is (2 + 1)% = 3%.

4.8.2.7 Signals

Table 826: DUPPDPR Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
U3P	GROUP SIGNAL	-	Group signal for voltage inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timer
DISABLE	BOOLEAN	0	Signal to block the function during generator startup

Table 827: DUPPDPR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started
S	REAL	Apparent power
P	REAL	Active power
Q	REAL	Reactive power
PF_ANGL	REAL	Angle between apparent power and active power

4.8.2.8 Settings

Table 828: DUPPDPR Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	0.01 - 2.00	pu	0.01	0.10	Start value
Operate delay time	0.04 - 300.00	s	0.01	0.04	Operate delay time
Disable time	0.00 - 60.00	s	0.01	0.00	Additional wait time after CB closing

Table 829: DUPPDPR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On

Table 830: DUPPDPR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Measurement mode	PhsA, PhsB, PhsC Arone Pos Seq PhsAB PhsBC PhsCA PhsA PhsB PhsC	-	-	Pos Seq	Selection of power calculation method
Reset delay time	0.00 - 60.00	s	0.01	0.02	Reset delay time
Pol reversal	No Yes	-	-	No	Reversing the definition of the positive power direction

4.8.2.9 Measured values

Table 831: DUPPDPR Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0.0	Current amplitude (DFT) phase A
I_AMPL_B	REAL	0.0	Current amplitude (DFT) phase B
I_AMPL_C	REAL	0.0	Current amplitude (DFT) phase C
I_ANGL_A	REAL	0.0	Current phase angle phase A
I_ANGL_B	REAL	0.0	Current phase angle phase B
I_ANGL_C	REAL	0.0	Current phase angle phase C
I1_AMPL	REAL	0.0	Positive sequence current amplitude
I1_ANGL	REAL	0.0	Positive sequence current angle
U_AMPL_A	REAL	0.0	Phase A-to-earth voltage amplitude
U_AMPL_B	REAL	0.0	Phase B-to-earth voltage amplitude
U_AMPL_C	REAL	0.0	Phase C-to-earth voltage amplitude
U_ANGL_A	REAL	0.0	Phase A-to-earth voltage phase angle
U_ANGL_B	REAL	0.0	Phase B-to-earth voltage phase angle
U_ANGL_C	REAL	0.0	Phase C-to-earth voltage phase angle
U_AMPL_AB	REAL	0.0	Phase-to-phase A-B voltage amplitude
U_AMPL_BC	REAL	0.0	Phase-to-phase B-C voltage amplitude
U_AMPL_CA	REAL	0.0	Phase-to-phase C-A voltage amplitude
U_ANGL_AB	REAL	0.0	Phase-to-phase A-B voltage phase angle
U_ANGL_BC	REAL	0.0	Phase-to-phase B-C voltage phase angle
U_ANGL_CA	REAL	0.0	Phase-to-phase C-A voltage phase angle
U1_AMPL	REAL	0.0	Positive sequence voltage amplitude
U1_ANGL	REAL	0.0	Positive sequence voltage phase angle
Table continues on next page			

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block signal for all binary outputs
BLK_OPR	BOOLEAN	0	Block signal for operate output
BLK_ST	BOOLEAN	0	Block signal for start output
FR_TIMER	BOOLEAN	0	Freeze signal for timer
DISABLE	BOOLEAN	0	Signal to block the function during generator startup

4.8.2.10 Monitored data

Table 832: DUPPDPR Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started
S	REAL	-	MVA	Apparent power
P	REAL	-	MW	Active power
Q	REAL	-	MVAr	Reactive power
PF_ANGL	REAL	-	deg	Angle between apparent power and active power
START_DUR	REAL	-	%	Ratio of start time / operate time

4.8.2.11 Technical data

Table 833: DUPPDPR Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$ ±3% of the set value or $\pm 0.002 \times S_n$
Start time 1)2)	Typically 20 ms (±15 ms)
Reset time	<40 ms
Reset ratio	Typically 0.94
Retardation time	<45 ms
Operate time accuracy	±1.0% of the set value of ±20 ms

1) $U = U_n$, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.
2) Includes the delay of the signal output contact.

4.8.3 Directional reactive power undervoltage protection (Q→& U<) DQPTUV

4.8.3.1 Identification

Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional reactive power undervoltage protection	DQPTUV	Q>-->,3U<	32Q,27

4.8.3.2 Function block

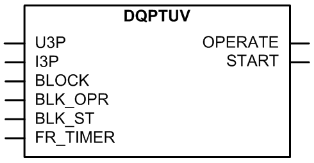


Figure 427: Function block

4.8.3.3 Functionality

Directional reactive power and under voltage protection DQPTUV is used at the grid connection point of distributed power generating units as stipulated by various grid codes to prevent voltage collapse of the grid due to network faults. DQPTUV measures phase voltages and current at the grid connection point. The generating facility is disconnected from the network with a specific time delay if all phase voltages decrease and remain at or below the specified limit and if reactive power is simultaneously consumed (that is, under-excitation operation).

DQPTUV contains a blocking functionality to block function outputs, timer or the function itself.

4.8.3.4 Operation principle

The *Operation* setting is used to enable or disable the function. When "On" is selected, the function is enabled and when "Off" is selected, the function is disabled.

The operation of DQPTUV can be described using a module diagram. All modules in the diagram are explained in the next sections.

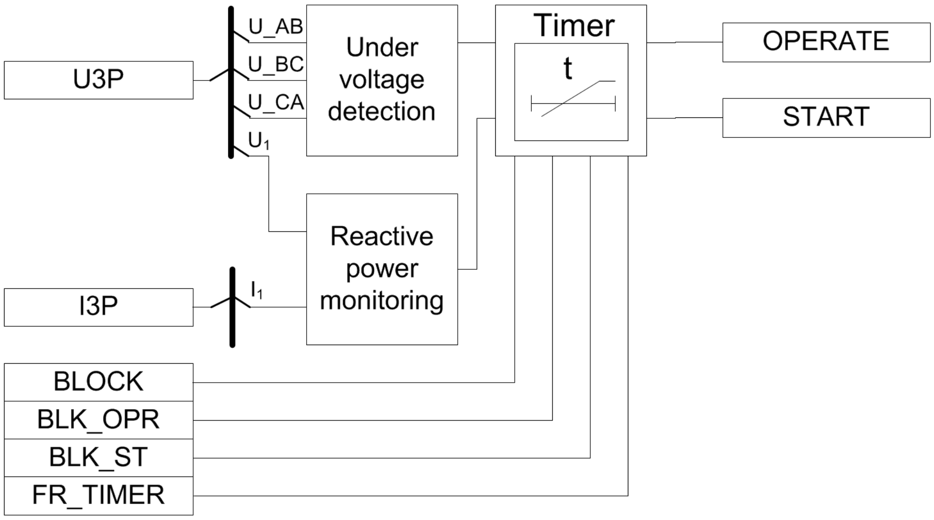


Figure 428: Functional module diagram

Under voltage detection

Under voltage detection compares the fundamental frequency component of all three phase-to-phase voltages with the set *Voltage start value*. When all three phase-to-phase voltages are lower than the set *Voltage start value*, the Under voltage detection module sends an enable signal to the Timer indicating an under voltage condition at the grid connection point.

Reactive power monitoring

This module calculates and monitors the reactive power based on positive sequence current and voltage. The usage of a positive sequence component makes the determination of power insensitive to a possible asymmetry in current and voltages. When the reactive power exceeds *Min reactive power* and flows in the operating area, the module sends an enable signal to the Timer indicating that the reactive power is being consumed at the grid connection point. A slight tilt in the curve can be obtained by the setting *Pwr sector reduction*.

To avoid false tripping, reactive power calculation is blocked if the magnitude of positive sequence current is less than the set *Min PS current*.

The magnitude of calculated reactive power Q is available in the monitored data view.

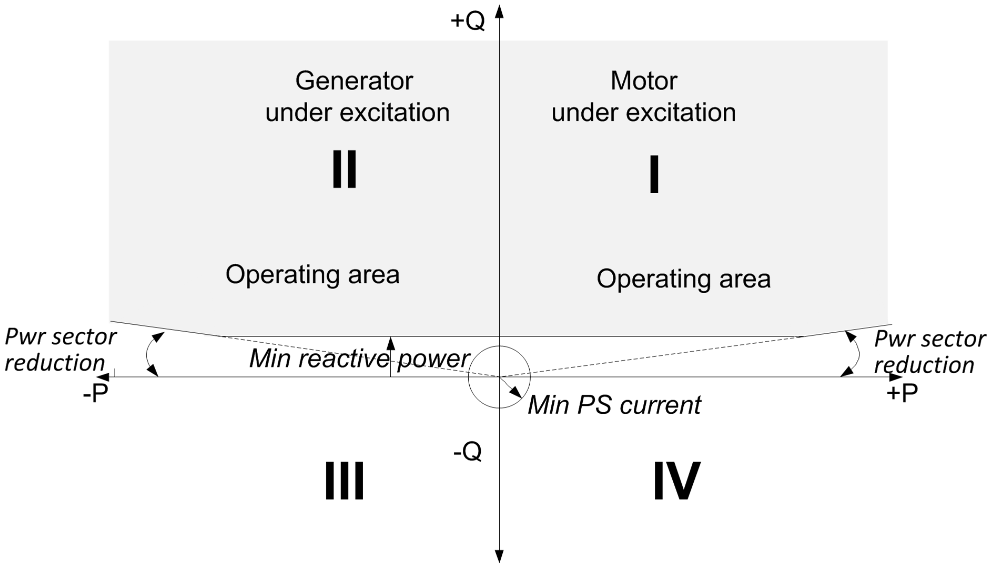


Figure 429: Operating area of DQPTUV function

In the above figure, the power directions are defined as follows.
Quadrant II = generator produces active power, but draws reactive power (under-excited).
Quadrant III = generator produces both active and reactive power.

The power direction can be reversed by setting *Pol reversal* to "True".

Timer

Once activated by both Under voltage detection and Reactive power monitoring module, the Timer activates the `START` output. The Timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time* the `OPERATE` output is activated. If the fault disappears before the module operates, the resetting happens instantaneously.

The Timer calculates the start duration value "START_DUR" which indicates the percentage ratio of the start situation and the set operate time. The value is available through the Monitored data view.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets internal timers. The binary input `BLK_ST` can be used to block the start signals. The binary input `BLK_OPR` can be used to block both the operation signals. The operation timer counting can be frozen to the prevailing value by activating the `FR_TIMER` input.

4.8.3.5 Base value

In this function block, some of the settings are in per unit (pu). These pu values are related to certain base values, for example, the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example, “Phase Grp 1”, “Phase Grp 2” and “Phase Grp 3”. One of the groups should be selected to use with the *Base value Sel phase* settings.

4.8.3.6 Application

Use of distributed power generating units (PGU) is rapidly increasing due to liberalized markets (deregulation) and the global trend to use more renewable sources of energy. As the capacity of these generating units increase, they are connected directly to medium voltage networks. Until recent years it had been a practice by grid operators to disconnect the distributed power generator from the network in case of fault in the network.

If this causes considerable loss of power generation, this may affect the system’s ability to recover. Therefore, to ensure power system stability, various grid codes have revised their requirements and requires that the distributed PGUs have to make a contribution to network support. In case of faults, the distributed power generator should not be disconnected from the network. Instead, the PGU must contribute to voltage stability to maintain the security and reliability of the network operation. However, if the generators stay connected, it must be ensured that they do not take reactive power from the network because this may lead to collapse of the grid. DQPTUV is used for detecting such situations, that is, simultaneous undervoltage and reactive power (under excited generators) and trip the generators.

The protection function DQPTUV is developed considering various grid codes. For example, in the German transmission code 2007 it is requested that if all three phase-to-phase voltage at the grid connection point decrease and remain at and below a value of 85 percentage of the rated and if reactive power is simultaneously consumed at the grid connection point (under-excited operation), the generating facility must be disconnected from the network with a time delay of 0.5 seconds. The disconnection must take place at the generator circuit breaker.

It is recommended that two instances of DQPTUV are used for protection when several power generating units are operated in parallel and feeding to one common network grid, the first instance should be set to operate at 0.5 s, so as to disconnect the power generating unit. In case the expected results are not achieved, second instance set to operate between 1...1.5 s should trip the breaker at network connection point.

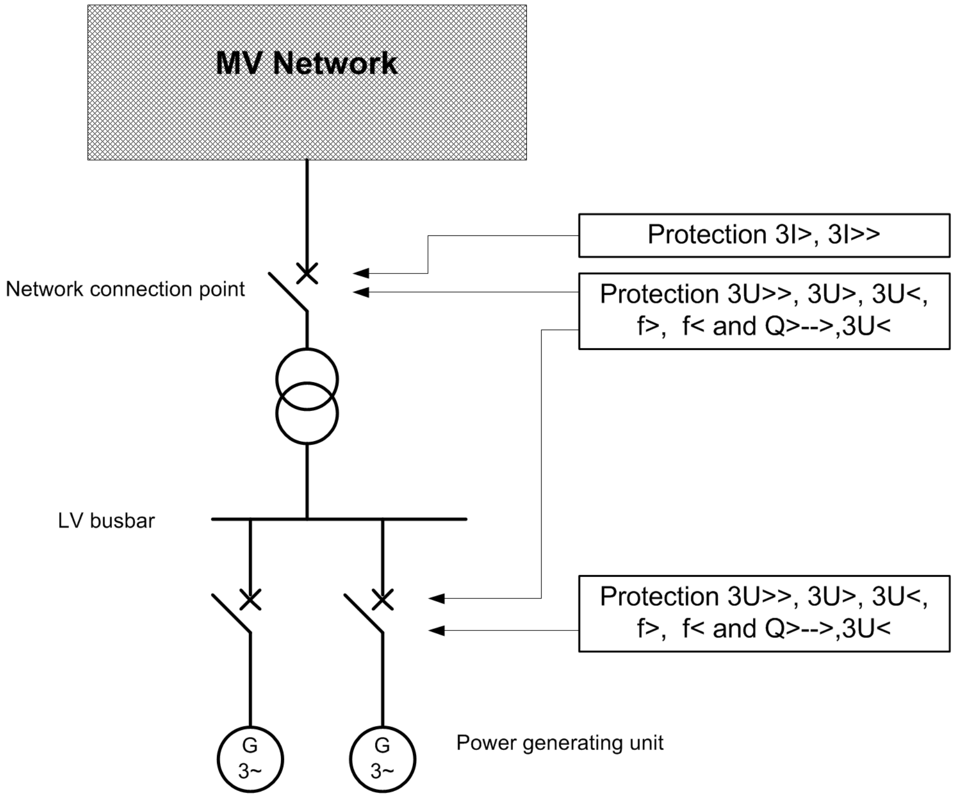


Figure 430: A typical distributed power generating unit connected to a grid

4.8.3.7 Signals

Table 834: DQPTUV Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current input
U3P	GROUP SIGNAL	-	Group signal for voltage input
BLOCK	BOOLEAN	0	Block all binary outputs and reset timer
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer count

Table 835: DQPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.8.3.8 Settings

Table 836: DQPTUV Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.20 - 1.20	pu	0.01	0.85	Start value for under voltage detection
Operate delay time	0.1 - 300.00	s	0.01	0.50	Operate delay time

Table 837: DQPTUV Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Pol reversal	FALSE TRUE	-	-	FALSE	Reverse the definition of the positive reactive power direction

Table 838: DQPTUV Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On

Table 839: DQPTUV Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Min reactive power	0.01 - 0.50	pu	0.01	0.05	Minimum reactive power needed for function to operate
Min PS current	0.02 - 0.20	pu	0.01	0.05	Minimum positive sequence current needed for reactive power calculation
Pwr sector reduction	0.0 - 10.0	Deg	1.0	3.0	Adjustable angle for power

4.8.3.9 Measured values

Table 840: DQPTUV Measured values

Name	Type	Default	Description
U_AMPL_AB	REAL	0.0	Voltage amplitude phase to phase AB
U_AMPL_BC	REAL	0.0	Voltage amplitude phase to phase BC
U_AMPL_CA	REAL	0.0	Voltage amplitude phase to phase CA
U1_REAL	REAL	0.0	Positive sequence voltage real part
U1_IMAG	REAL	0.0	Positive sequence voltage imaginary part
I1_AMPL	REAL	0.0	Positive sequence current amplitude
I1_REAL	REAL	0.0	Positive sequence current real part
I1_IMAG	REAL	0.0	Positive sequence current imaginary part
BLOCK	BOOLEAN	0	Block all binary outputs and reset timer
Table continues on next page			

Name	Type	Default	Description
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer count

4.8.3.10 Monitored data

Table 841: DQPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate
START	BOOLEAN	0=FALSE 1=TRUE	-	Start
Q	REAL	-	MVAr	Calculated positive sequence reactive power
START_DUR	REAL	-	%	Ratio of start time / operate time

4.8.3.11 Technical data

Table 842: DQPTUV Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$ Power: 1.5% or $0.002 \times Q_n$ (±1.5%) for power, PF -0.71...0.71 Voltage: ±1.5% of the set value or $\pm 0.002 \times U_n$
Start time [1)]	Typically 22 ms
Reset time	<40 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5 and so on

1) *Start value* = $0.05 \times S_n$, Reactive power before fault = 0.8 × *Start value*. Reactive power overshoot 2 times. Results based on statistical distribution of 1000 measurement.

4.9 Multipurpose analog protection MAPGAPC

4.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Multipurpose analog protection	MAPGAPC	MAP	MAP

4.9.2 Function block

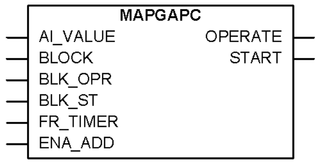


Figure 431: Function block

4.9.3 Functionality

The multipurpose analog protection function MAPGAPC is used as a general protection with many possible application areas as it has flexible measuring and setting facilities. The function can be used as an underprotection or overprotection with a settable absolute hysteresis limit. The function operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.9.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the multipurpose analog protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

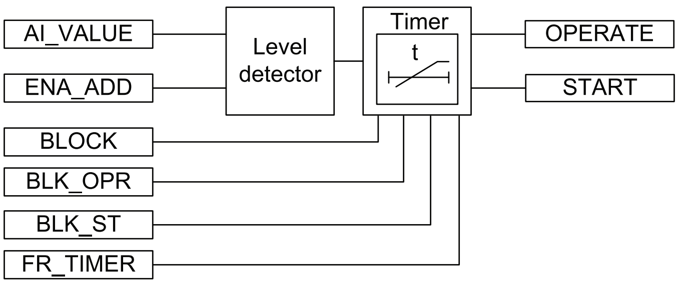


Figure 432: Functional module diagram

Level detector

The level detector compares `AI_VALUE` to the *Start value* setting. The *Operation mode* setting defines the direction of the level detector.

Table 843: Operation mode types

Operation Mode	Description
"Under"	If the input signal AI_VALUE is lower than the set value of the "Start value" setting, the level detector enables the timer module.
"Over"	If the input signal AI_VALUE exceeds the set value of the *Start value* setting, the level detector enables the timer module.

The *Absolute hysteresis* setting can be used for preventing unnecessary oscillations if the input signal is slightly above or below the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area. If the ENA_ADD input is activated, the threshold value of the internal comparator is the sum of the *Start value Add* and *Start value* settings. The resulting threshold value for the comparator can be increased or decreased depending on the sign and value of the *Start value Add* setting.

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated. If the starting condition disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

MAPGAPC can be blocked from the binary input BLOCK. The activation of the BLOCK input deactivates all outputs and resets internal timers. The start signals from the function can be blocked from the binary input BLK_ST. The operate signals from the function can be blocked from the binary input BLK_OPR. The operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input signal.

4.9.5 Application

The function block can be used for any general analog signal protection, either underprotection or overprotection. The setting range is wide, allowing various protection schemes for the function. Thus, the absolute hysteresis can be set to a value that suits the application.

The temperature protection using the RTD sensors can be done using the function block. The measured temperature can be fed from the RTD sensor to the function input that detects too high temperatures in the motor bearings or windings, for example. When the ENA_ADD input is enabled, the threshold value of the internal comparator is the sum of the *Start value Add* and *Start value* settings. This allows a temporal increase or decrease of the level detector depending on the sign and value of the *Start value Add* setting, for example, when the emergency start is activated.

If, for example, *Start value* is 100, *Start value Add* is 20 and the ENA_ADD input is active, the input signal needs to rise above 120 before MAPGAPC operates.

4.9.6 Signals

Table 844: MAPGAPC Input signals

Name	Type	Default	Description
AI_VALUE	REAL	0.0	Analog input value
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer
ENA_ADD	BOOLEAN	0	Enable start using added start value

Table 845: MAPGAPC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started signal

4.9.7 Settings

Table 846: MAPGAPC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	-10000.0 - 10000.0	-	0.1	0.0	Start value
Start value Add	-100.0 - 100.0	-	0.1	0.0	Added value to start value
Operate delay time	0.03 - 200.00	s	0.01	0.03	Operate delay time

Table 847: MAPGAPC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
Operation mode	Over Under	-	-	Over	Operation mode (1=Over;2=Under)

Table 848: MAPGAPC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Absolute hysteresis	0.01 - 100.00	-	0.01	0.10	Absolute hysteresis for operation
Reset delay time	0.00 - 60.00	s	0.01	0.00	Reset delay time

4.9.8 Measured values

Table 849: MAPGAPC Measured values

Name	Type	Default	Description
AI_VALUE	REAL	0.0	Analog input value
BLOCK	BOOLEAN	0	Block overall function
BLK_OPR	BOOLEAN	0	Block operate output
BLK_ST	BOOLEAN	0	Block start output
FR_TIMER	BOOLEAN	0	Freeze internal operate timer
ENA_ADD	BOOLEAN	0	Enable start using added start value

4.9.9 Monitored data

Table 850: MAPGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operated
START	BOOLEAN	0=FALSE 1=TRUE	-	Started signal
START_DUR	REAL	-	%	Start duration in percentage of the total operating time

4.9.10 Technical data

Table 851: MAPGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

4.9.11 Technical revision history

Table 852: MAPGAPC technical revision history

Technical revision	Change
B	• Change in function description available in PCM600 • Internal improvements
C	Correction in instance number appearing in PCM600

Section 5 Protection related functions

5.1 Three-phase inrush detector INRPHAR

5.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase inrush detector	INRPHAR	3I2f>	68

5.1.2 Function block

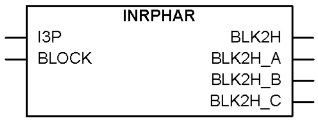


Figure 433: Function block

5.1.3 Functionality

The transformer inrush detection INRPHAR is used to coordinate transformer inrush situations in distribution networks.

Transformer inrush detection is based on the following principle: the output signal `BLK2H` is activated once the numerically derived ratio of second harmonic current I_2H and the fundamental frequency current I_1H exceeds the set value.

The operate time characteristic for the function is of definite time (DT) type.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

5.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of an inrush current detection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

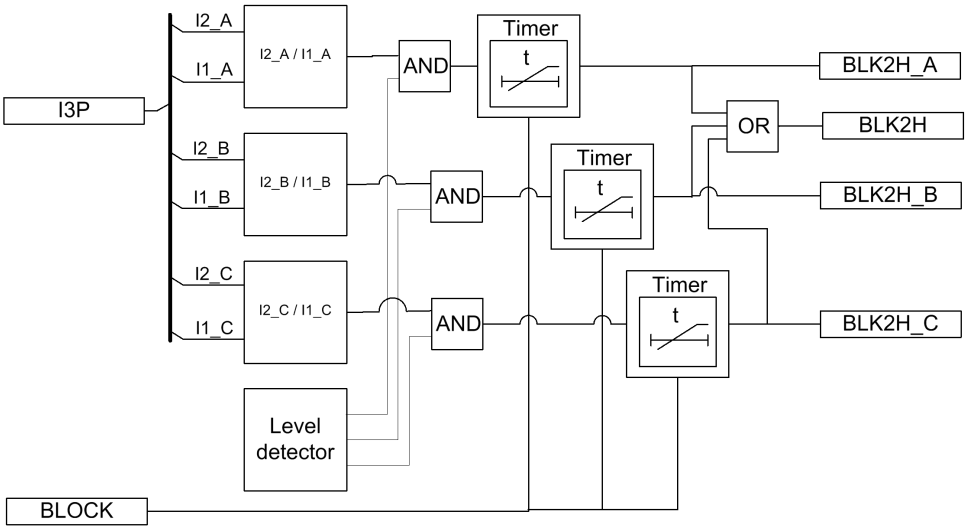


Figure 434: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

I_2H/I_1H

This module calculates the ratio of the second harmonic (I_2H) and fundamental frequency (I_1H) phase currents. The calculated value is compared to the set *Start value*. If the calculated value exceeds the set *Start value*, the module output is activated.

Level detector

The output of the phase specific level detector is activated when the fundamental frequency current I_1H exceeds five percent of the nominal current.

Timer

Once activated, the timer runs until the set *Operate delay time* value. The time characteristic is according to DT. When the operation timer has reached the *Operate delay time* value, the `BLK2H` output is activated. After the timer has elapsed and the inrush situation still exists, the `BLK2H` signal remains active until the I_2H/I_1H ratio drops below the value set for the ratio in all phases, that is, until the inrush situation is over. If the drop-off situation occurs within the operate time up counting, the reset timer is activated. If the drop-off time exceeds *Reset delay time*, the operate timer is reset.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets internal timers.

It is recommended to use the second harmonic and waveform based inrush blocking from the transformer differential protection function TR2PTDF function if available.

5.1.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

5.1.6 Application

Transformer protections require high stability to avoid tripping during magnetizing inrush conditions. A typical example of an inrush detector application is doubling the start value of an overcurrent protection during inrush detection.

The inrush detection function can be used to selectively block overcurrent and earth-fault function stages when the ratio of second harmonic component over the fundamental component exceeds the set value.

Other applications of this function include the detection of inrush in lines connected to a transformer.

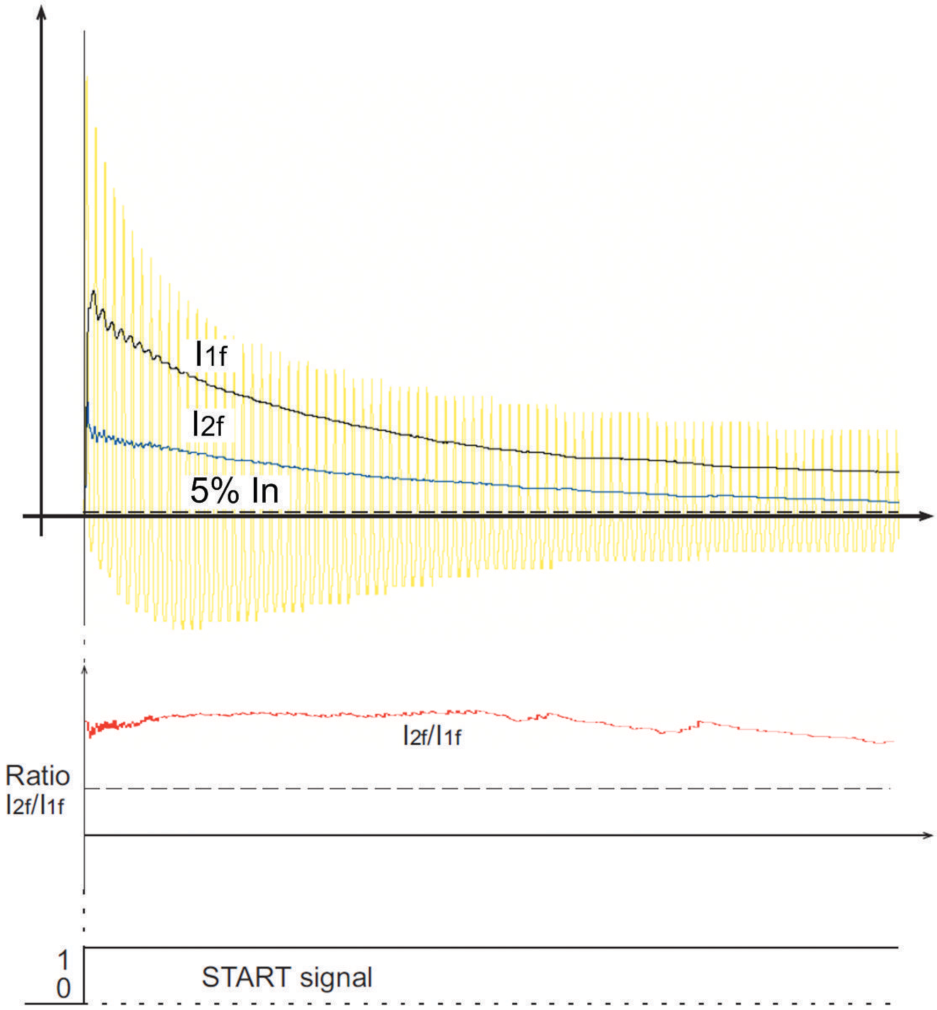


Figure 435: Inrush current in transformer

5.1.7 Signals

Table 853: INRPHAR Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
BLOCK	BOOLEAN	0	Block signal for all binary outputs

Table 854: INRPHAR Output signals

Name	Type	Description
BLK2H	BOOLEAN	Second harmonic based block
BLK2H_A	BOOLEAN	Second harmonic based block, phase A
BLK2H_B	BOOLEAN	Second harmonic based block, phase B
BLK2H_C	BOOLEAN	Second harmonic based block, phase C

5.1.8 Settings

Table 855: INRPHAR Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Start value	5 - 100	%	1	20	Ratio of the 2. to the 1. harmonic leading to restraint
Operate delay time	0.020 - 60.000	s	0.001	0.020	Operate delay time

Table 856: INRPHAR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 857: INRPHAR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Reset delay time	0.000 - 60.000	s	0.001	0.020	Reset delay time

5.1.9 Measured values

Table 858: INRPHAR Measured values

Name	Type	Default	Description
I_1H_A	REAL	0	Current fundamental frequency component, phase A
I_1H_B	REAL	0	Current fundamental frequency component, phase B
I_1H_C	REAL	0	Current fundamental frequency component, phase C
I_2H_A	REAL	0	Current second harmonic component, phase A
I_2H_B	REAL	0	Current second harmonic component, phase B
I_2H_C	REAL	0	Current second harmonic component, phase C
BLOCK	BOOLEAN	0	Block signal for all binary outputs

5.1.10 Monitored data

Table 859: INRPHAR Monitored data

Name	Type	Values (Range)	Unit	Description
BLK2H_A	BOOLEAN	0=FALSE 1=TRUE	-	Second harmonic based block, phase A
BLK2H_B	BOOLEAN	0=FALSE 1=TRUE	-	Second harmonic based block, phase B
BLK2H_C	BOOLEAN	0=FALSE 1=TRUE	-	Second harmonic based block, phase C

5.1.11 Technical data

Table 860: INRPHAR Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	Current measurement: ±1.5% of the set value or ±0.002 × I_n Ratio I2f/I1f measurement: ±5.0% of the set value
Reset time	+35 ms / -0 ms
Reset ratio	Typically 0.96
Operate time accuracy	+30 ms / -0 ms

5.2 Circuit breaker failure protection CCBRBRF

5.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit breaker failure protection	CCBRBRF	3I>/I0>BF	51BF/51NBF

5.2.2 Function block

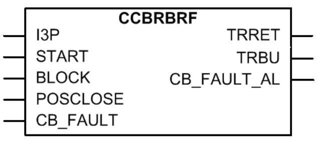


Figure 436: Function block

5.2.3 Functionality

The breaker failure function CCBRBRF is activated by trip commands from the protection functions. The commands are either internal commands to the terminal or external commands through binary inputs. The start command is always a default for three-phase operation. CCBRBRF includes a three-phase conditional or unconditional re-trip function, and also a three-phase conditional back-up trip function.

CCBRBRF uses the same levels of current detection for both re-trip and back-up trip. The operating values of the current measuring elements can be set within a predefined setting range. The function has two independent timers for trip purposes: a re-trip timer for the repeated tripping of its own breaker and a back-up timer for the trip logic operation for upstream breakers. A minimum trip pulse length can be set independently for the trip output.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

5.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the breaker failure protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

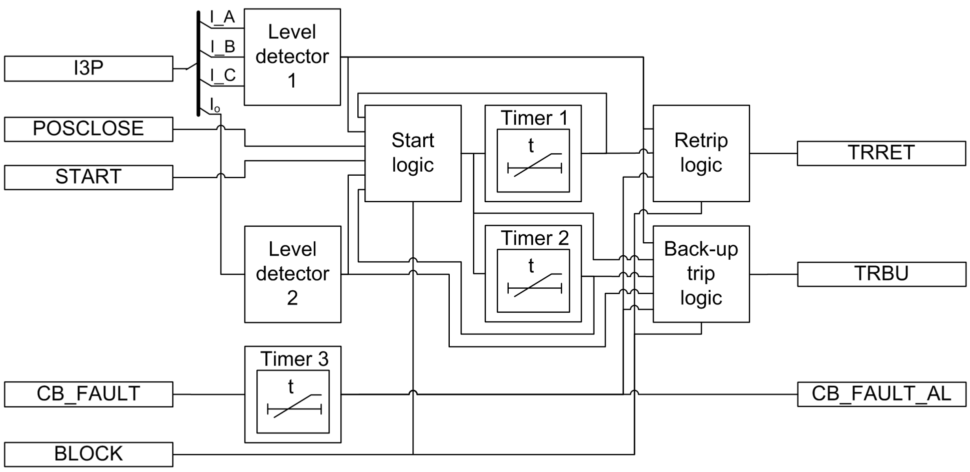


Figure 437: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Level detector 1

The measured phase currents are compared phase-wise to the set *Current value*. If the measured value exceeds the set *Current value*, the level detector reports the exceeding of the value to the Start, Retrip and Backup trip logics. The parameter should be set low enough so that the breaker failure situations with a small fault current or a high load current can be detected. The setting can be chosen in accordance with the most sensitive protection function to start the breaker failure protection.

Level detector 2

The measured residual current is compared to the set *Current value Res*. If the measured value exceeds the set *Current value Res*, the level detector reports the exceeding of the value to the Start and Backup trip logics. In high impedance earthed systems, the residual current at phase to earth faults is normally much smaller than the short circuit currents. To detect a breaker failure at single-phase earth faults in these systems, it is necessary to measure the residual current separately. In effectively earthed systems, also the setting of the earth-fault current protection can be chosen at a relatively low current level. The current setting should be chosen in accordance with the setting of the sensitive earth-fault protection.

Start logic

The Start logic is used to manage the starting of Timer 1 and Timer 2. It resets the function after the circuit breaker failure is handled. On the rising edge of the `START` input, the enabling signal is send to Timer 1 and Timer 2.

Once the Timer 1 and Timer 2 are activated, CCBRBRF can be reset only after the timers have reached the value set with the *Retrip time* and *CB failure delay* settings and the 150 ms time elapse after Timer 1 and Timer 2 are activated. The 150 ms time elapse is provided to prevent malfunctioning due to oscillation in the starting signal.

The resetting of the function depends on the *CB failure mode* setting.

- If *CB failure mode* is set to "Current", the resetting logic further depends on the *CB failure trip mode* setting.
    - If *CB failure trip mode* is set to "1 out of 3", the resetting logic requires that the values of all the phase currents drop below the *Current value* setting.
    - If *CB failure trip mode* is set to "1 out of 4", the resetting logic requires that either the values of the phase currents or the residual current drop below the *Current value* and *Current value Res* setting.
    - If *CB failure trip mode* is set to "2 out of 4", the resetting logic requires that the values of all the phase currents and the residual current drop below the *Current value* and *Current value Res* setting.
- If *CB failure mode* is set to "Breaker status" mode, the resetting logic requires that the circuit breaker is in the open condition.
- If *CB failure mode* setting is set to "Both", the logic resets when both CB is open and currents falls below the set limit.

The activation of the `BLOCK` input resets the function.

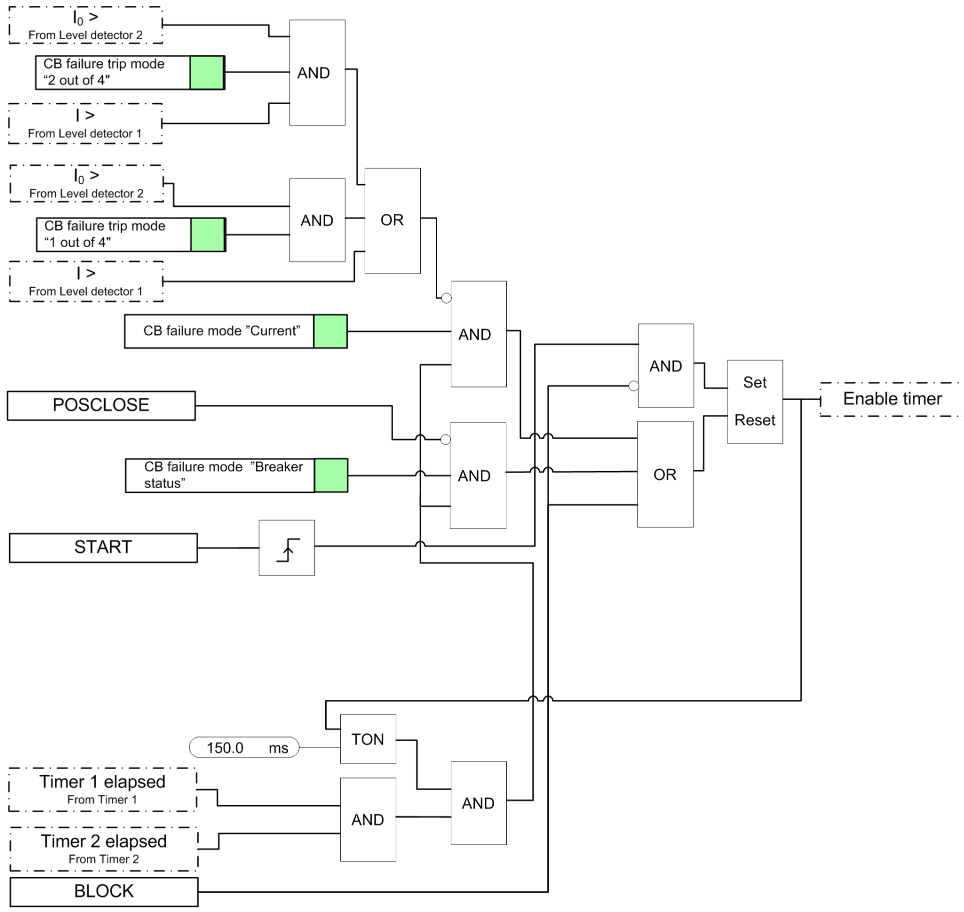


Figure 438: Start logic

Timer 1

Once activated, the timer runs until the set *Retrip time* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the value set with *Retrip time*, the retrip logic is activated. A typical setting is 0...50 ms.

When setting the value of the *Retrip time* setting, the time delays should be considered in the calculation.

- Circuit breaker operating time (t_{cbopen}), which is the time between activating the trip command for the circuit breaker trip coil and CB reaching the open position
- Reset time (t_{BFP_reset}) of current detection in current based operation mode, which is the time between the moment when the circuit breaker is opened and

the moment when the measured current is detected to be under the set level of the level detector limits
- Additional safety margin (t_{margin}), which is to avoid unintentional operation of circuit breaker failure protection, retripping or backup tripping, when the CB is opened.

The minimum time delay for the retrip can be estimated as:

$$Retriptime \geq t_{cbopen} + t_{BFP\_reset} + t_{margin}$$

(Equation 139)

Timer 2

Once activated, the timer runs until the set *CB failure delay* value is elapsed. The time characteristic is according to DT. When the operation timer has reached the set maximum time value *CB failure delay*. The value of this setting is made as low as possible at the same time as any unwanted operation is avoided. A typical setting is 90...150 ms which is dependent on the retrip timer.

The minimum time delay for the backup trip can be estimated as:

$$CBfailuredelay \geq Retriptime + t_{cbopen} + t_{BFP\_reset} + t_{margin}$$

(Equation 140)

t_{cbopen}	Maximum opening time for the circuit breaker
t_{BFP_reset}	Maximum time for the breaker failure protection to detect the correct breaker function (the current criteria reset)
t_{margin}	Safety margin

The example shows the time line of the circuit breaker opening with the trip in the normal and faulty breaker condition. Normally, the fault is cleared after the delay which consists of the protection time delay and breaker operating time delay. The breaker failure function is initiated at the same moment. To avoid unwanted retripping, that is, retrip output activation although the CB is already opened, the retrip time delay must cover the circuit breaker operating time, reset time of the current detection unit of the circuit breaker failure function and also some additional safety margin. The safety margin can be selected application-wise. The time delay for the backup trip must be longer compared to the retrip time so that the unwanted backup tripping can be avoided. However, there are requirements for the total fault clearing time to avoid system instability.

It is often required that the total fault clearance time is less than the given critical time. This time is often dependent on the ability to maintain transient stability in case of a fault close to a power plant.

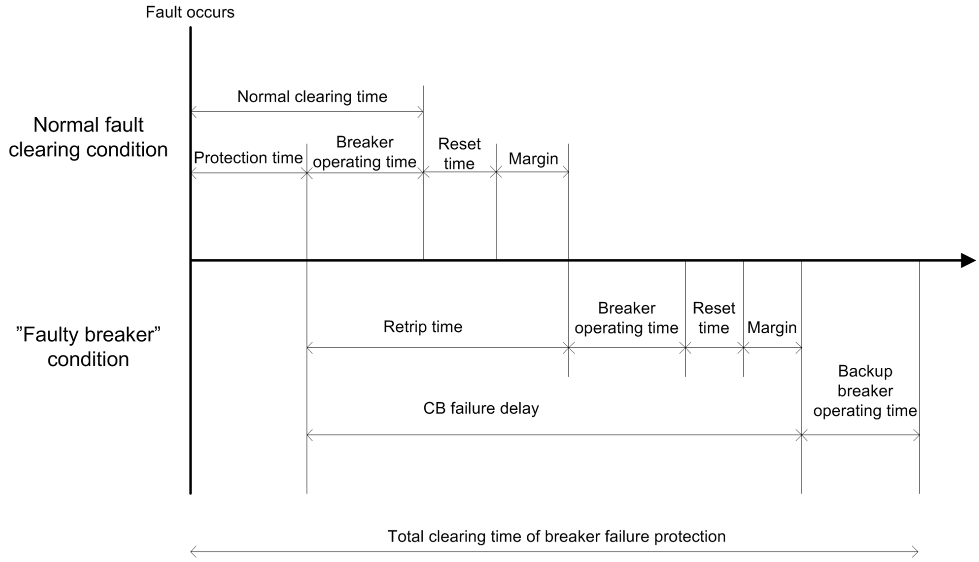


Figure 439: Timeline of the breaker failure protection

Timer 3

This module is activated by the `CB_FAULT` signal. Once activated, the timer runs until the set *CB fault delay* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the maximum time value *CB fault delay*, the `CB_FAULT_AL` output is activated. After the set time, an alarm is given so that the circuit breaker can be repaired. A typical value is 5 s.

Retrip logic

The Retrip logic provides the `TRRET` output, which can be used to give a retrip signal for the main circuit breaker. Timer 1 activates the Retrip logic. The operation of the Retrip logic depends on the *CB fail retrip mode* setting.

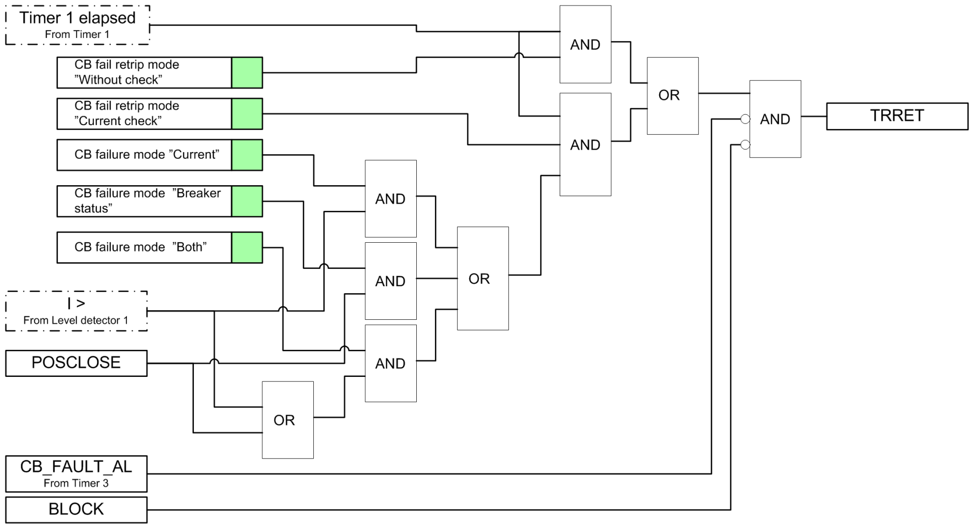


Figure 440: Retrip logic internal design

- The Retrip logic is inactive if the *CB fail retrip mode* setting is set to "Off".
- If *CB fail retrip mode* is set to the "Current check" mode, the activation of the retrip output TRRET depends on the *CB failure mode* setting.
  - If *CB failure mode* is set to the "Current" mode, TRRET is activated when the value of any phase current exceeds the *Current value* setting. The TRRET output remains active for the time set with the *Trip pulse time* setting or until all phase current values drop below the *Current value* setting, whichever is longer.
  - If *CB failure mode* is set to the "Breaker status" mode, TRRET is activated if the circuit breaker is in the closed position. The TRRET output remains active for the time set with the *Trip pulse time* setting or the time the circuit breaker is in the closed position, whichever is longer.
  - If *CB failure mode* is set to "Both", TRRET is activated when either of the "Breaker status" or "Current" mode condition is satisfied.

- If *CB fail retrip mode* is set to the "Without check" mode, TRRET is activated once the Timer 1 is activated without checking the current level. The TRRET output remains active for a fixed time set with the *Trip pulse timer* setting.

The activation of the BLOCK input or the CB_FAULT_AL output deactivates the TRRET output.

Backup trip logic

The Backup trip logic provides the TRBU output which can be used to trip the upstream backup circuit breaker when the main circuit breaker fails to clear the fault. The Backup trip logic is activated by Timer 2 module or timer-enabling signal from the start logic module (rising edge of the START input detected), and simultaneously `CB_FAULT_AL` is active. The operation of the Backup logic depends on the *CB failure mode* setting.

- If the *CB failure mode* is set to "Current", the activation of `TRBU` depends on the *CB failure trip mode* setting.
  - If *CB failure trip mode* is set to "1 out of 3", the failure detection is based on any of the phase currents exceeding the *Current value* setting. Once `TRBU` is activated, it remains active for the time set with the *Trip pulse time* setting or until the values of all the phase currents drop below the *Current value* setting, whichever is longer.
  - If *CB failure trip mode* is set to "1 out of 4", the failure detection is based on either a phase current or a residual current exceeding the *Current value* or *Current value Res* setting. Once `TRBU` is activated, it remains active for the time set with the *Trip pulse time* setting or until the values of all the phase currents or residual currents drop below the *Current value* and *Current value Res* setting, whichever is longer.
  - If *CB failure trip mode* is set to "2 out of 4", the failure detection requires that any of the two currents among phase current and a residual current exceeds their respective set value. Once `TRBU` is activated, it remains active for the time set with the *Trip pulse time* setting or until the values of all the phase currents and residual currents drop below the *Current value* and *Current value Res* setting, whichever is longer.

In most applications, "1 out of 3" is sufficient.

- If the *CB failure mode* is set to "Breaker status", the `TRBU` output is activated if the circuit breaker is in the closed position. Once activated, the `TRBU` output remains active for the time set with the *Trip pulse time* setting or the time the circuit breaker is in the closed position, whichever is longer.
- If the *CB failure mode* setting is set to "Both", `TRBU` is activated when the "Breaker status" or "Current" mode conditions are satisfied.

The activation of the `BLOCK` input deactivates the `TRBU` output.

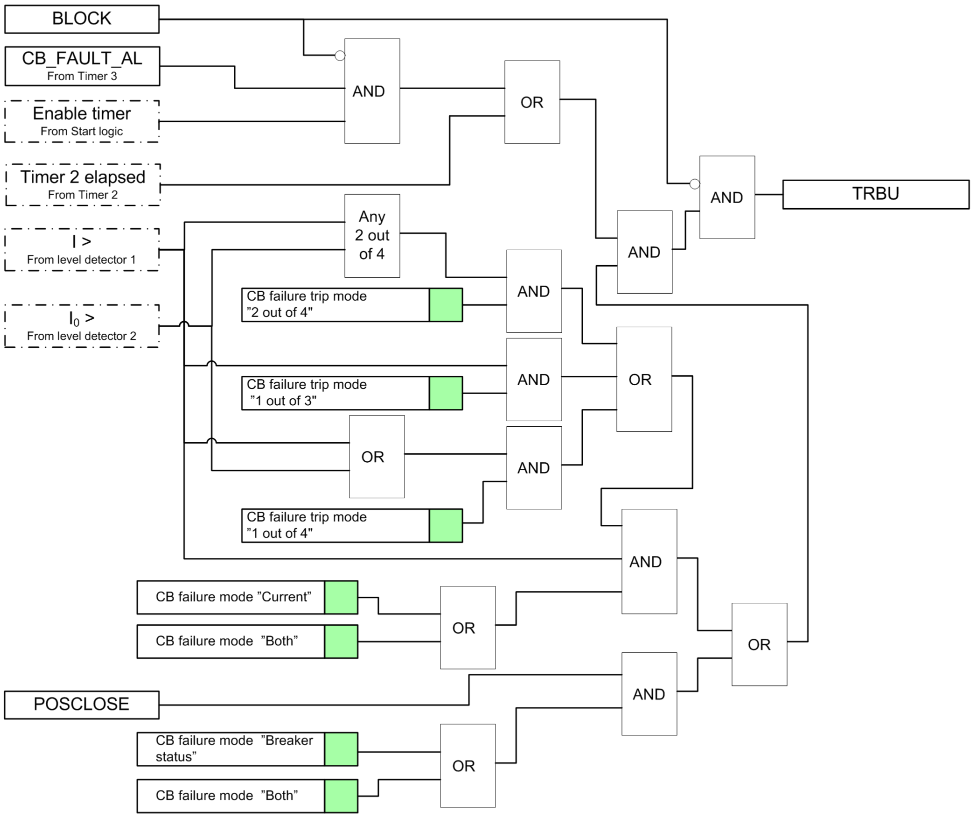


Figure 441: Backup trip logic internal design

5.2.5 Base values

In this function block, some of the settings are set in per unit (p.u). These p.u. values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "Phase Grp 1", "Phase Grp 2" and "Phase Grp 3". Similarly, "Residual Grp 1", "Residual Grp 2" and "Residual Grp 3" are supported for the residual current or voltage-related settings. One of the groups to be used with the *Base value Sel phase* or *Base value Sel Res* settings must be selected.

5.2.6 Application

The n-1 criterion is used in the design of a fault clearance system. This means that the fault is cleared even if some component in the fault clearance system is faulty. A circuit breaker is a necessary component in the fault clearance system. For practical and economical reasons, it is not feasible to duplicate the circuit breaker for the protected component, but breaker failure protection is used instead.

The breaker failure function issues a backup trip command to upstream circuit breakers in case the original circuit breaker fails to trip for the protected component. The detection of a failure to break the current through the breaker is made by measuring the current or by detecting the remaining trip signal (unconditional).

CCBRBRF can also retrip. This means that a second trip signal is sent to the protected circuit breaker. The retrip function is used to increase the operational reliability of the breaker. The function can also be used to avoid backup tripping of several breakers in case mistakes occur during IED maintenance and tests.

CCBRBRF is initiated by operating different protection functions or digital logics inside the IED. It is also possible to initiate the function externally through a binary input.

CCBRBRF can be blocked by using an internally assigned signal or an external signal from a binary input. This signal blocks the function of the breaker failure protection even when the timers have started or the timers are reset.

The retrip timer is initiated after the start input is set to true. When the pre-defined time setting is exceeded, CCBRBRF issues the retrip and sends a trip command, for example, to the circuit breaker's second trip coil. Both a retrip with current check and an unconditional retrip are available. When a retrip with current check is chosen, the retrip is performed only if there is a current flow through the circuit breaker.

The backup trip timer is also initiated at the same time as the retrip timer. If CCBRBRF detects a failure in tripping the fault within the set backup delay time, which is longer than the retrip time, it sends a backup trip signal to the chosen backup breakers. The circuit breakers are normally upstream breakers which feed fault current to a faulty feeder.

The backup trip always includes a current check criterion. This means that the criterion for a breaker failure is that there is a current flow through the circuit breaker after the set backup delay time.

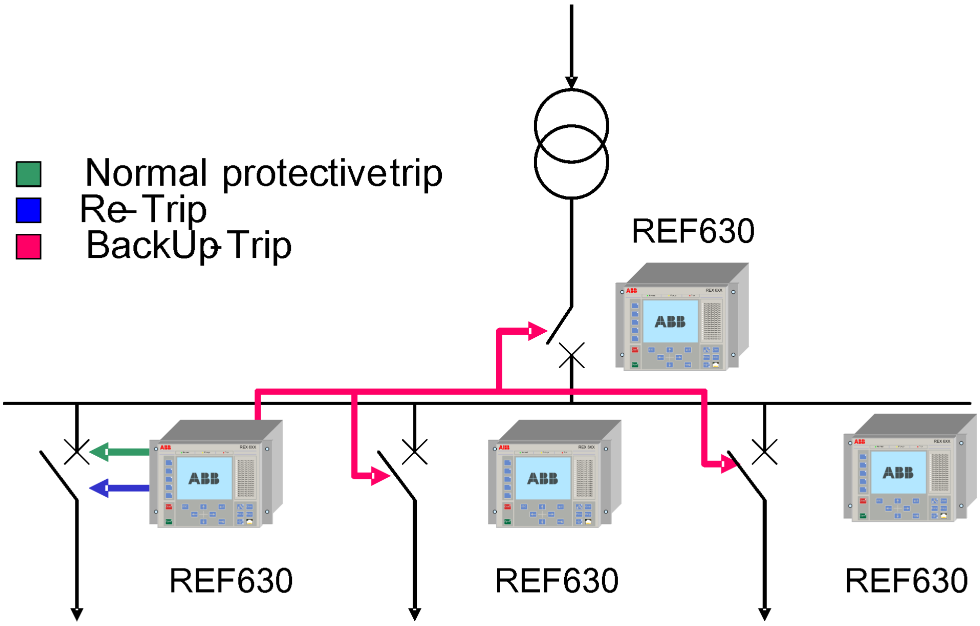


Figure 442: Typical breaker failure protection scheme in distribution substations

5.2.7 Signals

Table 861: CCBRBRF Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
START	BOOLEAN	0	CBFP start command
POSCLOSE	BOOLEAN	0	CB in closed poisition
BLOCK	BOOLEAN	0	Block CBFP operation
CB_FAULT	BOOLEAN	0	CB faulty and unable to trip

Table 862: CCBRBRF Output signals

Name	Type	Description
TRRET	BOOLEAN	Retrip
TRBU	BOOLEAN	Backup trip
CB_FAULT_AL	BOOLEAN	Delayed CB failure alarm

5.2.8 Settings

Table 863: CCBRBRF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On/Off
Current value	0.05 - 1.00	pu	0.01	0.30	Operating phase current
Current value Res	0.05 - 1.00	pu	0.01	0.30	Operating residual current
Retrip time	0.00 - 60.00	s	0.01	0.00	Delay timer for retrip
CB failure delay	0.00 - 60.00	s	0.01	0.15	Delay timer for backup trip

Table 864: CCBRBRF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual
Measurement mode	DFT Peak-to-Peak	-	-	DFT	Phase current measurement mode of function
CB failure mode	Current Breaker status Both	-	-	Current	Operating mode of function
CB failure trip mode	2 out of 4 1 out of 3 1 out of 4	-	-	2 out of 4	Backup trip current check mode
CB fail retrip mode	Off Without check Current check	-	-	Off	Operating mode of retrip logic
CB fault delay	0.00 - 60.00	s	0.01	5.00	Circuit breaker faulty delay
Trip pulse time	0.00 - 60.00	s	0.01	0.20	Pulse length of retrip and backup trip outputs

5.2.9 Measured values

Table 865: CCBRBRF Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Phase1 current DFT amplitude
I_AMPL_B	REAL	0	Phase2 current DFT amplitude
I_AMPL_C	REAL	0	Phase3 current DFT amplitude
I_PTOP_A	REAL	0	Phase1 current Peak to Peak value
I_PTOP_B	REAL	0	Phase2 current Peak to Peak value
I_PTOP_C	REAL	0	Phase3 current Peak to Peak value
I0_AMPL	REAL	0	Residual current amplitude
Table continues on next page			

Name	Type	Default	Description
START	BOOLEAN	0	CBFP start command
POSCLOSE	BOOLEAN	0	CB in closed poisition
BLOCK	BOOLEAN	0	Block CBFP operation
CB_FAULT	BOOLEAN	0	CB faulty and unable to trip

5.2.10 Monitored data

Table 866: CCBRBRF Monitored data

Name	Type	Values (Range)	Unit	Description
TRRET	BOOLEAN	0=FALSE 1=TRUE	-	Retrip
TRBU	BOOLEAN	0=FALSE 1=TRUE	-	Backup trip
CB_FAULT_AL	BOOLEAN	0=FALSE 1=TRUE	-	Delayed CB failure alarm

5.2.11 Technical data

Table 867: CCBRBRF Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5% of the set value or ±0.002 × I_n
Operate time accuracy	±1.0% of the set value or ±30 ms

5.2.12 Technical revision history

Table 868: CCBRBRF technical revision history

Technical revision	Change
B	• Step value changed from 0.05 to 0.01 for *Current value* and *Current value Res* settings • Internal improvements

5.3 Tripping logic TRPPTRC

5.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Tripping logic	TRPPTRC	I->O	94

5.3.2 Function block

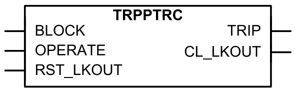


Figure 443: Function block

5.3.3 Functionality

The tripping logic function TRPPTRC is used as a trip command collector and handler after the protection functions. The features of this function influence the trip signal behavior of the circuit breaker. The user can set the minimum trip pulse length when the non-latched mode is selected. It is also possible to select the latched mode for the trip signal.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

5.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

When the TRPPTRC function is disabled, all trip outputs intended to go through the function to the circuit breaker trip coil are blocked!

The operation of the tripping logic function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

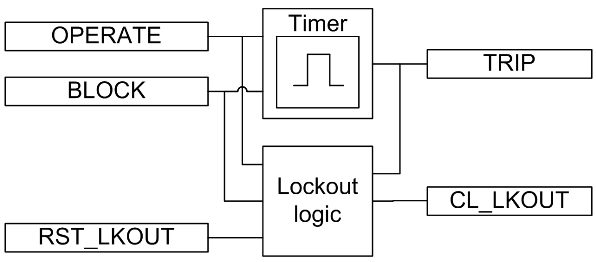


Figure 444: Functional module diagram

Timer

The duration of the `TRIP` output signal from TRPPTRC can be adjusted with the *Trip pulse time* setting when *Trip lockout* is "Off". The pulse length should be long enough to secure the opening of the breaker. For three-pole tripping, TRPPTRC has a single input OPERATE, through which all trip output signals are routed from the protection functions within the IED, or from external protection functions via one or more of the IED's binary inputs. The function has a single trip output TRIP for connecting the function to one or more of the IED's binary outputs and also to other functions within the IED requiring this signal.

Lockout logic

TRPPTRC is provided with possibilities to activate a lockout. When activated, the lockout can be manually reset after checking the primary fault by activating the RST_LKOUT input or from the LHMI clear menu parameter. When using the "Lockout & latched trip" mode (*Automatic lockout* = "On", *Trip lockout* = "On"), the resetting of the TRIP output can be done similarly as when using the "Lockout" mode (*Automatic lockout* = "On", *Trip lockout* = "Off"). It is also possible to reset remotely through a separate communication parameter.

The minimum pulse trip function is not active when using the "Lockout & latched trip" mode (*Automatic lockout* = "On", *Trip lockout* = "On").

The CL_LKOUT and TRIP outputs can be blocked with the BLOCK input.

Table 869: Lockout modes for the TRPPTRC trip output

Lockout mode	Description
Automatic lockout	If set to "On", the activation of the TRIP output activates the CL_LKOUT lockout output.
Trip lockout	If set to "On" (together with *Automatic lockout* = "On"), the TRIP output will be latched together with the activation of the CL_LKOUT output.

5.3.5 Application

All trip signals from different protection functions are routed through the trip logic. The most simplified application of the logic function is linking the trip signal and ensuring that the signal is long enough.

The tripping logic in the protection relay is intended to be used in the three-phase tripping for all fault types (3ph operating). To prevent the closing of a circuit breaker after a trip, the function can block the DAXCBR closing.

The TRPPTRC function is intended to be connected to one trip coil of the corresponding circuit breaker. If tripping is needed for another trip coil or another circuit breaker which needs, for example, different trip pulse time, another trip logic function can be used.

The inputs from the protection functions are connected to the `OPERATE` input. Usually, a logic block OR is required to combine the different function outputs to this input. The `TRIP` output is connected to the binary outputs on the IO board.

TRPPTRC is used for simple three-phase tripping applications.

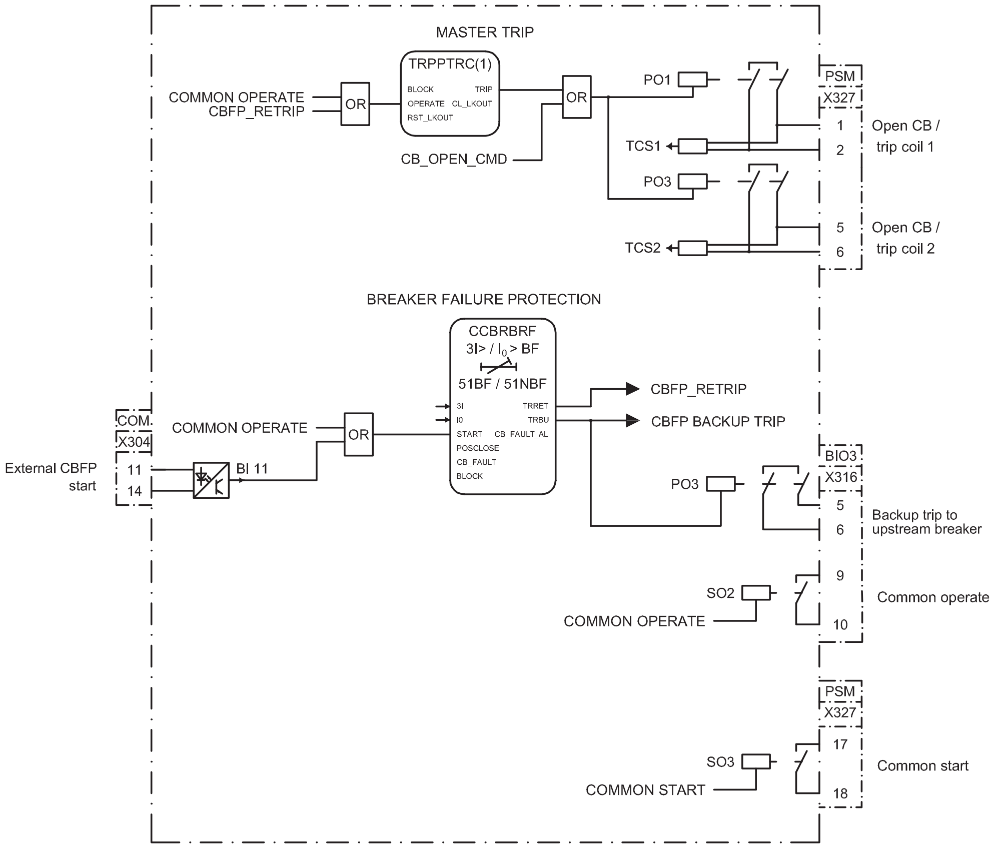


Figure 445: Typical TRPPTRC connection

5.3.6 Signals

Table 870: TRPPTRC Input signals

Name	Type	Default	Description
OPERATE	BOOLEAN	0	Request to trip circuit breaker.
BLOCK	BOOLEAN	0	Block of function
RST_LKOUT	BOOLEAN	0	Input for resetting the circuit breaker lockout function

Table 871: TRPPTRC Output signals

Name	Type	Description
TRIP	BOOLEAN	General trip output signal
CL_LKOUT	BOOLEAN	Circuit breaker lockout output (set until reset)

5.3.7 Settings

Table 872: TRPPTRC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Trip lockout	Off On	-	-	Off	On: activate output (CL_LKOUT) and trip latch, Off: only out
Automatic lockout	Off On	-	-	Off	On: lockout from trip, Off: no lockout
Trip pulse time	0.000 - 60.000	s	0.001	0.150	Minimum duration of trip output signal

5.3.8 Measured values

Table 873: TRPPTRC Measured values

Name	Type	Default	Description
OPERATE	BOOLEAN	0	Request to trip circuit breaker.
BLOCK	BOOLEAN	0	Block of function
RST_LKOUT	BOOLEAN	0	Input for resetting the circuit breaker lockout function

5.3.9 Monitored data

Table 874: TRPPTRC Monitored data

Name	Type	Values (Range)	Unit	Description
TRIP	BOOLEAN	0=FALSE 1=TRUE	-	General trip output signal
CL_LKOUT	BOOLEAN	0=FALSE 1=TRUE	-	Circuit breaker lockout output (set until reset)

5.4 Fault locator SCEFRFLO

5.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fault locator function	SCEFRFLO	FLOC	21FL

5.4.2 Function block

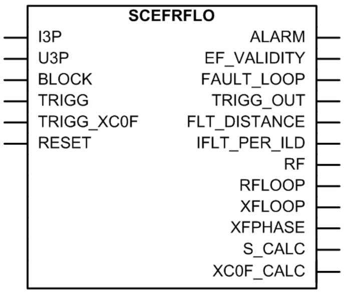


Figure 446: Function block

5.4.3 Functionality

The fault locator function SCEFRFLO provides impedance-based fault location. It is designed for radially operated distribution systems. It is applicable for locating short circuits in distribution networks. Earth faults can be located in effectively earthed and low resistance and in low-reactance earthed networks. Under certain limitations, SCEFRFLO can also be applied for earth-fault location in unearthed distribution networks.

The fault distance calculation is based on locally measured fundamental frequency current and voltage phasors. The full operation of SCEFRFLO requires that all three currents and phase-to-earth voltages are measured.

The fault distance calculation is done in two steps. The fault type is determined first using the built-in Phase Selection Logic PSL. After this, the fault distance is calculated.

The fault distance estimate is obtained when SCEFRFLO is triggered. The triggering can be blocked with the binary input signal `BLOCK`.

5.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The actual fault distance calculation consists of two steps. The fault type is determined first by using the built-in phase selection logic PSL. After this, the fault distance is calculated. As a fundamental operation criterion, the maximum of the phase current magnitudes must exceed a threshold value of 1 percent of the nominal phase current value of the CT primary current. When this condition is not met, all the outputs of the function are blocked.

5.4.4.1 Fault type selection

The identification of the faulty phases is compulsory for the correct operation of the fault locator function. This is because only one of the impedance measuring elements, that is, the fault loops, provides the correct result for a specific fault type. A three-phase fault is an exception and it could, in theory, be calculated with any of the fault loops.

Fault type	Description	Output `FAULT_LOOP`
Phase A to Gnd	Phase A-to-earth fault	1
Phase B to Gnd	Phase B-to-earth fault	2
Phase C to Gnd	Phase C-to-earth fault	3
Phase A to B	Phase A-to-B short circuit fault	4
Phase B to C	Phase B-to-C short circuit fault	5
Phase C to A	Phase C-to-A short circuit fault	6
Three phase	Three-phase short circuit	7

The fault loop used in the fault distance calculation is indicated in the `FAULT_LOOP` output as integer numbers 1, 2, 3, 4, 5, 6 or 7.

In case of phase-to-phase-to-earth faults AB-earth, BC-earth or CA-earth, the selected fault loop depends on the location of the individual earth faults. When the faults are located at the same feeder, the corresponding phase-to-phase loop AB, BC or CA is used for calculation. When the faults are located at different feeders, the phase-to-earth loop A, B or C, corresponding to the faulty phase at the protected feeder, is used for calculation.

Identification of the faulty phase is provided by the built-in PSL based on combined impedance and current criteria. PSL is virtually setting-free and has only one parameter, *Z Max phase load*, for discriminating a large symmetrical load from a three-phase fault. The *Z Max phase load* parameter can be calculated using the equation:

$$Z\,Max\,phase\,load = 0.8\left(\frac{U^2}{S_{\max}}\right)$$

(Equation 141)

U	nominal phase-to-phase voltage
S_{max}	maximum three-phase load

For example, if U = 20 kV and S_{max} = 1 MVA, *Z Max phase load* = 320 ohm.

5.4.4.2 Fault distance calculation

As soon as a fault condition is recognized by PSL, the fault distance calculation is started using one of the seven impedance measuring elements, that is, the fault loops. SCEFRFLO employs independent algorithms for each fault type in order to achieve optimal performance.

The inherent result from the fault distance calculation is the ohmic fault loop impedance value.

$$ZFLOOP = RFLOOP + j \times XFLOOP + RF$$

(Equation 142)

The result can be utilized as such or it can be further processed in system level fault localization applications.

Depending on the fault loop, the composition of terms RFLOOP, XFLOOP and RF is different.

t

Fault loops 1, 2 and 3

Fault loops 1, 2 and 3 are used for single-phase earth faults. When the individual earth faults are located at different feeders, they are also used in the case of a phase-to-phase-to-earth fault. In this case, the phase-to-earth loop 1, 2 or 3, corresponding to the faulty phase at the protected feeder, is used for calculation.

Fault loops 1, 2 and 3 measure the impedances which, at the same time, are the outputs of SCEFRFLO.

$$RFLOOP = R_1 + R_N + R_{fault}$$
$$XFLOOP = X_1 + X_N$$
$$RF = R_{fault}$$

(Equation 143)

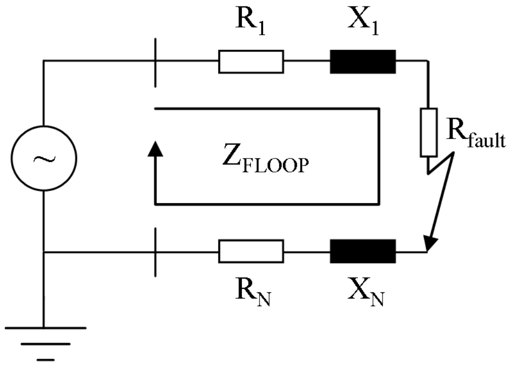


Figure 447: Fault loop impedance for phase-to-earth fault impedance loops 1, 2 or 3

The earth-fault distance calculation algorithm is selected with setting *EF algorithm* to "Load compensation" or "Load modelling". For correct operation of both algorithms there should not be any zero-sequence current sources, for example, earthing transformers, in front of the IED location.

"Load compensation" utilizes symmetrical components to compensate the effect of a load on the measured voltages and currents. It should be selected in case of radial feeders with low impedance or effectively earthed systems, where the fault current is fed from one side only and there are no in-feeds along the protected line.

"Load modelling" takes into account the effect of the load in measured currents and voltages by load modelling. The "Load modelling" algorithm can be applied in case of radial feeders with low impedance or effectively earthed systems, where the fault current is fed from one side only.

The "Load modelling" algorithm requires the *Equivalent load Dis* setting, that is, an equivalent load distance, as an additional parameter. The maximum value of the voltage drop, denoted U_{drop}(real), appears at the end of the line. The *Equivalent load Dis* parameter is the distance at which a single load tap corresponding to the total load of the feeder would result in a voltage drop equal to U_{drop}(real). The dashed curve shows the voltage drop profile in this case.

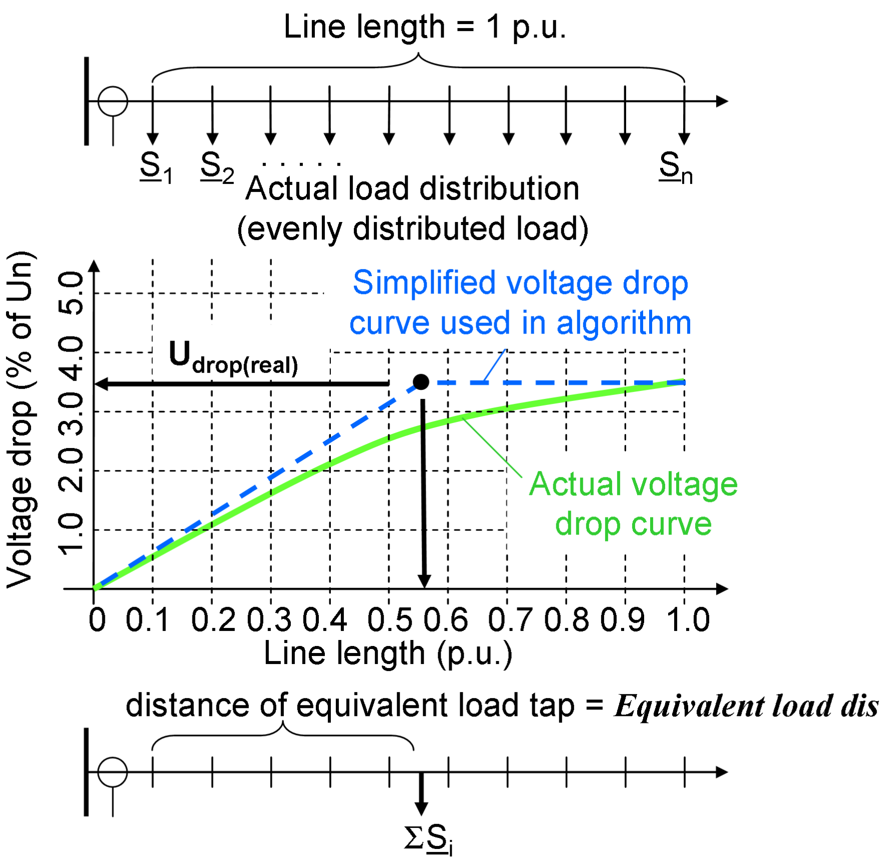


Figure 448: Description of the equivalent load distance

The value of *Equivalent load Dis* can be calculated based on the load flow and voltage drop calculations using equation:

Equivalent load Dis = $U_{drop(real)}$ / $U_{drop(s=1)}$,

$U_{drop(real)}$	the actual maximum voltage drop of the feeder
$U_{drop(s=1)}$	the fictional voltage drop if the entire load is tapped at the end of the feeder

the *Equivalent load Dis* parameter can be determined by conducting a single-phase earth-fault test (R_{fault} = 0 ohm) at that point of the feeder where the maximum actual voltage drop takes place. This point is typically located at the end of the main line. The calculated value of *Equivalent load Dis* can be obtained from the `S_CALC` output.

In case of evenly distributed load, *Equivalent load Dis* ~ 0.5. When the load is tapped at the end of the line, *Equivalent load Dis* = 1.0. If nothing else is known, a good initial guess for *Equivalent load Dis* is 0.5.

When "Load modelling" algorithm is used, the user can select with the *EF algorithm current* setting whether the I0 or I2-current based algorithm is used. The difference between I0 and I2 is that I2 does not require the settings *Ph capacitive React* and *Ph leakage Ris*. In case of I0, these settings are required in order to compensate for the influence of line charging capacitances. This typically improves the accuracy of a fault location estimate when fault resistance is involved in the fault.

Under certain restrictions the "Load modelling" algorithm can also be applied into unearthed networks. Based on simulation and field tests, when R_{fault} = 0 ohm, the defined earth-fault current magnitude should exceed the pre-fault load current $I_{ef(Rfault=0)} / I_{Load} \geq 1$. This ratio is recorded and can be read from the `IFLT_PER_ILD` output. The low ratio affects also the validity estimate of calculated fault distance, which can be read from the `EF_VALIDITY` output. Sufficient fault current magnitude can be achieved, for example, with proper switching operations in the background network, which increases the fault current. After the switching operation, a re-energizing of the faulted line is done and a new estimate obtained. The fault resistance decreases the fault location accuracy and it should not be too large, maximum a few hundreds of ohms.

The range of the setting *Equivalent load Dis* is 0.01...1.00. Any value of `S_CALC` outside this range needs to be ignored.

Fault loops 12, 23 and 31

Fault loops 12, 23 and 31 are used for the phase-to-phase short circuit faults and also for the phase-to-phase-to-earth faults if the individual earth-faults are located in the same feeder.

Fault loops 12, 23 and 31 measure the impedances, which at the same time are the outputs of SCEFRFLO.

$$RFLOOP = R_1 + R_{fault} / 2$$
$$XFLOOP = X_1$$
$$RF = R_{fault} / 2$$

(Equation 144)

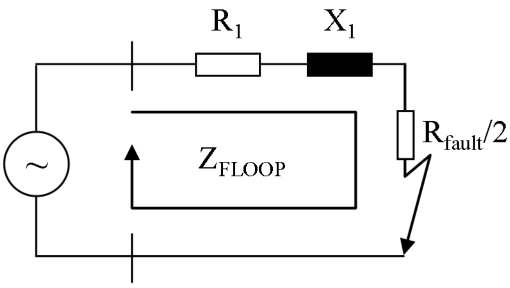


Figure 449: Fault loop impedance for phase-to-phase fault impedance loops 12, 23 and 31

For the fault loops 12, 23, 31, the estimated fault resistance is half the total fault resistance between the phases.

The fault distance calculation algorithm for the phase-to-phase fault impedance loops (12, 23 or 31) is defined by using setting *Load Com PP loops* = "Disabled"/"Enabled" setting and setting *Simple mode PP loops* = "Disabled"/"Enabled".

The load compensation can be enabled or disabled with the *Load Com PP loops = FALSE/TRUE* setting. The load compensation should be disabled only if the ratio between the fault current and load current is large or when the value of the fault distance estimate for the short circuit fault is required for each shot of an auto-reclosing cycle.

The fault distance calculation is the most accurate when the calculation is made with the fault loop model. This model requires positive sequence impedances as initial data. If the data is not accessible, the calculation can be made with a simple fault loop model that does not need any impedance data. The simple fault loop model is enabled, with the value *Simple mode PP loops = TRUE*. When the simple model is enabled, the conversion of electrical fault distance into a physical distance is not done in the IED and the `FLT_DISTANCE` output is not valid. The estimated impedances are still calculated and shown normally in their respective outputs.

Fault loop 123

Fault loop 123 is used only for the three-phase short circuit fault and it measures the impedances that are the outputs of SCEFRFLO:

$$RFLOOP = R_1 + R_{fault}$$
$$XFLOOP = X_1$$
$$RF = R_{fault}$$

(Equation 145)

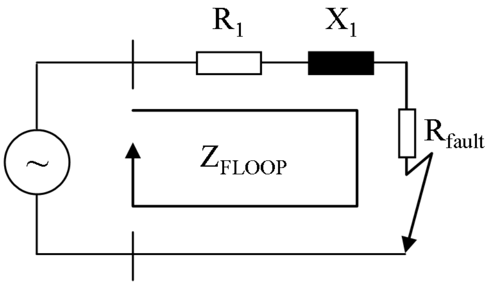


Figure 450: Fault loop impedance for a three-phase fault impedance loop 123

The three-phase fault distance is calculated with a special measuring element using positive sequence quantities. This is advantageous especially in case of non-transposed (asymmetric) lines, as the line parameter has less influence. If the line is non-transposed, all the phase-to-phase loops have different fault loop reactance. The use of positive sequence quantities results in the average value of phase-to-phase loop reactance. This is the most representative estimate in case of three-phase faults.

The fault distance calculation algorithm for the three-phase fault impedance loop is defined by using the setting *Load Com PP loops* = "Disabled"/"Enabled" and setting *Simple mode PP loops* = "Disabled"/"Enabled" setting.

The load compensation can be enabled or disabled with the *Load Com PP loops = FALSE/TRUE* setting. The load compensation should be disabled only if the ratio between the fault current and load current is large or when the value of the fault distance estimate for the short circuit fault is required for each shot of an auto-reclosing cycle.

The fault distance calculation is the most accurate when the calculation is made with the fault loop model. This model requires positive sequence impedances as initial data. If the data is not accessible, then the calculation can be made with a simple fault loop model that does not need any impedance data. The simple fault loop model is enabled, with the value *Simple mode PP loops = TRUE*. When the simple model is enabled, the conversion of electrical fault distance into a physical distance is not done in the IED and the `FLT_DISTANCE` output is not valid. The estimated impedances are still calculated and shown normally in their respective outputs.

The function calculates XFPHASE, which is the positive sequence fault reactance in primary ohms and is available as an output.

Table 875: Explanation of used abbreviations

Abbreviation	Description
RFLOOP	Estimated fault loop resistance in primary ohms
XFLOOP	Estimated fault reactance in primary ohms
XFPHASE	Positive sequence fault reactance in primary ohms
RF	Estimated fault resistance in primary ohms
R_1	Positive sequence resistance from the substation to the fault location
X_1	Positive sequence reactance from the substation to the fault location
R_N	Earth return path resistance from the substation to the fault location = $(R_0 - R_1)/3$
X_N	Earth return path reactance from the substation to the fault location = $(X_0 - X_1)/3$
R_0	Zero sequence resistance from the substation to the fault location
X_0	Zero sequence reactance from the substation to the fault location
R_{fault}	Physical fault resistance at the fault location. In case of earth faults, it includes the arc and the earthing resistance. In case of the phase-to-phase faults, it equals to the arc resistance between the phases. In case of three-phase faults, it equals to the arc resistance per phase.

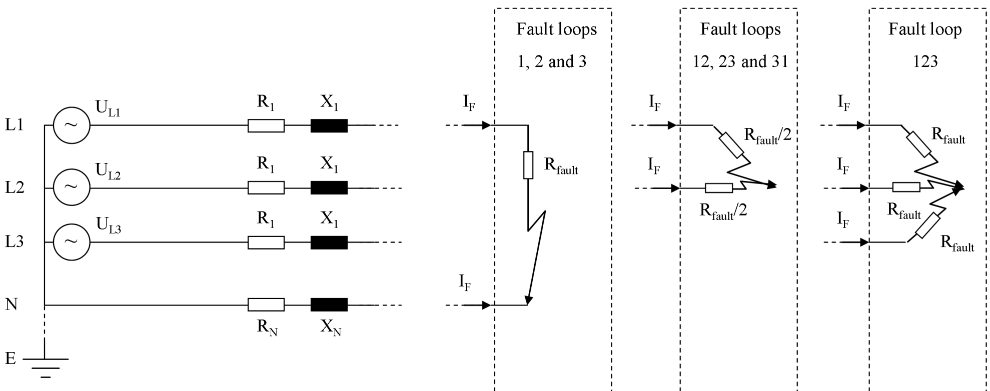


Figure 451: Physical fault resistance in different fault loops

For fault loops 12, 23 and 31 the estimated fault resistance (the RF output) is half of the total physical fault resistance between the phases. In earth faults, the estimated fault resistance includes the arc and the earthing resistance. In case of a three-phase fault the estimated fault resistance equals the arc resistance per phase.

5.4.4.3 Steady-state asymmetry and load compensation

In reality, power systems are never totally symmetrical. The asymmetry produces steady-state quantities in the form of zero and negative sequence voltages and currents. If not compensated, these are the error sources for the fault distance calculation, especially in the case of earth faults. In SCEFRFLO, all the fault distance calculation algorithms utilize the delta (Δ) quantities which eliminate the steady-state asymmetry. The delta quantities are also used for load compensation for short circuit faults (fault loops 12, 23, 31 and 123).

The delta quantities describe the change in the measured quantities due to the fault:

$\Delta x = x_{fault} - x_{pre\text{-}fault}$.

The *Pre fault time* setting is used for generating the delta quantities. The pre-fault values are captured at least *Pre fault time* earlier than the actual fault moment occurs.

Load current is one of the main error sources for the fault distance calculation. The effect of the load current increases with high fault resistance values. SCEFRFLO employs independent load compensation methods for each type of fault in order to achieve optimal performance. For the earth faults (fault loops 1, 2, and 3), the load compensation is done numerically within the fault distance algorithm. For the short circuit faults (fault loops 12, 23, 31 and 123), the delta quantities are used for the load compensation.

5.4.4.4 Triggering the SCEFRFLO

The fault distance estimate is obtained when SCEFRFLO is triggered. The triggering can be blocked with the `BLOCK` binary input signal.

SCEFRFLO requires a minimum of two cycles of measuring time after the fault occurrence. This provides time for filtering the fault distance estimate. The behavior of the fault distance estimate of SCEFRFLO varies as a function of time:

- Immediately after the fault occurrence, the estimate is affected by initial transient in voltages and currents
- After one cycle, when the fault has occurred, the fault distance starts to converge towards the final value.
- After two cycles, when the fault has occurred, the fault distance estimate is ready and SCEFRFLO can be triggered. The more there is measuring time, the better the fault distance estimate is.

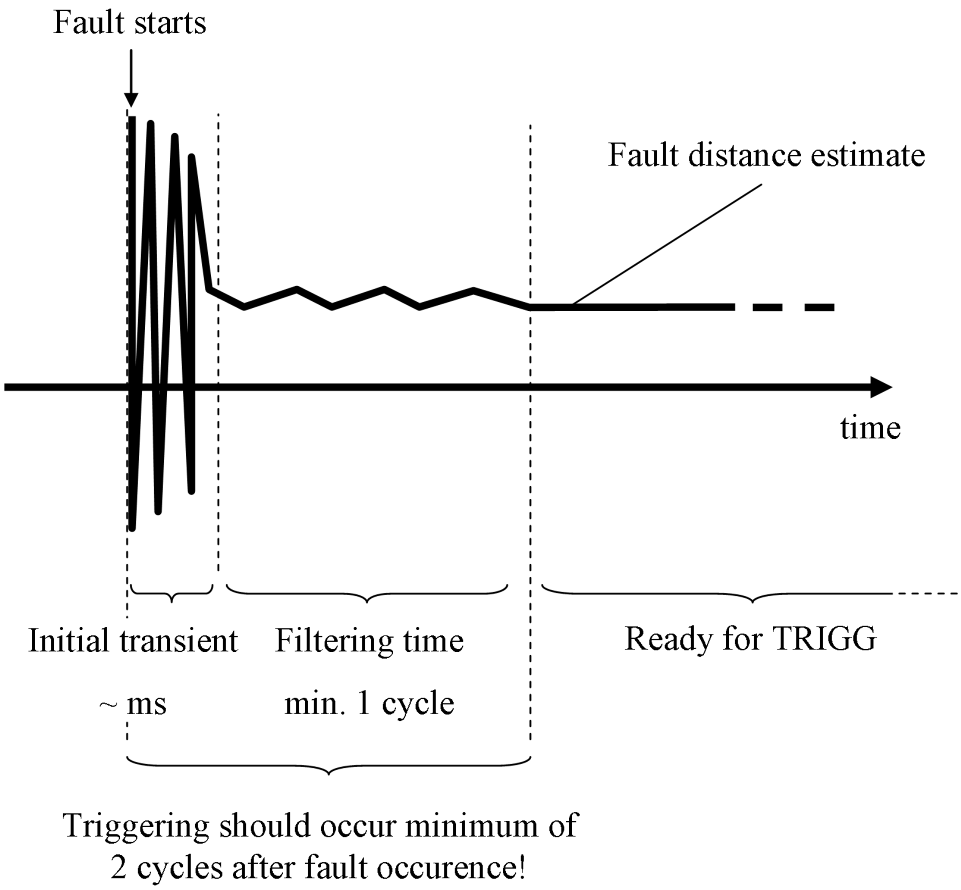


Figure 452: The behavior of the fault distance estimate in time

The actual trigger time is saved in the registers (recorded data). The trigger method is defined with the control parameter *Calculation Trg mode* with the values "External", "Internal" and "Continuous".

External

In case of external triggering, an external trigger signal should be connected to the TRIGG input. The trigger signal is typically a trip signal from a protective function. The TRIGG_OUT output signal can be monitored to see if the distance estimate is updated. The *Pre fault time* setting should be set at a default value of 100 ms using the external triggering. This guarantees that the load compensation uses valid data from the load conditions.

Internal

In case of internal triggering, the TRIGG input is not used for triggering. Instead, the trigger signal is created by PSL. The challenge is to time the triggering moment so that there is sufficient measuring time without the feeder breaker being operated. This is done by timing the actual triggering moment based on the *Pre fault time* setting.

To prove that the internal triggering has time to operate before the feeder breaker is opened, the *Pre fault time* setting must be set to a valuer smaller than or equal to the minimum operating time of the function used for tripping the breaker. For example, if the short circuit protection operating time delay is 0.2 s and the earth-fault protection operating time delay is 0.3 s, *Pre fault time* should be 0.2 s. The actual triggering occurs (200 ms - 40 ms) = 160 ms after PSL has recognized the fault condition. 40 ms is reserved for the PSL function for identifying the fault type.

PSL is a non-directional function and therefore, internal triggering should not be used when directionality is required. The `TRIGG` output can be monitored to see if the distance estimate is updated.

Continuous

Continuous trigger mode can be utilized during the secondary testing of the function block. In this mode, the function outputs are continuously updated at the task time interval and can thus be monitored for testing purposes. Recorded data are updated when the internal or external triggering occurs.

Example configuration for the triggering of SCEFRFLO

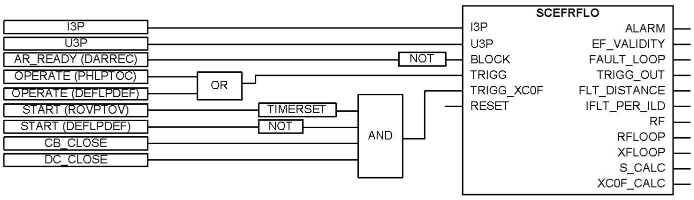


Figure 453: A typical configuration for the triggering of SCEFRFLO

The `OPERATE` signal from the non-directional overcurrent function PHLPTOC is used to provide an indication of a short circuit fault. The `OPERATE` signal from the directional earth-fault function DEFLPDEF is used to provide an indication of an earth fault at the protected feeder.

SCEFRFLO with autoreclosing function

When SCEFRFLO is used with the autoreclosing sequence, the distance estimate from the first trip is typically the most accurate one. The fault distance estimates from successive trips are possible but accuracy may be degraded due to inaccurate load compensation. During the autoreclosing cycle dead time, the load condition of the feeder is unsure.

In unearthed networks, the earth-fault magnitude during normal network configuration may not be enough for an accurate fault location estimate. However, the accuracy of the fault location estimate can be improved by increasing the earth-fault current magnitude. This can be done with proper switching operations that enlarge the background network after the tripping of the faulty feeder. The re-energization of the feeder on to the fault gives the improved estimate for fault distance. The needed switching operations can also be done during the dead time of the delayed autoreclosing sequence.

Triggering of SCEFRFLO may also be inhibited during the autoreclosing sequence. This is achieved by connecting the signal AR_READY from the autoreclosing function that indicates that the autoreclosing sequence is in progress to the BLOCK input of SCEFRFLO. Blocking of SCEFRFLO triggering is suggested during the autoreclosing sequence when the load compensation or steady-state asymmetry elimination is based on the delta quantities. This applies to the short circuit faults (fault loops 12, 23, 31 and the 123) when the setting is *Load Com PP loops = TRUE* or to earth faults with the value *EF algorithm = Load compensation*.

5.4.4.5 Result validity indicator for earth faults

Fault localization is a challenging task. There are many factors that can deteriorate the accuracy of the calculated fault distance estimate. The most important factors are:

- Fault resistance. The smaller the fault resistance, the more accurate the result is likely to be. The accuracy of the fault distance estimation deteriorates if the resistive part of the fault loop impedance becomes much larger than the reactive part due to the large fault resistance. The fault resistance is typically quite low during short circuits. However, it can be the most dominant error source in earth faults.
- Asymmetry. The asymmetry of the line parameters and the loading affects the fault distance estimation accuracy. If the asymmetry has a very high value, the accuracy of the fault distance estimation deteriorates.
- Saturation. The saturation of current or voltage transformers increases certain harmonics, especially the second, the fifth and the seventh. Saturation deteriorates the fault distance estimate.
- In unearthed networks, the ratio between the earth-fault current (R_{fault} = 0 ohms) and load current magnitude is critical. The higher the ratio, the better the fault distance estimate.

Furthermore, the distribution networks have specific features which further complicate and challenge fault localization algorithms. These include, for example, non-homogeneity of lines, presence of laterals and load taps.

The validity of the estimated earth fault distance is judged and reported together with the fault distance estimate. The EF_VALIDITY output has various values:

Table 876: The EF_VALIDITY output values

N/A	Indicator is not applicable (fault type is a short circuit).
High	Result is not affected by error sources.
Moderate	Result is slightly affected by error sources. The additional error in the fault distance estimate can be tens of percents.
Poor	Fault distance algorithm is greatly affected by error sources and cannot function properly. In this case, the result is only trend setting. The result can only indicate, for example, whether the fault is in the beginning or in the end of the feeder section.

5.4.4.6 ALARM output

The SCEFRFLO function contains an alarm output for the calculated fault distance. If the value of the calculated fault distance *FLT_DISTANCE* is between the *Low alarm Dis limit* setting and *High alarm Dis limit*, the ALARM output is set to *TRUE*.

The ALARM output can be utilized, for example, in regions with waterways or other places where knowledge of certain fault locations is of high importance.

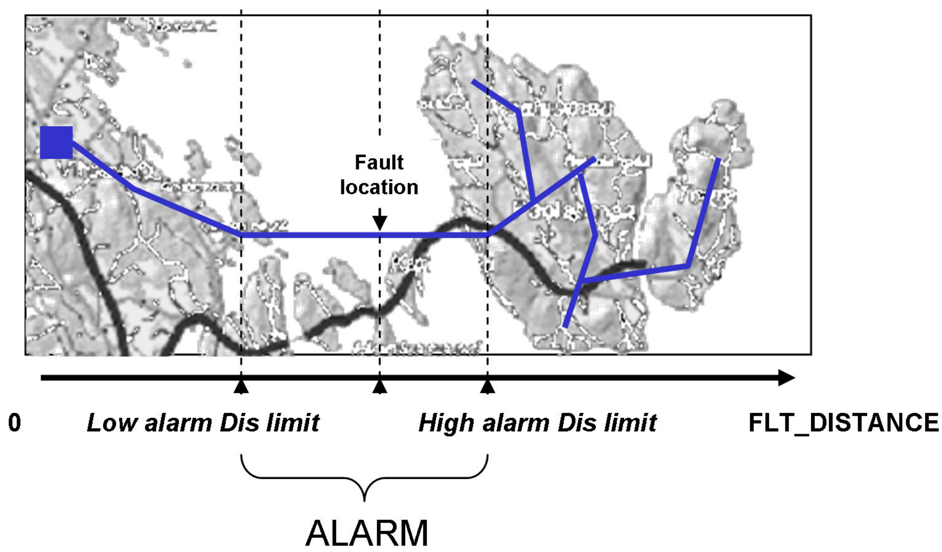


Figure 454: An example of the ALARM output usage

5.4.4.7 Impedance settings

The fault distance calculation in SCEFRFLO is based on the fault impedance loop modeling. The fault loop is parameterized with the impedance settings, for example *R1 line section A, X1 line section A, R0 line section A,* and *X0 line section A*. The earth fault loops (fault loops 1, 2 and 3) require both positive and zero sequence impedances as an initial data. For the short circuit fault loops (fault loops 12, 23, 31 and 123), only positive sequence impedances are needed. Even these can be omitted if the *Simple mode PP loops* = "Enabled". In this case, the conversion of electrical fault distance into a physical distance cannot be done in the IED and the `FLT_DISTANCE` output is not valid.

If the impedance settings are in use, it is important that the settings closely match the impedances through which the fault current flows. The impedance settings, for example *R1 line section A, X1 line section A, R0 line section A,* and *X0 line section A*, are given in the units of primary ohm/pu and the line section lengths in per unit (pu). Pu can be the unit that the user prefers and it allows the user to give the impedances in ohm/km and length in km, for example, (pu = km), or impedance in ohm/mile and length in mile (pu = mile). The resulting fault distance is also obtained in pu and it should match the units entered for the line section lengths.

Table 877: Positive sequence impedance values for typical 11 kV conductors, “Flat” tower configuration assumed

Name	R1 (Ω/km)	X1 (Ω/km)
ACSR 50 sq.mm	0.532	0.373
ACSR 500 sq.mm	0.0725	0.270

Table 878: Positive sequence impedance values for typical 10/20 kV conductors, “Flat” tower configuration assumed

Name	R1 (Ω/km)	X1 (Ω/km)
Al/Fe 36/6 Sparrow	0.915	0.383
Al/Fe 54/9 Raven	0.578	0.368
Al/Fe 85/14 Pigeon	0.364	0.354
Al/Fe 93/39 Imatra	0.335	0.344
Al/Fe 108/23 Vaasa	0.287	0.344
Al/Fe 305/39 Duck	0.103	0.314

Table 879: Positive sequence impedance values for typical 33 kV conductors, “Flat” tower configuration assumed

Name	R1 (Ω/km)	X1 (Ω/km)
ACSR 50 sq.mm	0.529	0.444
ACSR 100 sq.mm	0.394	0.434
ACSR 500 sq.mm	0.0548	0.346

Positive-sequence impedance values

Accurate fault localization requires accurate values of the setting for line impedances. As datasheet impedance values are valid only for a certain tower configuration, the user has to adjust the datasheet impedance values according to the actual install configuration. This minimizes the fault localization error due to inaccurate settings.

The positive sequence reactance per phase can be calculated using the following equation which also applies for symmetrically transposed three-phase aluminum overhead lines without ground wires:

$$X_1 \approx f_n \times 2\pi \times 10^{-4} \left(2 \times \ln \frac{a_{en}}{r} + 0.5 \right) \; [Ohm / km]$$

(Equation 146)

f_n	Fundamental frequency [Hz]
a_{en}	$(a_{12}.a_{23}.a_{31})^{1/3}$ = geometric average of phase distances [m]
a_{xy}	distance [m] between phases X and Y
r	radius [m] for single conductor

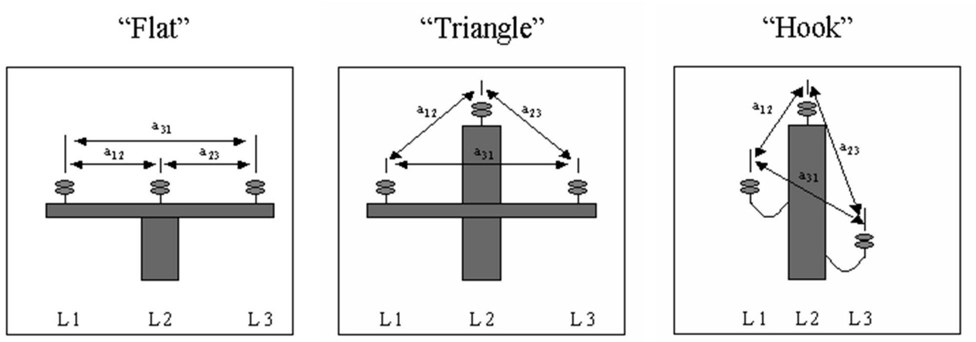


Figure 455: Typical distribution line tower configurations

Zero sequence impedance values

The zero sequence impedances are needed only in case of earth fault localization. In case of the localization of a two-phase or three-phase short-circuit fault, positive sequence impedances are sufficient.

The positive sequence impedance values for the lines are known or can easily be obtained from datasheets. The zero sequence values, on the other hand, are not so easy to obtain as they depend on actual installation conditions and configurations. Sufficient accuracy can, however, be obtained with rather simple calculations using these equations (applies per phase for symmetrically transposed three-phase aluminium overhead lines without ground wires):

$$R0[50Hz] \approx R1 + 0.14804 \; [ohm / km]$$

(Equation 147)

$$R0[60Hz] \approx R1 + 0.17765 \ [ohm/km]$$

(Equation 148)

$$X0 = f_n \times 4\pi \times 10^{-4} \times \left(3 \times \ln \frac{W}{r_{en}} + 0.25\right) \ [ohm/km]$$

(Equation 149)

R1	conductor AC resistance [ohm/km]
f_n	fundamental frequency [Hz]
W	$658\sqrt{\frac{\rho_{earth}}{f_n}}$ = equivalent depth [m] of the earth return path
ρ_{earth}	earth resistivity [ohm, m]
r_{en}	$\left(r \cdot (a_{12}^2 \cdot a_{23}^2 \cdot a_{31}^2)^{\frac{1}{3}}\right)^{\frac{1}{3}}$ = equivalent radius [m] for conductor bundle
r	radius [m] for single conductor
a_{xy}	distance [m] between phases X and Y

Settings Ph leakage Ris and Ph capacitive React

The *Ph leakage Ris* and *Ph capacitive React* settings are used for improving fault distance estimation accuracy due to earth faults. They are critical in finding the accurate fault location in unearthed networks. In other types of networks, they are less critical.

The *Ph leakage Ris* setting represents the leakage losses (resistive losses due to insulators and so on) of the protected feeder in terms of resistance per phase. The *Ph capacitive React* setting represents the total phase-to-earth capacitive reactance of the protected feeder per phase. Based on experience, a proper estimate for the *Ph leakage Ris* is greater than 20 to 40 times *Ph capacitive React*.

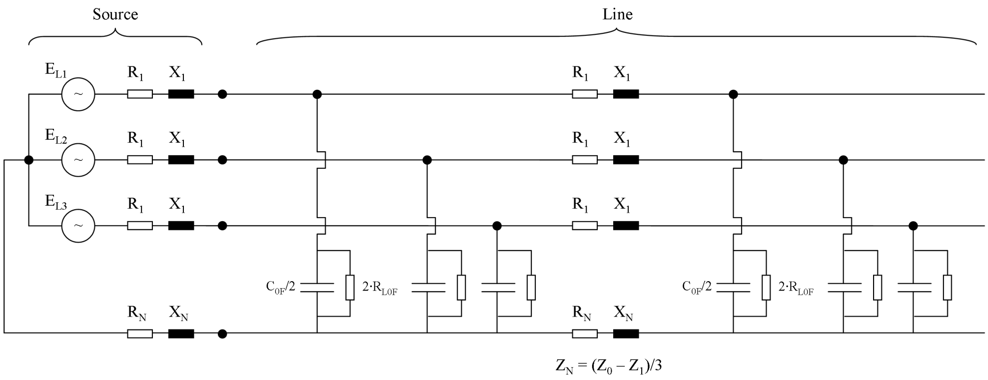


Figure 456: Equivalent diagram of the protected feeder, RL0F = Ph leakage Ris

The determination of the value of the *Ph capacitive React* setting can be based either on network data or measurement.

If the total phase-to-earth capacitance (including all branches) per phase C_{0F} of the protected feeder is known,

$$Ph\ capacitive\ React = 1/(\omega \times C_{0F}),\ \omega = 2 \times \pi \times fn$$

(Equation 150)

f_n system nominal frequency (50 Hz or 60 Hz)

If the earth-fault current of protected feeder I_{ef} is known (R_f=0 ohm) in case of an unearthed network, then the corresponding earth capacitance per phase can be calculated using the equation:

$$C_{OF} = \frac{I_{ef}}{3 \cdot \omega \cdot U_V}$$

(Equation 151)

U_V phase-to-ground voltage

SCEFRFLO can also determine the value for the *Ph capacitive React* setting by measurements. The calculation of the value of *Ph capacitive React* setting is accomplished by conducting an earth-fault test outside the protected feeder during commissioning, for example at the substation busbar. The calculated value of the *Ph capacitive React* setting is obtained from the `XC0F_CALC` output. This value must be manually entered for the *Ph capacitive React* setting.

The calculated value matches the current switching state of the feeder and if the switching state of the protected feeder changes, the value is no longer valid. In this case, the setting should be updated, for example by repeating the test.

The calculation procedure of the *Ph capacitive React* setting is triggered by the binary signal connected to the TRIGG_XC0F input. The trigger signal should indicate that an earth-fault is detected outside the protected feeder.

Figure 457 shows a typical configuration of the *Ph capacitive React* setting calculation triggering.

The logic is based on:

- If the earth-fault is detected by overvoltage function (START of ROVPTOV) and fault is not seen by forward looking earth-fault protection functions (START of DEFLPDEF), then after a set delay (TIMERSET) output XC0F_CALC is updated.
- The Delay (TIMERSET) must be set longer than the start delay of directional earth-fault function (DEFLPEF) inside terminal , but shorter than the minimum operate time of directional earth-fault functions in the substation. For example, if the start delay is 100 ms and the shortest operate time 300 ms, then a value of 200 ms can be used.
- Additionally, circuit breaker and disconnector status is used to verify that entire feeder is measured.

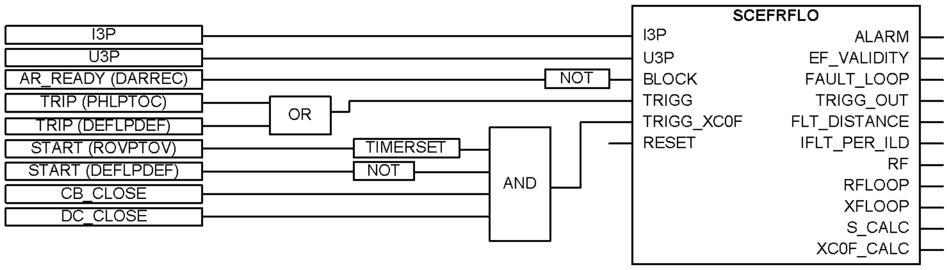


Figure 457: Typical configuration for XC0F calculation triggering

Modelling a non-homogenous line

A typical distribution feeder is built with several different types of overhead lines and cables. This means that the feeder is electrically non-homogenous. The impedance diagram is non-linear.

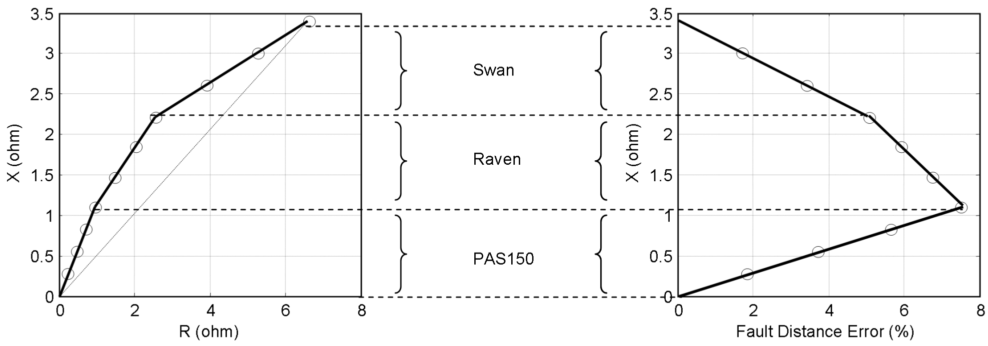


Figure 458: Non-homogeneity of a feeder in an impedance diagram

If the impedance of an individual line section varies, an accurate conversion of the fault loop reactance into a physical fault distance, for example into kilometres, is not possible with only one impedance setting. Therefore, SCEFRFLO allows the modeling of the line impedance variation in IED with three line sections and with independent impedance settings. This improves the accuracy of the physical fault distance conversion done in the IED, especially in cases where the line impedance non-homogeneity is severe. The number of line sections used in the conversion procedure from ohmic fault distance into physical fault distance are defined by using the *Num of line sections* setting.

If *Num of line sections = 0*, the conversion of the electrical fault distance into a physical distance is not done in the IED and the `FLT_DISTANCE` output is not valid. Estimated impedances are still calculated and are shown on their respective outputs. In order to guarantee accurate impedance estimation, the user should give as good values as possible for the longitudinal impedance settings *R1 line section A, X1 line section A, R0 line section A, X0 line section A* and the *Line Len section A* parameter corresponding to the total line length. Other longitudinal impedance settings are disabled (sections B and C).

If *Num of line sections = 1*, the longitudinal impedance settings *R1 line section A, X1 line section A, R0 line section A, X0 line section A* and the *Line Len section A* parameter are enabled for the conversion of the electrical fault distance into a physical distance. This option should be used only in the case of a homogeneous line, for example, when the protected feeder consists of only one conductor type. Also this option should be used if the user is only interested in calculated fault loop reactance XFLOOP and final fault location is done in higher system level utilizing, for example DMS-system.

If *Num of line sections = 2*, the longitudinal impedance settings *R1 line section A, X1 line section A, R0 line section A, X0 line section A, R1 line section B, X1 line section B, R0 line section B, X0 line section B* and the parameters *Line Len section A, Line Len section B* are enabled for the conversion of the electrical fault distance into a physical distance. This option should be used in the case of a non-homogenous line, for example, when the protected feeder consists of two types of conductors.

If *Num of line sections = 3*, the longitudinal impedance settings *R1 line section A, X1 line section A, R0 line section A, X0 line section A, R1 line section B, X1 line section B, R0 line section B, X0 line section B, R1 line section C, X1 line section C, R0 line section C, X0 line section C* and the parameters *Line Len section A, Line Len section B, Line Len section C* are enabled for the conversion of the electrical fault distance into a physical distance. This option should be used in the case of a non-homogenous line, for example, when the protected feeder consists of more than two types of conductors.

In order to illustrate the effect of line impedance non-homogeneity in conversion of fault loop reactance into physical fault distance, consider a 10 km long feeder with 3 line types:

- 4 km of PAS 150 (R1 = 0.236 ohm/km, X1 = 0.276 ohm/km)
- 3 km of Al/Fe 54/9 Raven (R1 = 0.536 ohm/km, X1 = 0.369 ohm/km)
- 3 km of Al/Fe 21/4 Swan (R1 = 1.350 ohm/km, X1 = 0.398 ohm/km)

The total line impedance for the 10 km line is R1 = 6.602 ohm (0.6602 ohm/km) and X1 = 3.405 ohm (0.3405 ohm/km). The example impedance diagram, Figure 458, illustrates the conversion error as a function of physical fault location if only one impedance setting was used:

R1 line section A	0.6602 ohm/pu
X1 line section A	0.3405 ohm/pu
Line Len section A	10 pu
Num of line sections	1

At the maximum, an error of nearly eight percent is created by the conversion procedure. Figure 458 shows an example of impedance diagram of the protected feeder in the case of a non-homogenous line (on the left) and a physical fault distance error due to conversion with one impedance setting (on the right). The fault location is varied from 1 km to 10 km in 1 km steps (marked with circles).

With three impedance settings there is no error in conversion:

R1 line section A	0.236 ohm/pu
X1 line section A	0.276 ohm/pu
Line Len section A	4 pu
R1 line section B	0.536 ohm/pu
X1 line section B	0.369 ohm/pu
Line Len section B	3 pu
R1 line section C	1.350 ohm/pu
X1 line section C	0.398 ohm/pu
Line Len section C	3 pu
Num of line sections	3

The previous example assumed a short-circuit fault and therefore only positive-sequence impedance settings were used. The results, however, also apply for earth faults.

Taps or spurs in the feeder

If the protected feeder consists of taps or spurs, the measured fault impedance can correspond to several physical fault locations, for example A or B as shown in the diagram. The actual fault location must be identified using additional information, for example the short circuit current indicators placed on the tapping points.

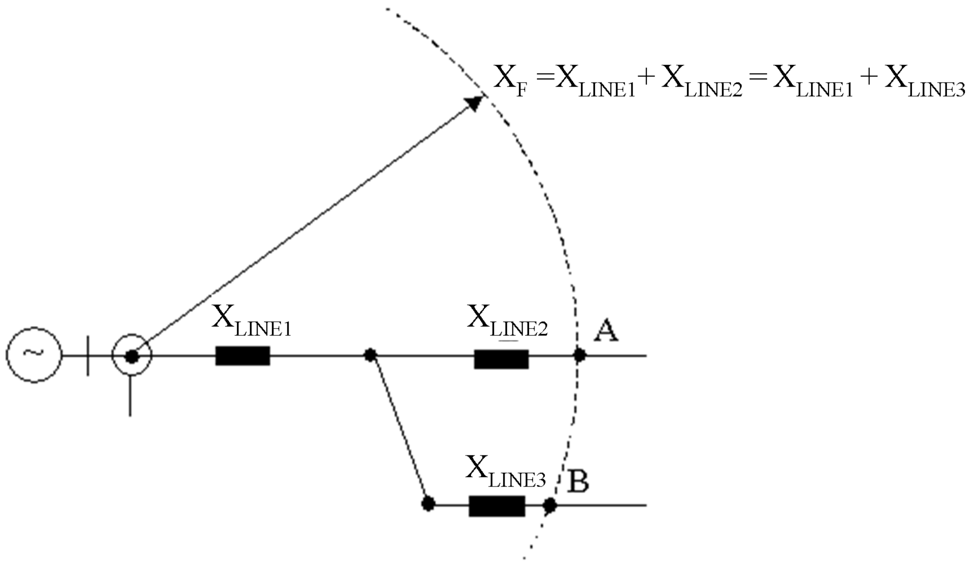


Figure 459: Fault on a distribution feeder with spurs

5.4.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

5.4.6 Recorded data

General

All the information required later for fault analysis is recorded when the recording function of SCEFRFLO is triggered. The triggering can be either internal or external.

Table 880: Recorded data of the SCEFRFLO

Parameter name	Description
1 Recording time	Record data of bank 1 for trigger time stamp
1 FAULT_LOOP	Record data of bank 1 for fault loop
1 RF	Record data of bank 1 for fault resistance
1 RFLOOP	Record data of bank 1 for fault loop resistance
1 XFLOOP	Record data of bank 1 for fault loop reactance
1 FLT_DISTANCE	Record data of bank 1 for fault distance
1 XCOF_CALC	Record data of bank 1 for line phase-to-earth capacitance
1 S_CALC	Record data of bank 1 for equivalent load distance
1 IFLT_PER_ILD	Record data of bank 1 for ratio between fault current and load current
1 EF_VALIDITY	Record data of bank 1 for validity of earth-fault location
1 ALARM	Record data of bank 1 for alarm signal
1 PhV Pre value PhA	Record data of bank 1 for phase A pre-fault voltage amplitude
1 PhV Pre angle PhA	Record data of bank 1 for phase A pre-fault voltage angle
1 PhV Pre value PhB	Record data of bank 1 for phase B pre-fault voltage amplitude
1 PhV Pre angle PhB	Record data of bank 1 for phase B pre-fault voltage angle
1 PhV Pre value PhC	Record data of bank 1 for phase C pre-fault voltage amplitude
1 PhV Pre angle PhC	Record data of bank 1 for phase C pre-fault voltage angle
1 A Pre value PhA	Record data of bank 1 for phase A pre-fault current amplitude
1 A Pre angle PhA	Record data of bank 1 for phase A pre-fault current angle
1 A Pre value PhB	Record data of bank 1 for phase B pre-fault current amplitude
1 A Pre angle PhB	Record data of bank 1 for phase B pre-fault current angle
1 A Pre value PhC	Record data of bank 1 for phase C pre-fault current amplitude
1 A Pre angle PhC	Record data of bank 1 for phase C pre-fault current angle
1 PhV Flt value PhA	Record data of bank 1 for phase A voltage amplitude during fault
Table continues on next page	

Parameter name	Description
1 PhV Flt angle PhA	Record data of bank 1 for phase A voltage angle during fault
1 PhV Flt value PhB	Record data of bank 1 for phase B voltage amplitude during fault
1 PhV Flt angle PhB	Record data of bank 1 for phase B voltage angle during fault
1 PhV Flt value PhC	Record data of bank 1 for phase C voltage amplitude during fault
1 PhV Flt angle PhC	Record data of bank 1 for phase C voltage angle during fault
1 A Flt value PhA	Record data of bank 1 for phase A current amplitude during fault
1 A Flt angle PhA	Record data of bank 1 for phase A current angle during fault
1 A Flt value PhB	Record data of bank 1 for phase B current amplitude during fault
1 A Flt angle PhB	Record data of bank 1 for phase B current angle during fault
1 A Flt value PhC	Record data of bank 1 for phase C current amplitude during fault
1 A Flt angle PhC	Record data of bank 1 for phase C current angle during fault

The registers can be reset with the `RESET` binary input signal.

Three sets of recorded data are available in total. They are saved in data banks 1...3. Data bank 1 holds the most recent recorded data and older data are moved into the next banks (1 to 2 and 2 to 3) when a fault is detected. When all three banks have data and a new unbalance is detected, the latest data set is placed into bank 1 and the data in bank 3 is overwritten by the data from bank 2

5.4.7 Application

The main objective of line protection and monitoring terminals is fast, selective and reliable operation for faults on a protected line section. Besides this, information on the distance to fault is very important for those involved in operation and maintenance. Reliable information on the fault location greatly decreases the downtime of the protected lines and increases the total availability of a power system.

SCEFRFLO can be applied as a device level solution or as a part of a system level solution. In the device level applications, the physical fault distance (FLT_DISTANCE) is calculated in the IED based on settings. A more accurate result can be expected if the fault loop impedance (XFLOOP, RFLOOP) estimated by SCEFRFLO is utilized in the system level fault location applications.

SCEFRFLO provides the distance to the fault together with the information about the measuring loop that has been used in the calculation. Also, an estimate for the fault resistance at the fault point is calculated. In addition, both pre-fault and fault quantities of voltages and currents are available for a post-fault analysis in the recorded data. The validity of the estimated earth-fault distance is judged and reported together with the fault distance estimate.

5.4.8 Configuration

SCEFRFLO requires three phase currents for operation. The phase currents can be measured with conventional current transformers or Rogowski coils.

The full operation of SCEFRFLO requires that all three phase-to-earth voltages are measured. The voltages can be measured with conventional voltage transformers or voltage dividers connected between the phase and earth. Other alternative is to measure phase-to-phase voltages and residual voltage (Uo). Both alternatives are covered by setting the configuration parameter *Phase voltage Meas* to "Accurate". When the *Phase voltage Meas* setting is set to "PP without Uo" and only phase-to-phase voltages are available, only short-circuit measuring loops (fault loops 12, 23, 31, 123) can be measured accurately. In this case, the earth-fault loops (fault loops 1, 2, 3) cannot provide correct fault distance estimates and the triggering of the function is automatically disabled.

5.4.9 Signals

Table 881: SCEFRFLO Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Signal for blocking the triggering
TRIGG	BOOLEAN	0	Triggering signal for outputs of the function
TRIGG_XC0F	BOOLEAN	0	Triggering signal for XC0F calculation
RESET	BOOLEAN	0	Input signal for resetting registers

Table 882: SCEFRFLO Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm signal indicating that fault is located between set limits
EF_VALIDITY	INTEGER	Validity of earth fault location
FAULT_LOOP	INTEGER	Fault impedance loop used for distance measurement
TRIGG_OUT	BOOLEAN	Signal indicating function triggering
FLT_DISTANCE	REAL	Fault distance in units selected by the user (pu)
IFLT_PER_ILD	REAL	Ratio between fault current and load current in case of an earth fault
RF	REAL	Fault resistance in primary ohms
RFLOOP	REAL	Fault loop resistance in primary ohms
XFLOOP	REAL	Fault loop reactance in primary ohms
Table continues on next page		

Name	Type	Description
XFPHASE	REAL	Positive sequence fault reactance in primary ohms
S_CALC	REAL	Estimated equivalent load distance
XC0F_CALC	REAL	Estimated phase-to-earth capacitive reactance of the feeder

5.4.10 Settings

Table 883: SCEFRFLO Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Z Max phase load	1.00 - 10000.00	ohm	0.01	80.00	Impedance per phase of max. load, over-curr./under-imp., PSL
Ph leakage Ris	1 - 1000000	ohm	1	210000	Line PhE leakage resistance in primary ohms
Ph capacitive React	1 - 1000000	ohm	1	7000	Line PhE capacitive reactance in primary ohms
R1 line section A	0.001 - 1000.000	ohm/pu	0.001	1.000	Positive-sequence line resistance, line section A
X1 line section A	0.001 - 1000.000	ohm/pu	0.001	1.000	Positive-sequence line reactance, line section A
R0 line section A	0.001 - 1000.000	ohm/pu	0.001	4.000	Zero-sequence line resistance, line section A
X0 line section A	0.001 - 1000.000	ohm/pu	0.001	4.000	Zero-sequence line reactance, line section A
Line Len section A	0.001 - 1000.000	pu	0.001	1.000	Line length, section A

Table 884: SCEFRFLO Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Equivalent load Dis	0.01 - 1.00	-	0.01	0.50	Equivalent load distance when EF algorithm = load modelling
Num of line sections	0 - 3	-	1	1	Number of line sections
R1 line section B	0.001 - 1000.000	ohm/pu	0.001	1.000	Positive-sequence line resistance, line section B
X1 line section B	0.001 - 1000.000	ohm/pu	0.001	1.000	Positive-sequence line reactance, line section B
R0 line section B	0.001 - 1000.000	ohm/pu	0.001	4.000	Zero-sequence line resistance, line section B
X0 line section B	0.001 - 1000.000	ohm/pu	0.001	4.000	Zero-sequence line reactance, line section B
Line Len section B	0.001 - 1000.000	pu	0.001	1.000	Line length, section B
R1 line section C	0.001 - 1000.000	ohm/pu	0.001	1.000	Positive-sequence line resistance, line section C
X1 line section C	0.001 - 1000.000	ohm/pu	0.001	1.000	Positive-sequence line reactance, line section C
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
R0 line section C	0.001 - 1000.000	ohm/pu	0.001	4.000	Zero-sequence line resistance, line section C
X0 line section C	0.001 - 1000.000	ohm/pu	0.001	4.000	Zero-sequence line reactance, line section C
Line Len section C	0.001 - 1000.000	pu	0.001	1.000	Line length, section C

Table 885: SCEFRFLO Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation mode Off / On
Phase voltage Meas	Accurate PP without Uo	-	-	Accurate	Phase voltage measurement principle
Calculation Trg mode	External Internal Continuous	-	-	External	Trigger mode for distance calculation
Pre fault time	0.100 - 300.000	s	0.001	0.100	Time delay for healthy values of I and U before fault [s]

Table 886: SCEFRFLO Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
High alarm Dis limit	0.001 - 1.000	pu	0.001	1.000	High alarm limit for calculated distance
Low alarm Dis limit	0.001 - 1.000	pu	0.001	1.000	Low alarm limit for calculated distance
EF algorithm	Load comp Load modelling	-	-	Load comp	PE-loop calculation algorithm
EF algorithm current	I0 based I2 based	-	-	I0 based	Earth-fault current model
Load Com PP loops	Disabled Enabled	-	-	Enabled	Enable load compensation for PP/3P-loops
Simple mode PP loops	Disabled Enabled	-	-	Disabled	Enable calc. without impedance settings for PP/3P-loops

5.4.11 Measured values

Table 887: SCEFRFLO Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Amplitude of the phase A current
I_AMPL_B	REAL	0	Amplitude of the phase B current
I_AMPL_C	REAL	0	Amplitude of the phase C current
U_AMPL_A	REAL	0	Amplitude of the phase A voltage
U_AMPL_B	REAL	0	Amplitude of the phase B voltage

Table continues on next page

Name	Type	Default	Description
U_AMPL_C	REAL	0	Amplitude of the phase C voltage
BLOCK	BOOLEAN	0	Signal for blocking the triggering
TRIGG	BOOLEAN	0	Triggering signal for outputs of the function
TRIGG_XC0F	BOOLEAN	0	Triggering signal for XC0F calculation
RESET	BOOLEAN	0	Input signal for resetting registers

5.4.12 Monitored data

Table 888: SCEFRFLO Monitored data

Name	Type	Values (Range)	Unit	Description
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal indicating that fault is located between set limits
EF_VALIDITY	INTEGER	1=High 0=N/A 2=Moderate 3=Poor	-	Validity of earth fault location
FAULT_LOOP	INTEGER	1=Phase A to Gnd 2=Phase B to Gnd 3=Phase C to Gnd 4=Phase A to B 5=Phase B to C 6=Phase C to A 7=Three phase 0=No fault	-	Fault impedance loop used for distance measurement
TRIGG_OUT	BOOLEAN	0=FALSE 1=TRUE	-	Signal indicating function triggering
RF	REAL	-	ohm	Fault resistance in primary ohms
RFLOOP	REAL	-	ohm	Fault loop resistance in primary ohms
XFLOOP	REAL	-	ohm	Fault loop reactance in primary ohms
XFPHASE	REAL	-	ohm	Positive sequence fault reactance in primary ohms
XC0F_CALC	REAL	-	ohm	Estimated phase-to-earth capacitive reactance of the feeder
1 Recording time	INTEGER	-	-	Record data of bank 1 for fault time stamp
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
1 FAULT_LOOP	INTEGER	1=Phase A to Gnd 2=Phase B to Gnd 3=Phase C to Gnd 4=Phase A to B 5=Phase B to C 6=Phase C to A 7=Three phase 0=No fault	-	Record data of bank 1 for fault loop
1 RF	REAL	-	Ohm	Record data of bank 1 for fault resistance
1 RFLOOP	REAL	-	Ohm	Record data of bank 1 for fault loop resistance
1 XFLOOP	REAL	-	Ohm	Record data of bank 1 for fault loop reactance
1 FLT_DISTANCE	REAL	-	-	Record data of bank 1 for fault distance
1 XC0F_CALC	REAL	-	Ohm	Record data bank1 feeder phase-to-earth capacitive reactance
1 S_CALC	REAL	-	-	Record data of bank 1 for equivalent load distance
1 IFLT_PER_ILD	REAL	-	-	Record data of bank 1 for ratio between fault current and load current
1 EF_VALIDITY	INTEGER	1=High 0=N/A 2=Moderate 3=Poor	-	Record data of bank 1 for validity of earth fault location
1 ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Record data of bank 1 for alarm signal
1 A Pre value PhA	REAL	-	A	Record data of bank 1 for phase A pre-fault current amplitude
1 A Pre angle PhA	REAL	-	deg	Record data of bank 1 for phase A pre-fault current angle
1 A Pre value PhB	REAL	-	A	Record data of bank 1 for phase B pre-fault current amplitude
1 A Pre angle PhB	REAL	-	deg	Record data of bank 1 for phase B pre-fault current angle
1 A Pre value PhC	REAL	-	A	Record data of bank 1 for phase C pre-fault current amplitude
1 A Pre angle PhC	REAL	-	deg	Record data of bank 1 for phase C pre-fault current angle

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 A Flt value PhA	REAL	-	A	Record data of bank 1 for phase A current amplitude during fault
1 A Flt angle PhA	REAL	-	deg	Record data of bank 1 for phase A current angle during fault
1 A Flt value PhB	REAL	-	A	Record data of bank 1 for phase B current amplitude during fault
1 A Flt angle PhB	REAL	-	deg	Record data of bank 1 for phase B current angle during fault
1 A Flt value PhC	REAL	-	A	Record data of bank 1 for phase C current amplitude during fault
1 A Flt angle PhC	REAL	-	deg	Record data of bank 1 for phase C current angle during fault
1 PhV Pre value PhA	REAL	-	kV	Record data of bank 1 for phase A pre-fault voltage amplitude
1 PhV Pre angle PhA	REAL	-	deg	Record data of bank 1 for phase A pre-fault voltage angle
1 PhV Pre value PhB	REAL	-	kV	Record data of bank 1 for phase B pre-fault voltage amplitude
1 PhV Pre angle PhB	REAL	-	deg	Record data of bank 1 for phase B pre-fault voltage angle
1 PhV Pre value PhC	REAL	-	kV	Record data of bank 1 for phase C pre-fault voltage amplitude
1 PhV Pre angle PhC	REAL	-	deg	Record data of bank 1 for phase C pre-fault voltage angle
1 PhV Flt value PhA	REAL	-	kV	Record data of bank 1 for phase A voltage amplitude during fault
1 PhV Flt angle PhA	REAL	-	deg	Record data of bank 1 for phase A voltage angle during fault
1 PhV Flt value PhB	REAL	-	kV	Record data of bank 1 for phase B voltage amplitude during fault
1 PhV Flt angle PhB	REAL	-	deg	Record data of bank 1 for phase B voltage angle during fault
1 PhV Flt value PhC	REAL	-	kV	Record data of bank 1 for phase C voltage amplitude during fault

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 PhV Flt angle PhC	REAL	-	deg	Record data of bank 1 for phase C voltage angle during fault
2 Recording time	INTEGER	-	-	Record data of bank 2 for fault time stamp
2 FAULT_LOOP	INTEGER	1=Phase A to Gnd 2=Phase B to Gnd 3=Phase C to Gnd 4=Phase A to B 5=Phase B to C 6=Phase C to A 7=Three phase 0=No fault	-	Record data of bank 2 for fault loop
2 RF	REAL	-	Ohm	Record data of bank 2 for fault resistance
2 RFLOOP	REAL	-	Ohm	Record data of bank 2 for fault loop resistance
2 XFLOOP	REAL	-	Ohm	Record data of bank 2 for fault loop reactance
2 FLT_DISTANCE	REAL	-	-	Record data of bank 2 for fault distance
2 XC0F_CALC	REAL	-	Ohm	Record data bank2 feeder phase-to-earth capacitive reactance
2 S_CALC	REAL	-	-	Record data of bank 2 for equivalent load distance
2 IFLT_PER_ILD	REAL	-	-	Record data of bank 2 for ratio between fault current and load current
2 EF_VALIDITY	INTEGER	1=High 0=N/A 2=Moderate 3=Poor	-	Record data of bank 2 for validity of earth fault location
2 ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Record data of bank 2 for alarm signal
2 A Pre value PhA	REAL	-	A	Record data of bank 2 for phase A pre-fault current amplitude
2 A Pre angle PhA	REAL	-	deg	Record data of bank 2 for phase A pre-fault current angle
2 A Pre value PhB	REAL	-	A	Record data of bank 2 for phase B pre-fault current amplitude
2 A Pre angle PhB	REAL	-	deg	Record data of bank 2 for phase B pre-fault current angle
2 A Pre value PhC	REAL	-	A	Record data of bank 2 for phase C pre-fault current amplitude

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 A Pre angle PhC	REAL	-	deg	Record data of bank 2 for phase C pre-fault current angle
2 A Flt value PhA	REAL	-	A	Record data of bank 2 for phase A current amplitude during fault
2 A Flt angle PhA	REAL	-	deg	Record data of bank 2 for phase A current angle during fault
2 A Flt value PhB	REAL	-	A	Record data of bank 2 for phase B current amplitude during fault
2 A Flt angle PhB	REAL	-	deg	Record data of bank 2 for phase B current angle during fault
2 A Flt value PhC	REAL	-	A	Record data of bank 2 for phase C current amplitude during fault
2 A Flt angle PhC	REAL	-	deg	Record data of bank 2 for phase C current angle during fault
2 PhV Pre value PhA	REAL	-	kV	Record data of bank 2 for phase A pre-fault voltage amplitude
2 PhV Pre angle PhA	REAL	-	deg	Record data of bank 2 for phase A pre-fault voltage angle
2 PhV Pre value PhB	REAL	-	kV	Record data of bank 2 for phase B pre-fault voltage amplitude
2 PhV Pre angle PhB	REAL	-	deg	Record data of bank 2 for phase B pre-fault voltage angle
2 PhV Pre value PhC	REAL	-	kV	Record data of bank 2 for phase C pre-fault voltage amplitude
2 PhV Pre angle PhC	REAL	-	deg	Record data of bank 2 for phase C pre-fault voltage angle
2 PhV Flt value PhA	REAL	-	kV	Record data of bank 2 for phase A voltage amplitude during fault
2 PhV Flt angle PhA	REAL	-	deg	Record data of bank 2 for phase A voltage angle during fault
2 PhV Flt value PhB	REAL	-	kV	Record data of bank 2 for phase B voltage amplitude during fault
2 PhV Flt angle PhB	REAL	-	deg	Record data of bank 2 for phase B voltage angle during fault

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 PhV Flt value PhC	REAL	-	kV	Record data of bank 2 for phase C voltage amplitude during fault
2 PhV Flt angle PhC	REAL	-	deg	Record data of bank 2 for phase C voltage angle during fault
3 Recording time	INTEGER	-	-	Record data of bank 3 for fault time stamp
3 FAULT_LOOP	INTEGER	1=Phase A to Gnd 2=Phase B to Gnd 3=Phase C to Gnd 4=Phase A to B 5=Phase B to C 6=Phase C to A 7=Three phase 0=No fault	-	Record data of bank 3 for fault loop
3 RF	REAL	-	Ohm	Record data of bank 3 for fault resistance
3 RFLOOP	REAL	-	Ohm	Record data of bank 3 for fault loop resistance
3 XFLOOP	REAL	-	Ohm	Record data of bank 3 for fault loop reactance
3 FLT_DISTANCE	REAL	-	-	Record data of bank 3 for fault distance
3 XC0F_CALC	REAL	-	Ohm	Record data bank3 feeder phase-to-earth capacitive reactance
3 S_CALC	REAL	-	-	Record data of bank 3 for equivalent load distance
3 IFLT_PER_ILD	REAL	-	-	Record data of bank 3 for ratio between fault current and load current
3 EF_VALIDITY	INTEGER	1=High 0=N/A 2=Moderate 3=Poor	-	Record data of bank 3 for validity of earth fault location
3 ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Record data of bank 3 for alarm signal
3 A Pre value PhA	REAL	-	A	Record data of bank 3 for phase A pre-fault current amplitude
3 A Pre angle PhA	REAL	-	deg	Record data of bank 3 for phase A pre-fault current angle
3 A Pre value PhB	REAL	-	A	Record data of bank 3 for phase B pre-fault current amplitude
3 A Pre angle PhB	REAL	-	deg	Record data of bank 3 for phase B pre-fault current angle

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3 A Pre value PhC	REAL	-	A	Record data of bank 3 for phase C pre-fault current amplitude
3 A Pre angle PhC	REAL	-	deg	Record data of bank 3 for phase C pre-fault current angle
3 A Flt value PhA	REAL	-	A	Record data of bank 3 for phase A current amplitude during fault
3 A Flt angle PhA	REAL	-	deg	Record data of bank 3 for phase A current angle during fault
3 A Flt value PhB	REAL	-	A	Record data of bank 3 for phase B current amplitude during fault
3 A Flt angle PhB	REAL	-	deg	Record data of bank 3 for phase B current angle during fault
3 A Flt value PhC	REAL	-	A	Record data of bank 3 for phase C current amplitude during fault
3 A Flt angle PhC	REAL	-	deg	Record data of bank 3 for phase C current angle during fault
3 PhV Pre value PhA	REAL	-	kV	Record data of bank 3 for phase A pre-fault voltage amplitude
3 PhV Pre angle PhA	REAL	-	deg	Record data of bank 3 for phase A pre-fault voltage angle
3 PhV Pre value PhB	REAL	-	kV	Record data of bank 3 for phase B pre-fault voltage amplitude
3 PhV Pre angle PhB	REAL	-	deg	Record data of bank 3 for phase B pre-fault voltage angle
3 PhV Pre value PhC	REAL	-	kV	Record data of bank 3 for phase C pre-fault voltage amplitude
3 PhV Pre angle PhC	REAL	-	deg	Record data of bank 3 for phase C pre-fault voltage angle
3 PhV Flt value PhA	REAL	-	kV	Record data of bank 3 for phase A voltage amplitude during fault
3 PhV Flt angle PhA	REAL	-	deg	Record data of bank 3 for phase A voltage angle during fault
3 PhV Flt value PhB	REAL	-	kV	Record data of bank 3 for phase B voltage amplitude during fault

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3 PhV Flt angle PhB	REAL	-	deg	Record data of bank 3 for phase B voltage angle during fault
3 PhV Flt value PhC	REAL	-	kV	Record data of bank 3 for phase C voltage amplitude during fault
3 PhV Flt angle PhC	REAL	-	deg	Record data of bank 3 for phase C voltage angle during fault

5.4.13 Technical data

Table 889: SCEFRFLO Technical data

Characteristic	Value
Operation accuracies	At the frequency $f = f_n$
	Current: ±1.5% of the set value or $\pm 0.002 \times I_n$ Voltage: ±1.5% of the set value or $\pm 0.002 \times U_n$ Fault location accuracy: ±2.5% of the line length or ±0.2 km/0.13 mile. Actual fault location accuracy depends on the fault and the power system characteristics.
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

5.4.14 Technical revision history

Table 890: SCEFRFLO technical revision history

Technical revision	Change
B	Additional recording data bank 2 and 3 added
C	Output `XFPHASE` is added

5.5 Switch onto fault CVRSOF

5.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Automatic switch-onto-fault logic	CVRSOF	SOTF	SOTF

5.5.2 Function block

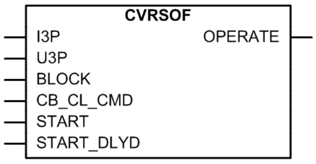


Figure 460: Function block

5.5.3 Functionality

CVRSOF is a complementary function, especially for the distance protection function (DSTPDIS), but it can also be used to complement the non-directional or directional overcurrent protection functions (PHxPTOC, DPHxPDOC).

CVRSOF accelerates the operation of the protection, ensuring a fast trip when the breaker is closed onto faulted feeder or bus. Without CVRSOF, there is a risk that if the breaker is closed onto close-in three-phase fault, the measured voltages may be too small for the impedance zones or the directional overcurrent stages to operate reliably. This condition exists when the voltage transformers are located in the feeder or the bus side to be energized and therefore the voltage memory required for a correct directional measurement is not available.

5.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of automatic switch-onto-fault logic can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

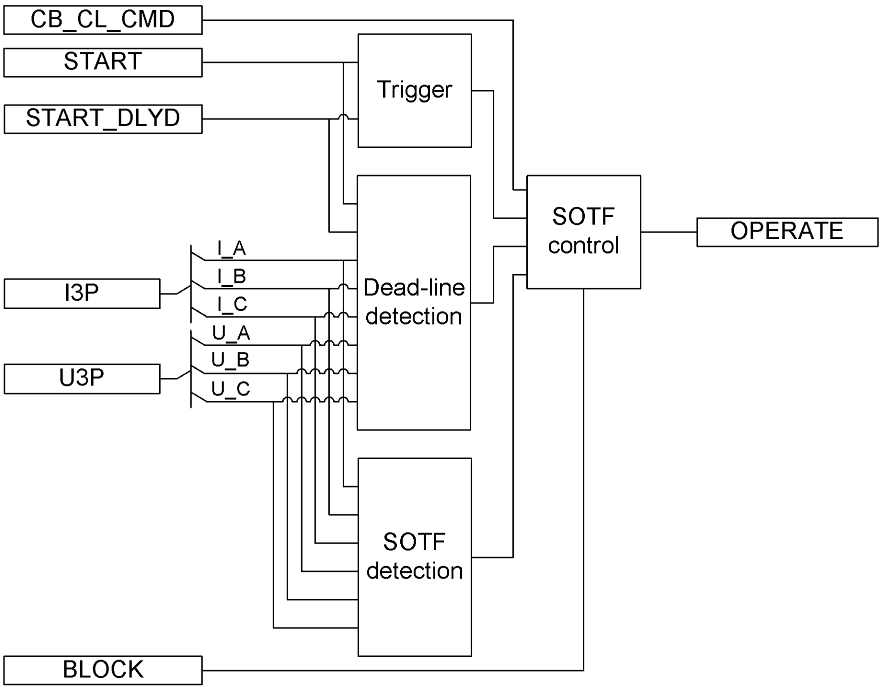


Figure 461: Functional module diagram

Trigger

This module is used for detecting a possible fault immediately after circuit breaker closing. The use of external protection function (typically the start-signal from a non-directional distance zone or overcurrent stage) is required for fault indication. The `START` and `START_DLYD` inputs are available for the purpose.

- The `START` input has no delay. Thus, a switch-onto-fault situation is immediately signalled to SOTF control.
- `START_DLYD` is used when an additional delay is required to start the signal. The switch-onto-fault situation is signalled to the SOTF control after the set *Operate delay time*.

Dead-line detection

The dead-line detection should be used only when the voltage transformers are located on the line side of the circuit breaker.

The *Automatic SOTF Ini* setting is used to configure the internal dead-line detection function.

Table 891: Options for dead-line detection

Value of Automatic SOTF Ini	Description
“DLD disabled”	The dead-line detection function is disabled. This operation mode must be applied when voltage transformers are located on the bus side of the circuit breaker.
“Voltage”	The dead-line detection function is enabled and based solely on the undervoltage condition. A dead-line condition is declared, if all the phase voltages are below the *Voltage dead Lin Val* setting. The dead line is detected if the dead-line condition is declared and simultaneously no fault is detected by the `START` and `START_DLYD` inputs . The dead-line condition is signalled to the SOTF control after the delay defined with the *Dead line time* setting.
“Current”	The dead-line detection function is enabled and based solely on the undercurrent condition. A dead-line condition is declared, if all the phase currents are below the *Current dead Lin Val* setting. The dead line is detected if the dead-line condition is declared and simultaneously no fault is detected by the `START` and `START_DLYD` inputs. The dead-line condition is signalled to the SOTF control after delay defined with the *Dead line time* setting.
“Current & Voltage”	The dead-line detection function is enabled and based on undercurrent and undervoltage condition. A dead line condition is declared, if all the phase currents are below the *Current dead Lin Val* setting and simultaneously all phase voltages are below the *Voltage dead Lin Val* setting. The dead line is detected if the dead-line condition is declared and simultaneously no fault is detected by the `START` and `START_DLYD` inputs. The dead-line condition is signalled to the SOTF control after delay defined with the *Dead line time* setting.

SOTF detection

The purpose of this module is to detect the switch onto fault situation based on the current and voltage measurements. If the voltage, in any of the phases, is below the *Voltage dead Lin Val* setting and simultaneously the current in the same phase exceeds the *Current dead Lin Val* setting, the SOTF situation is signalled to SOTF control module after the set *Cur voltage Det time*.

SOTF control

The SOTF control module needs to be activated before the operation is possible in the switch-onto-fault situation. There are two ways to activate the SOTF control module.

- By CB_CL_CMD (circuit breaker closing command)
- By the dead-line condition received from the dead-line detection module

The dead-line detection should be used only when the voltage transformers are located on the line side of the circuit breaker.

When the CB_CL_CMD input is activated or the dead-line condition is detected, the SOTF control module becomes active. The reset timer is started when CB_CL_CMD is inactivated or the dead-line condition disappears. Thus the module becomes inactive after the set *SOTF reset time* is exceeded.

When the SOTF control module is active, the *Operation mode* setting defines the operation criteria for the detection of a switch-onto-fault condition. The detection can be based on the external start signals from the distance or overcurrent functions, or on the measured internal voltage and current levels or on both.

Table 892: Options for SOTF detection

Value of Operation mode	Description
“Start”	The OPERATE output is activated immediately after a signal from the trigger module. This indicates that the breaker is closed onto fault.
“Current & Vlotage”	The OPERATE output is activated immediately after a signal from the SOTF detection module. This indicates that the breaker is closed onto fault. This operation mode can be used, for example, if the non-directional distance zone is not available.
“Both”	The OPERATE output is activated immediately after a signal from the trigger or SOTF detection modules. This indicates that the breaker is closed onto fault.

The OPERATE output can be blocked by activating the BLOCK input.

5.5.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

5.5.6 Application

The operation of CVRSOF is generally based on the non-directional distance zone or the non-directional overcurrent stage. When the feeder-side voltage transformers are used for providing the polarization quantity for the distance or directional overcurrent protection, the use of non-directional impedance or current based protection for starting CVRSOF secures a fast switch-onto-fault tripping in the close-in three-phase short circuits. The non-directional protection provides a fast fault clearance when the protection is used for energizing a bus from the feeder with a short-circuit fault in it. Other protection functions, like time delayed zero sequence overcurrent functions, can be connected to CVRSOF to increase the dependability of the scheme. The other main advantage of using CVRSOF is that it typically accelerates the tripping in case of energizing a feeder onto a fault. Without CVRSOF, this tripping is normally performed by the normal time-graded protection or alternatively by the time-delayed local backup protection, for which operate times are considerably longer than with CVRSOF tripping.

An internal dead-line detection check is provided to activate the function when the voltage transformers are located on the feeder side. An initiation by the dead-line detection is highly recommended for the busbar configurations where more than one circuit breaker at one feeder end can energize the protected feeder or the feeder can also be energized from the other end.

Setting guidelines

Input `START`: If a distance zone is used for starting the switch-onto-fault function, the zone has to be set to cover the entire protected feeder with a safety margin of minimum 20 percent. If the non-directional zone is not available, the internal *Current & Voltage* criterion or the start signal from the GFC function can be used instead. If a non-directional overcurrent is used for starting, the current setting must not be higher than what is required for the non-delayed and dependable tripping for a close-in three-phase fault during minimum source conditions. If the short-circuit current along the feeder is considerably higher than the maximum load currents, it is possible that the whole feeder length is covered by CVRSOF tripping. If it is required to delay the tripping, for example, due to high inrush currents, the starting signal can be connected to the `START_DLYD` input instead.

The *Current dead Lin Val* setting parameter is set to 20 percent of the base current by default. The parameter must be set with a sufficient margin of 15 to 20 percent under the minimum expected load current. The setting must still exceed the maximum charging current of a feeder.

The *Voltage dead Lin Val* setting parameter is set to 70 percent of the base voltage by default. This is a suitable setting in most cases, but it is recommended to check the suitability in the actual application.

The *Cur voltage Det time* setting parameter is set to 0.02 seconds by default. The is suitable in most applications. This delay can be coordinated, for example, with the dead time settings of the AR shots to prevent the release of CVRSOF by the dead-line detection function when the high speed auto-reclosing is in progress.

The *Dead line time* setting parameter is set to 0.2 seconds by default. This is suitable in most applications. The delay must not be set too short to avoid unwanted activations during the transients in the system.

The *SOTF reset time* setting parameter is set to 1 second by default. This is suitable for most applications.

5.5.7 Signals

Table 893: CVRSOF Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block of function
CB_CL_CMD	BOOLEAN	0	External enabling of SOTF by CB close command
START	BOOLEAN	0	Start from function to be accelerated by SOTF
START_DLYD	BOOLEAN	0	Start from function to be accelerated with delay by SOTF

Table 894: CVRSOF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate

5.5.8 Settings

Table 895: CVRSOF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 896: CVRSOF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Operation mode	Start Current&Voltage Both	-	-	Both	Mode of operation of SOTF Function
Automatic SOTF Ini	DLD disabled Voltage Current Current & Voltage	-	-	DLD disabled	Automatic switchonto fault initialization
Current dead Lin Val	0.01 - 1.00	pu	0.01	0.20	Dead line value, current. Used also in auto activation logic
Voltage dead Lin Val	0.01 - 1.00	pu	0.01	0.70	Dead line value, voltage. Used also in auto activation logic
Cur voltage Det time	0.03 - 60.00	s	0.01	0.03	Time delay for voltage and current based detection
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
Operate time delay	0.03 - 120.00	s	0.01	0.03	time delay to operate of switch onto fault function
SOTF reset time	0.00 - 60.00	s	0.01	1.00	SOTF detection period after initialization
Dead line time	0.03 - 60.00	s	0.01	0.20	Delay time for activation of dead line detection

5.5.9 Measured values

Table 897: CVRSOF Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Current amplitude phase A
I_AMPL_B	REAL	0	Current amplitude phase B
I_AMPL_C	REAL	0	Current amplitude phase C
U_AMPL_A	REAL	0	Voltage amplitude phase A
U_AMPL_B	REAL	0	Voltage amplitude phase B
U_AMPL_C	REAL	0	Voltage amplitude phase C
BLOCK	BOOLEAN	0	Block of function
CB_CL_CMD	BOOLEAN	0	External enabling of SOTF by CB close command
START	BOOLEAN	0	Start from function to be accelerated by SOTF
START_DLYD	BOOLEAN	0	Start from function to be accelerated with delay by SOTF

5.5.10 Monitored data

Table 898: CVRSOF Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Operate

5.5.11 Technical data

Table 899: CVRSOF Technical data

Characteristic	Value
Operation accuracies	At the frequency $f = f_n$
	Current: ±1.5% of the set value or ±0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n
Operate time accuracy	±1.0% of the set value or ±35 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

5.5.12 Technical revision history

Table 900: CVRSOF technical revision history

Technical revision	Change
B	Internal improvements

5.6 Current reversal logic CRWPSCH

5.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current reversal and weak-end infeed logic	CRWPSCH	CLCRW	85CRW

5.6.2 Function block

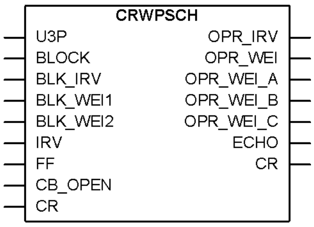


Figure 462: Function block

5.6.3 Functionality

The scheme communication logic DSOCPSCH may require additional logics to operate correctly in all possible power system conditions. Such special logics include, for example, the current reversal logic and weak-end infeed logic which are combined to the CRWPSCH function block.

Current reversal logic: In the parallel feeder applications, the direction of fault current on the healthy feeder can change when the circuit breaker on the faulty feeder opens to clear the fault. This can lead to an unwanted operation of the distance protection on the healthy parallel feeder when DSOCPSCH is used with the permissive overreach scheme. The main purpose of the current reversal logic is to prevent such unwanted operations.

The weak-end infeed (WEI) logic: Basically, the permissive communication schemes can operate only when the protection in the remote terminal can detect the fault. This detection requires a sufficient minimum fault current. If such current is not available due to a too weak remote end source, the weak-end infeed logic can be used to overcome the situation and trip the remote end breaker.

5.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of current reversal and weak-end infeed logic can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

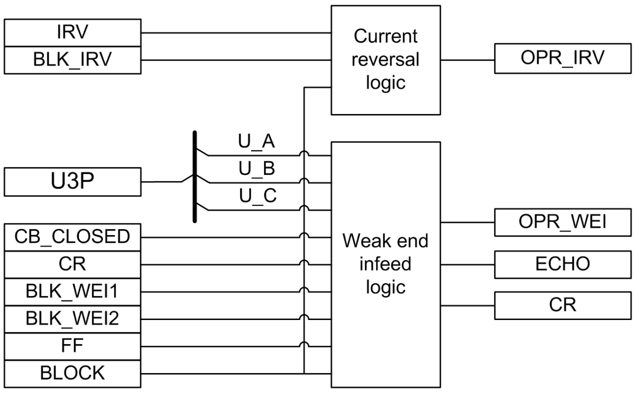


Figure 463: Functional module diagram

Current reversal logic

The current reversal logic is enabled by changing the value of the *Reversal mode* setting to “On”.

The current reversal logic uses the start signal of the reverse looking zone (Z3) connected to the `IRV` input, which is used to recognize the fault being in the reverse direction, that is, in the parallel feeder. When the reverse zone is activated, after a start delay (the *Reversal time* setting), the logic is ready to issue an `OPR_IRV` output signal. The `OPR_IRV` signal is connected to the `BLK_CS` input of the scheme communication logic function DSOCPSCH in order to block the sending of the carrier send signal (CS) and the activation of the `OPERATE` output of the communication logic. The `OPR_IRV` signal has a drop-off delay defined with the *Reversal reset time* setting.

An internal 10 ms drop-off timer is provided which secures the current reversal logic to be activated for the short duration input signals, even if the *Reversal reset time* setting is set to zero.

The `BLK_IRV` input is used to block the activation of the `OPR_IRV` output. The `BLK_IRV` input is typically connected to the forward looking zone start signals within the terminal. General blocking is achieved by activating the `BLOCK` input.

Weak-end infeed logic

The weak-end infeed logic is used in cases where the fault current infeed is too low due to, for example, high source impedance or fault current distribution between sources to activate the distance protection function. When activated, the CR signal is logically combined with the local criteria to initiate the tripping of the weak end breaker. The received signal is also echoed back to accelerate the tripping in the opposite end with the stronger source.

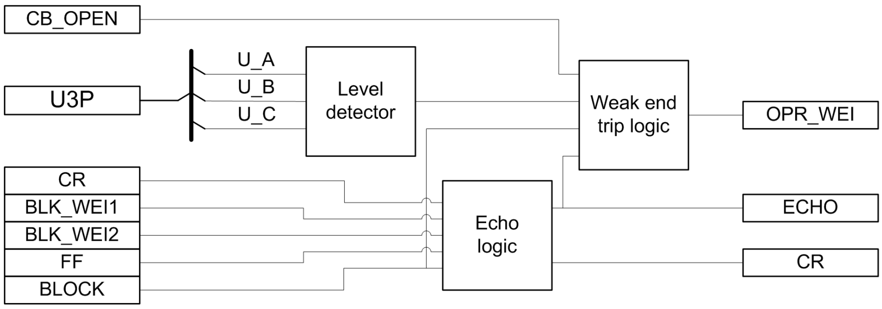


Figure 464: Functional module diagram of weak-end infeed logic

The WEI logic is enabled using the *Wei mode* setting.

- If *Wei mode*= “Off”, the WEI logic is disabled.
- If *Wei mode*= “Echo”, the WEI logic is enabled without the trip function.
- If *Wei mode*= “Echo & Trip”, the WEI logic is enabled with the trip function.

Level detector

The phase-to-earth voltages are monitored and the virtual phase-to-earth voltages are calculated inside the function. The undervoltage criteria are applied to the phase-to-phase voltages with the *PPV level for Wei* setting and for the phase-to-earth voltages with the *Phv level for Wei*. The level detector sends an enable signal for respective phase to the weak end trip logic when one or more voltages are below the corresponding settings. The level detector does blocks enable signal if all three phase voltages are above the set value more than 100 ms. This is to avoid sending an unnecessary operate signal, if the breaker is already open.

Echo logic

The WEI logic returns the received carrier signal with the `ECHO` output when it receives a CR signal under the condition that no fault has been detected by the forward and reverse looking zones and the duration of CR is longer than the coordination time delay (setting *Wei Crd time*). The received carrier receive signal is also given as the `CR` output.

When the WEI logic is enabled at both feeder ends, a spurious signal can be looped round by the echo logics. To avoid a continuous lockup of the system, the duration of the echoed signal is limited to 200 ms.

Weak-end trip logic

The weak-end trip logic is activated if the level detector and echo logic are activated. Then a general trip signal OPR_WEI is activated. Along with the OPR_WEI output signal, the OPR_WEI_x signals are also activated for the corresponding phase where undervoltage is detected. The activation of the CB_OPEN input blocks the tripping.

The ECHO and OPR_WEI outputs can be blocked using the FF and BLK_WEI1 inputs. The FF input is usually connected to the functional output of the fuse failure function and the BLK_WEI1 input is typically connected to the forward and reverse looking zone start signals within the terminal. In addition, the BLK_WEI2 input can be used to block the ECHO and OPR_WEI outputs. The BLK_WEI2 signal has an inbuilt 200 ms drop-off delay. The BLK_WEI2 input is usually connected to all the fault detection functions within the terminal except the undervoltage function.

The general blocking of the WEI logic is achieved by activating the BLOCK input.

5.6.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

5.6.6 Application

Current reversal logic

In parallel feeder applications, when the overreaching permissive communication schemes are used, unselective tripping may result due to the current reversal. Such a condition can occur in the healthy feeder when the fault is cleared in the faulty feeder. The tripping of the healthy parallel feeder may lead to losing of the connection between the two buses. To avoid this situation, the current reversal logic (transient blocking logic) can be used.

Assume that the relays Relay A1, Relay A2, Relay B1 and Relay B2 are equipped with the scheme communication logic DSOCPSCH and the permissive overreach scheme is enabled. A fault occurs at Feeder 1 close to the bus B. The Relay A2 at the healthy feeder 2 recognizes the fault in the forward direction by the overreaching zone Z2 and sends a CS signal to Relay B2 according to the PUTT scheme. The Relay B2 does not recognize the fault in the forward direction and does not operate even though a permissive CR signal is received from the Relay A2. Moreover, the Relay B2 does not send a permissive signal to the Relay A2.

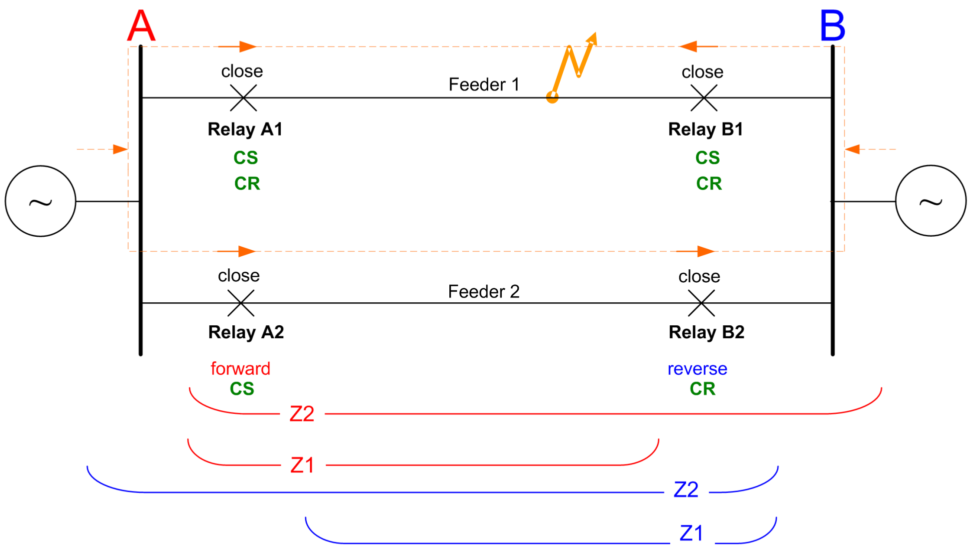


Figure 465: The fault occurs at one of the parallel lines. CS=carrier signal sending, CR=carrier signal receiving

In practice, the faulted feeder (Feeder 1) is not simultaneously tripped at both ends and it might occur that, for example, the circuit breaker closer to the fault at Relay B1 is tripped faster than the breaker at bus A due to the direct operation of the zone Z1 of Relay B1. The result is that when the breaker at Relay B1 opens, the direction of the fault current at the healthy feeder (Feeder 2) is reversed.

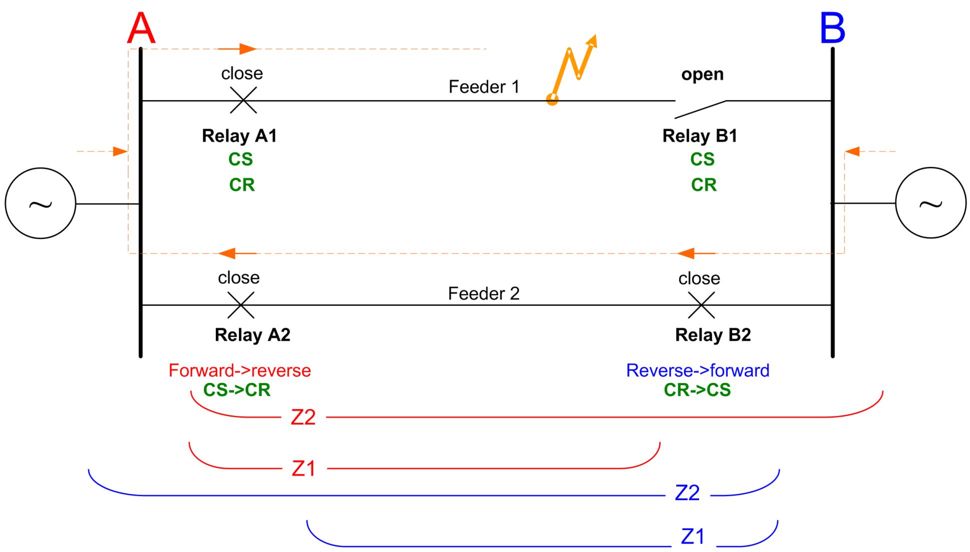


Figure 466: The circuit breaker at Relay B1 opens and creates a current reversal condition. CS=carrier signal sending, CR=carrier signal receiving.

The Relay A2 is still sending the CS signal because of the reset time delay of the forward zone of Relay A2 when the overreaching zone of Relay B2 starts to recognize the fault in the forward direction. The Relay B2 can mis-operate and trip the breaker of the healthy feeder.

This problem can be solved by using the reverse looking zone (Z3) to recognize the fault in reverse direction and temporarily block the operation of the scheme communication logic due to the current reversal condition. This is utilized in CRWPSCH.

Weak-end infeed logic

Avoid using the WEI function at both feeder ends. It can only be enabled at the weak end.

The weak-end infeed logic is recommended to be used only in permissive schemes.

Setting guidelines for current reversal logic

Setting *Reversal reset time*: Set the *Reversal reset time* setting at the maximum reset time of the communication channel. A minimum setting of 40 ms is recommended. A long *Reversal reset time* setting increases the security against unwanted tripping, but delays the fault clearing if the fault develops from one feeder to involve the other. However, the probability of this type of fault is small.

Setting *Reversal time*: Set the start delay *Reversal time* setting to less than 80 percent of the breaker operate time, but with a minimum of 20 ms.

Setting guidelines for weak-end infeed logic

The WEI function returns the received carrier signal with the ECHO output when it receives the carrier signal (CR) under the condition that no fault has been detected by forward and reverse looking zones and the duration is longer than the *Wei Crd time* coordination time delay setting. Set the *Wei Crd time* = "0.010 s" to avoid the spurious carrier received signals that activates the WEI logic and cause unwanted communications.

Set the voltage criteria *PPV level for Wei* and *PhV level for Wei* for the weak-end trip to 70 percent of the system base voltage. The setting should be below the minimum operate voltage of the system but above the voltage that occurs for a fault on the protected feeder. The phase-to-phase elements must be verified not to operate for the phase-to-earth faults.

5.6.7 Signals

Table 901: CRWPSCH Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block of function
BLK_IRV	BOOLEAN	0	Block of current reversal function
Table continues on next page			

Name	Type	Default	Description
BLK_WEI1	BOOLEAN	0	Block of WEI logic
BLK_WEI2	BOOLEAN	0	Block of WEI logic due to operation of other protections
IRV	BOOLEAN	0	Activation of current reversal logic
FF	BOOLEAN	0	Block of trip from WEI logic through fuse-failure function
CB_OPEN	BOOLEAN	0	Block of trip from WEI logic by an open breaker
CRL	BOOLEAN	0	POR Carrier receive for WEI logic

Table 902: CRWPSCH Output signals

Name	Type	Description
OPR_IRV	BOOLEAN	Operation of current reversal logic
OPR_WEI	BOOLEAN	Operation of WEI logic
OPR_WEI_A	BOOLEAN	Operation of WEI logic in phase A
OPR_WEI_B	BOOLEAN	Operation of WEI logic in phase B
OPR_WEI_C	BOOLEAN	Operation of WEI logic in phase C
ECHO	BOOLEAN	Carrier send by WEI logic
CR	BOOLEAN	POR Carrier signal received from remote end

5.6.8 Settings

Table 903: CRWPSCH Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Reversal mode	Off On	-	-	Off	Operating mode of Current Reversal Logic
Wei mode	Off Echo Echo & Trip	-	-	Off	Operating mode of WEI logic
PhV level for Wei	0.10 - 0.90	pu	0.01	0.70	Phase to Neutral voltage for detection of fault condition
PPV level for Wei	0.10 - 0.90	pu	0.01	0.70	Phase to Phase voltage for detection of fault condition
Reversal time	0.000 - 60.000	s	0.001	0.020	Pickup time for current reversal logic
Reversal reset time	0.000 - 60.000	s	0.001	0.060	Time Delay to prevent Carrier send and local trip
Wei Crd time	0.000 - 60.000	s	0.001	0.010	Coordination time for the WEI logic

Table 904: CRWPSCH Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase

5.6.9 Measured values

Table 905: CRWPSCH Measured values

Name	Type	Default	Description
U_AMPL_A	REAL	100	Phase to ground voltage phase A
U_AMPL_B	REAL	100	Phase to ground voltage phase B
U_AMPL_C	REAL	100	Phase to ground voltage phase C
BLOCK	BOOLEAN	0	Block of function
BLK_IRV	BOOLEAN	0	Block of current reversal function
BLK_WEI1	BOOLEAN	0	Block of WEI logic
BLK_WEI2	BOOLEAN	0	Block of WEI logic due to operation of other protections
IRV	BOOLEAN	0	Activation of current reversal logic
FF	BOOLEAN	0	Block of trip from WEI logic through fuse-failure function
CB_OPEN	BOOLEAN	0	Block of trip from WEI logic by an open breaker
CRL	BOOLEAN	0	POR Carrier receive for WEI logic

5.6.10 Monitored data

Table 906: CRWPSCH Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_IRV	BOOLEAN	0=FALSE 1=TRUE	-	Operation of current reversal logic
OPR_WEI	BOOLEAN	0=FALSE 1=TRUE	-	Operation of WEI logic
OPR_WEI_A	BOOLEAN	0=FALSE 1=TRUE	-	Operation of WEI logic in phase A
OPR_WEI_B	BOOLEAN	0=FALSE 1=TRUE	-	Operation of WEI logic in phase B
OPR_WEI_C	BOOLEAN	0=FALSE 1=TRUE	-	Operation of WEI logic in phase C
ECHO	BOOLEAN	0=FALSE 1=TRUE	-	Carrier send by WEI logic
CR	BOOLEAN	0=FALSE 1=TRUE	-	POR Carrier signal received from remote end

5.6.11 Technical data

Table 907: CRWPSCH Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5% of the set value or $\pm 0.002 \times U_n$
Operate time accuracy	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

5.7 Scheme communication logic DSOCPSCH

5.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Scheme communication logic	DSOCPSCH	CL	85

5.7.2 Function block

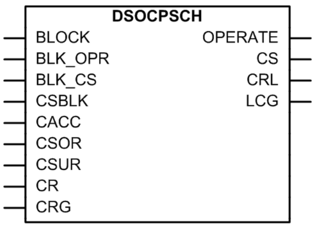


Figure 467: Function block

5.7.3 Functionality

To achieve instantaneous fault clearing independent of the fault location on the protected feeder, the scheme communication logic DSOCPSCH is provided. The available communication scheme types are:

- Direct intertrip (DUTT)
- Permissive underreach (PUTT)
- Permissive overreach (POTT)
- Directional comparison blocking (DCB)

The directional comparison unblocking scheme (DCUB) can also be implemented by complementing the permissive schemes with an additional logic called the unblocking function, which is also included in DSOCPSCH.

If the permissive overreach scheme is used, some of the power system conditions requires additional special logic circuits, like current reversal logic and weak-end infeed (WEI) logic for distance protection, CRWPSCH.

5.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the communication scheme logic function for distance protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

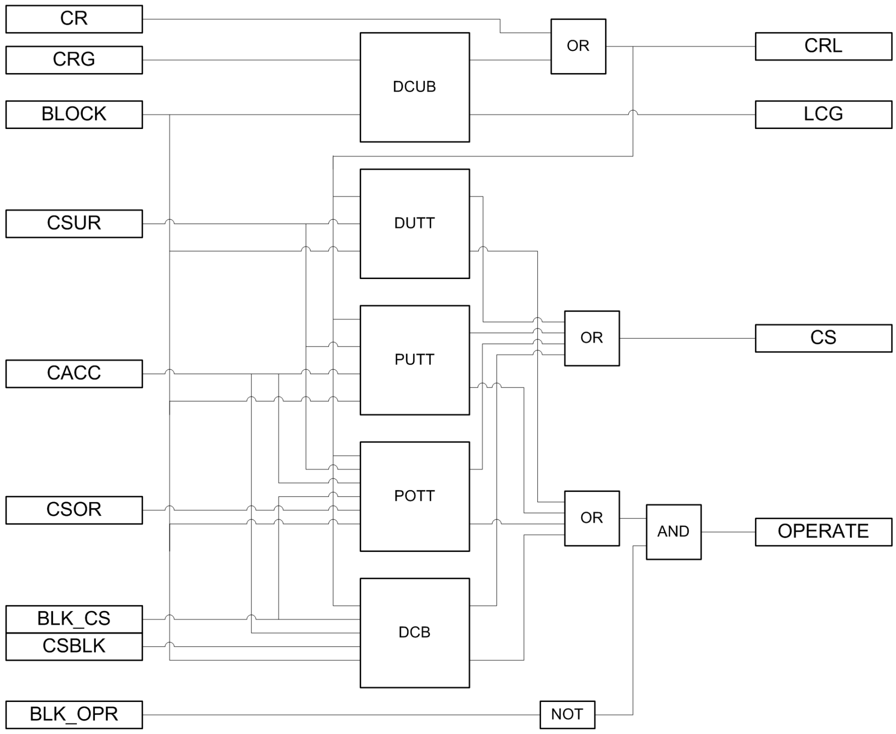


Figure 468: Functional module diagram

The applied communication scheme logic in DSOCPSCH is selected with the *SchemeType* setting.

- If *SchemeType* = “Intertrip”, it is (DUTT)
- If *SchemeType* = “Permissive UR” , it is (PUTT)
- If *SchemeType* = “Permissive OR”, it is (POTT)
- If *SchemeType* = “Blocking” , it is (DCB)

The unblocking scheme (DCUB) is enabled with the *Unblock mode* setting.

Direct underreaching transfer trip scheme (DUTT)

The direct intertrip is enabled with *SchemeType* = “Intertrip”.

In the direct intertrip scheme, the start signal from the underreaching zone Z1 is connected to the CSUR input to create a carrier send (CS) signal. The duration of the CSUR input signal is prolonged by the *Carrier Min Dur* setting to assure a sufficient duration for the CS signal.

The local circuit breaker is directly tripped (activation of the OPERATE output) with the carrier received (CR) signal after a settable pick-up delay *Coordination time* has elapsed without further local criteria.

The unblocking function (*Unblock* = “NoRestart” and *Unblock* = “Restart”) must not be enabled with the DUTT scheme, as the lost guard signal results in an immediate trip of the local circuit breaker.

The activation of the BLOCK input does a total blocking of the direct intertrip scheme. The activation of the BLK_OPR input blocks the OPERATE output.

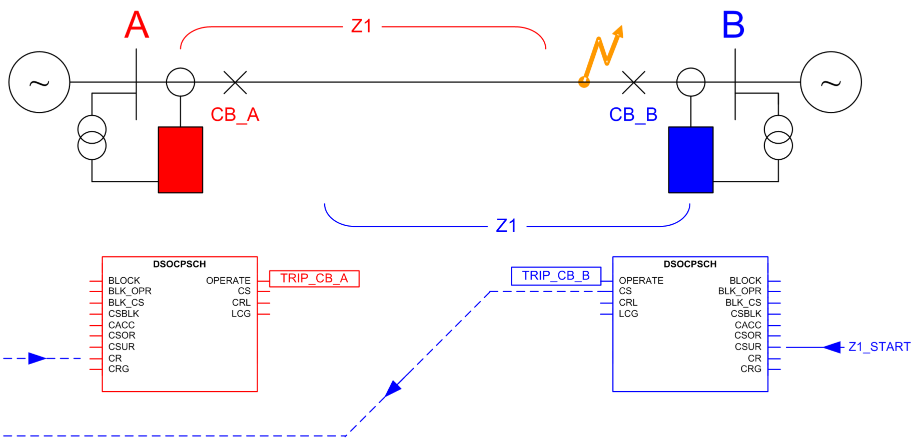


Figure 469: Simplified functional diagram of the direct intertrip scheme

Permissive underreaching transfer trip scheme (PUTT)

The permissive underreach is enabled with *SchemeType* = “Permissive UR”.

In the permissive underreach scheme, the start signal from the underreaching zone Z1 is connected to the CSUR input to create a CS signal. The duration of the CSUR input signal can be prolonged by the *Carrier Min Dur* setting to assure a sufficient duration of the CS signal.

In the permissive underreach scheme, the CR signal, or CRL signal if the unblocking function is enabled, is used to allow the overreaching zone Z2 to trip (activation of the OPERATE output) after the pick-up delay *Coordination time*. The start signal from the overreaching zone Z2 is connected to the CACC input.

Activating the BLOCK input blocks totally the permissive underreach scheme. Activating the BLK_OPR input blocks the OPERATE output.

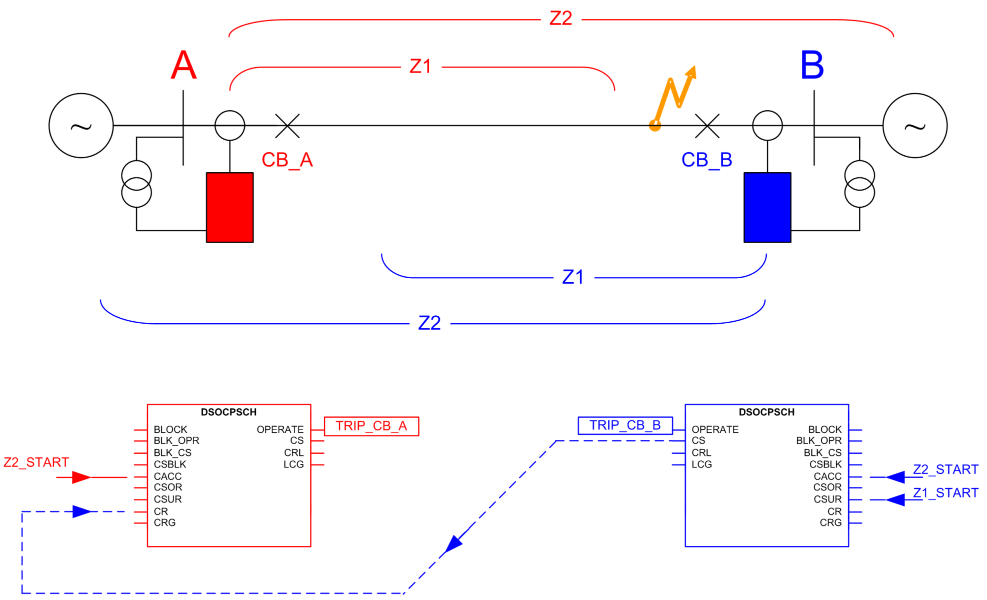


Figure 470: Simplified functional diagram of permissive underreach scheme

POTT (Permissive overrreaching transfer trip scheme)

The permissive overreach is enabled with *SchemeType* = “Permissive OR”.

In the permissive overreach scheme, the start signal from the overreaching zone Z2 is connected to the CSOR input to create a CS signal. The CS signal can also be issued simultaneously from the underreaching zone Z1. In this case, the start signal from the underreaching zone Z1 is connected to the CSUR input. The duration of the CSUR input signal is prolonged by the *Carrier Min Dur* setting, to assure a sufficient duration of the CS signal. The carrier send from CSOR overreaching zone can be blocked with the BLK_CS input.

In case of the parallel feeders, and when the external current reversal logic (CRWPSCH) is enabled, the CS signal is not prolonged and the value of *Carrier Min Dur* is set to zero in to secure correct operation.

In the permissive overreach scheme, the received signal CR or CRL, if unblocking function is enabled used to allow the overreaching zone Z2 to trip (activation of the OPERATE output) after the settable pick-up delay *Coordination time*. The start signal from the overreaching zone is connected to the CACC input.

Activating the BLOCK input blocks totally the permissive overreach scheme. Activating the BLK_OPR input blocks the OPERATE output.

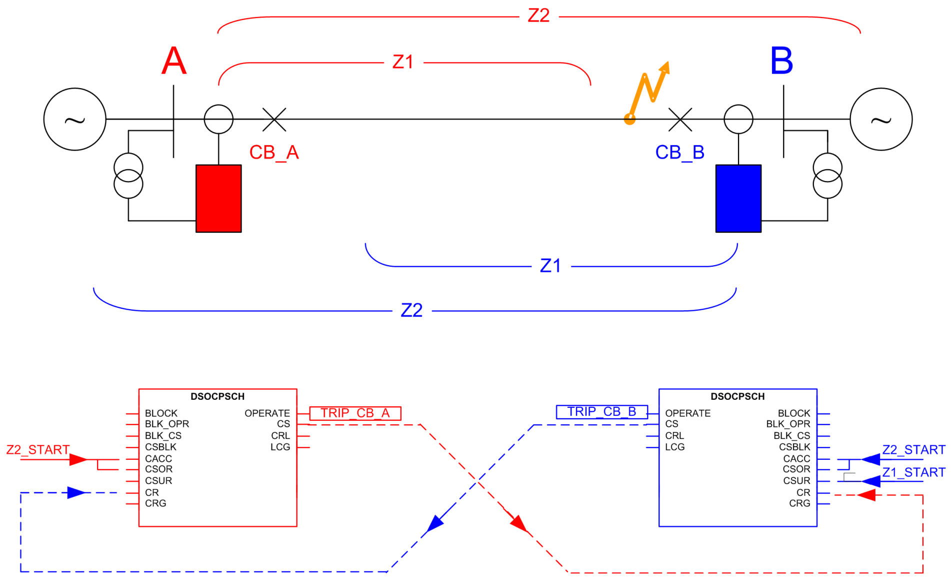


Figure 471: Simplified functional diagram of permissive overreach scheme

Directional comparison blocking scheme (DCB)

The directional comparison blocking scheme is enabled with *SchemeType* = "Blocking".

In the blocking scheme, the start signal from the reverse looking zone Z3 is connected to the CSBLK input in to create a CS signal. The starting of the reverse looking zone indicates that the fault is located outside the protected feeder. The duration of the CSBLK input signal can be prolonged with the *Carrier Min Dur* setting to assure a sufficient duration of the CS signal. The CS signal from the CSBLK reverse zone can be blocked with the BLK_CS input.

The principal operation of the blocking scheme is that the overreaching zone Z2 is allowed to trip (activation of the OPERATE output) after the settable *Coordination time* has elapsed, and if no blocking signal is received from the remote terminal. To prevent a false trip in case of an external fault, the block signal (CR) must be received before the *Coordination time* has elapsed. The start signal from the overreaching zone Z2 is connected to the CACC input.

The *Coordination time* setting in the blocking scheme depends, for example, on communication system delay and on the terminal response times in transmitting the CS signal to the other feeder end. The *Coordination time* setting must not be zero.

Activating the BLOCK input blocks totally the permissive overreach scheme. Activating the BLK_OPR input blocks the OPERATE output.

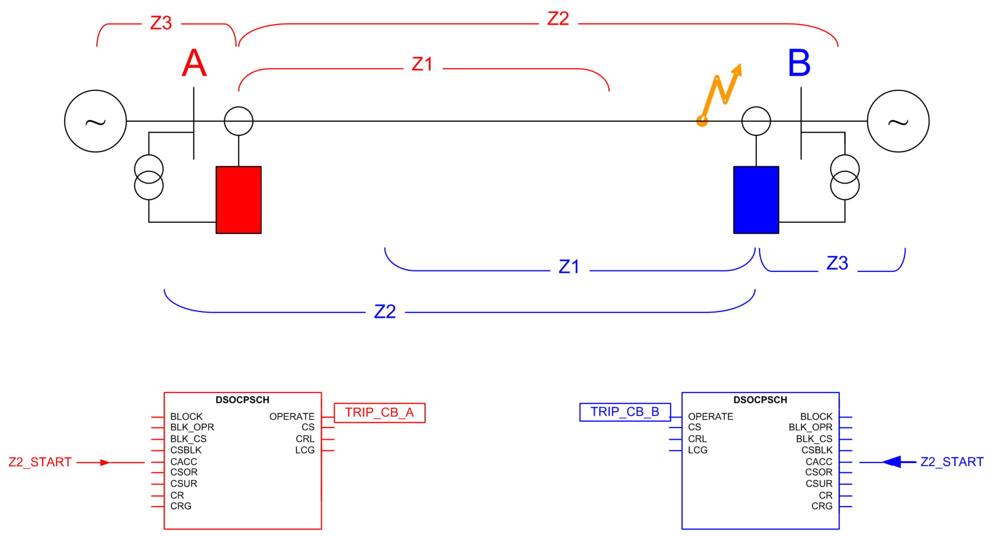


Figure 472: Simplified functional diagram of the blocking scheme, internal fault. The CS signal is not sent as the fault is not seen by the reverse-looking zones (Z3).

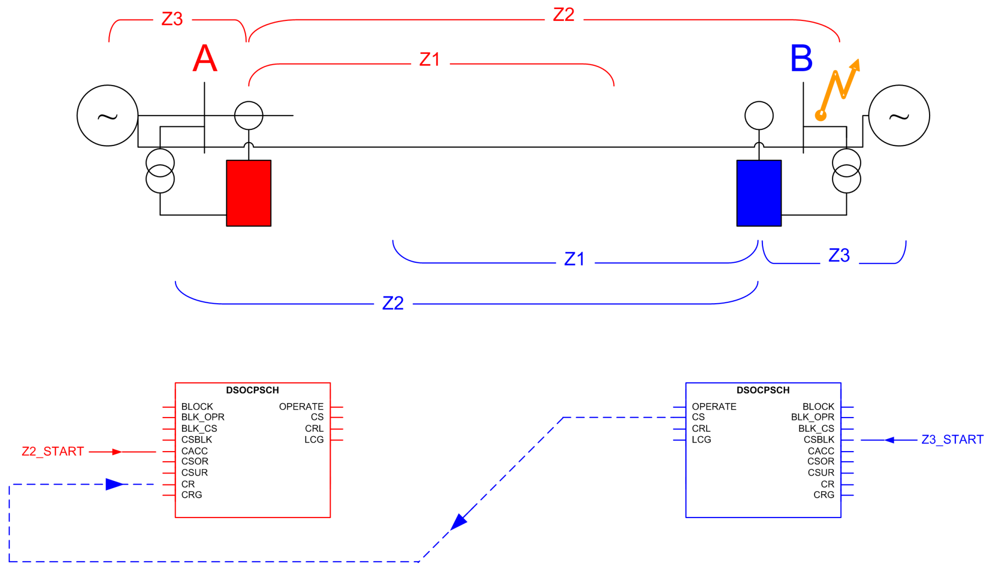


Figure 473: Simplified functional diagram of the blocking scheme, external fault. The IED at bus B sees the fault in the reverse direction and sends a blocking signal (CS) to the IED at bus A. There is no CB operation at either end.

The unblocking function used with the blocking function provides a possibility to supervise the communication channel. In this case, the `CRL` output signal is used as a local blocking signal.

The operation mode *Unblock* = “Restart” is not recommended as the blocking is activated only for 150 ms after the guard signal disappears. This results in an unwanted operation of the protection.

DCUB (Directional Comparison Unblocking)

The unblocking function is a complementary logic, which can be used together with the permissive communication schemes. In the unblocking scheme, the dependability of the permissive schemes is improved by using the loss of guard signal from the communication equipment to create locally a CRL output signal. This enables the permissive scheme to operate even if the communication channel is interrupted or lost.

The unblocking function uses a carrier guard signal (CRG), which must always be present. The absence of the CRG signal for a time longer than the value of the *Loss of carrier time* setting is used to generate a logical CRL signal. This enables the permissive scheme to operate despite the loss of the communication channel. A communication failure shorter than the value of the *Loss of carrier time* setting is always ignored.

The unblocking function is configured with the *Unblock* setting.

- *Unblock* = “Off”: The unblocking function is disabled.
- *Unblock* = “NoRestart”: If the CRG signal disappears for a longer time than defined in the *Loss of carrier time* setting. The logical CRL signal is generated. The CRL output signal is kept up until the CRG signal is present again. The communication failure is not signaled by the LCG output.
- *Unblock* = “Restart”: If the CRG signal disappears for a longer time than defined in the *Loss of carrier time* setting, theCRL output signal is generated. The CRL output signal is kept up for 150 ms, after which a communication failure is signaled by the LCG output. The LCG output is reset 200 ms after the CRG signal is present again. The purpose of this mode is to ensure tripping during a fixed delay of 150 ms after the loss of communication due to possible consequences of an internal fault. After this time, the accelerated tripping is allowed only if the actual CR signal is received again.

With operation modes *Unblock* = “NoRestart” and *Unblock* = “Restart” the created CRL output signal is internally ORed with the CR input to allow the permissive scheme to operate even when the communication channel has been interrupted or lost. The CRL and LCG output signals are also available as outputs for monitoring purposes. Activating the BLOCK input blocks the CRL and LCG outputs.

5.7.5 Application

To achieve fast fault clearing for the fault on the part of the protected feeder not covered by the instantaneous zone, Z1, the stepped distance protection function can be supported with DSOCPSCH.

Applying DSOCPSCH requires a communication channel capable of transmitting an "On" or "Off" signal in each direction. To enable fast tripping, the most important requirement for communication channel is the communication speed.

The performance of DSOCPSCH is directly related to the communication channel speed, and to the security against false or lost signals. Therefore, dedicated communication channels are recommended. With short distances up to a few kilometers, a typical communication media is a simple pilot wire based on auxiliary power. With distances up to 150 km, the fibre-optic cables utilizing the digital data transmission can be used. To avoid false signals causing unwanted operation, the security of the communication channel should be emphasized. It is also important to pay attention to the dependability of the communication channel to ensure that the signals are reliably transmitted during the power system faults.

Communication schemes supported by DSOCPSCH:

- Direct underreaching transfer trip, DUTT
- Permissive underreaching transfer trip, PUTT
- Permissive overreaching transfer trip, POTT
- Directional comparison blocking scheme, DCB
- Directional comparison unblocking scheme, DCUB

Depending on whether the communication channel is used for sending a block or a trip signal, the communication schemes can be divided into blocking schemes and permissive schemes.

In permissive schemes, the trip signals of the distance zones are interchanged between the terminals to receive a permission to trip during an internal fault. The tripping of the local terminal depends on both the starting of its own forward-looking zone, and on the received signal from the opposite terminal. In the underreaching scheme, no signals are sent during an external fault. During an external fault, a trip signal is also sent to the opposite terminal ff the fault is seen in the forward direction and the overreaching scheme is used. However, in case of external faults, tripping is always blocked because either no signal is received as the opposite terminal sees a reverse fault, or because the signal is received but the fault is seen in the reverse direction. In either case, the blocking is not dependent on the received signal so that a lost communication channel would not result in false operation.

In the blocking scheme, a blocking signal is sent to the opposite terminal if the fault is locally seen in the reverse direction, that is, during an external fault. Thus, the blocking is dependent on the received signal, and there is typically a need to delay the tripping of the terminal receiving the blocking signal. This delay depends, for example, on the response times of the communication channel and terminals. During an internal fault, there is no signal transmission between the terminals. Thereby the tripping does not depend on the received signal from the opposite terminal.

In conclusion, when compared to the blocking schemes, the permissive schemes are inherently faster and have better security** against false tripping, since tripping in an external fault is not possible in case of a channel interruption. In a blocking scheme, a lost communication channel simultaneously with an external fault may lead to a false operation of the protection if the communication channel is not being supervised. On the other hand, as the fast trip of the permissive scheme depends on the received signal, its dependability*** is lower than that of the blocking scheme. [1] [2]

The unblocking scheme is also available to enhance the dependability of the permissive scheme. If the communication channel is interrupted, and simultaneously a fault occurs in the forward direction within that time, tripping is still possible either during a fixed time interval counting from the beginning of the interruption, or for as long as the communication channel is lost. This is achieved by connecting the supervision output of the implemented communication functionality to the dedicated carrier guard signal input of DSOCPSCH. In general, the unblocking scheme provides better security than the blocking scheme because tripping in external faults is only possible if the fault occurs within the fixed time interval from the beginning of the channel interruption..

The direct transfer trip scheme uses the underreaching zone to trip the local breaker and to transfer the trip signal to a remote terminal. The remote terminal operates immediately based on the received transfer trip signal, without any additional conditions. This scheme is very simple, but the security is low as a spurious signal results in false operation of the protection.

Direct intertrip

In some applications, there is a need to trip the remote-end breaker immediately based on fault detection by the local measurements. This applies, for example, when the transformers or reactors are connected to the system without circuit breakers, or for remote tripping after the operation of the local breaker failure protection (CBFP).

In the direct intertrip scheme (DUTT), the carrier send signal (CS) is initiated by an underreaching zone, or by the tripping signal from an external IED, such as transformer or reactor protection. At the remote end, the received signals initiates a breaker trip immediately without any further local protection criteria. To limit the risk for unwanted trip due to spurious sending of signals, the trip can be delayed by the *Coordination time* setting, which should be set to 10...30 ms, depending on the type of the communication channel. The general requirement for implementing the communication channel operating in direct inter tripping applications is that it should be very secure and dependable.

Setting guidelines for the intertrip scheme, DUTT:

Scheme type = "Intertrip"

Coordination time = "0.050" s (10 ms + maximal transmission time)

[1] ** security = The ability to block operation in case of an external fault
[2] *** dependability = The ability to operate in case of an internal fault

Carrier Min Dur = "0.1" s

Permissive underreach scheme

In permissive underreach scheme, the permission to trip is obtained locally from the underreaching zone and sent to the remote end. The received signal is combined again with the local fault indication from the overreaching zone resulting to trip command after a settable pick-up delay *Coordination time*.

In the permissive underreach scheme, the IED of either feeder end sends a permissive signal to trip the other end. The communication channel needs to be able to receive and transmit at the same time. In permissive schemes, a general requirement for the communication channel is that it must be fast and secure, but also dependable. Inadequate security causes the unwanted tripping for the external faults. Inadequate speed or dependability causes delayed tripping for internal faults.

In the permissive underreach scheme, the CS signal is issued based on the underreaching zone, Z1.

The underreach scheme is not applicable on short feeder lengths due to the difficulties in the impedance measurement to distinguish between the internal and external faults in such cases.

The underreaching zones (Z1) at local and remote end must overlap to prevent a gap between the protection zones, where the faults would not be detected. If the underreaching zone does not meet the required sensitivity, for example, the fault infeed from a remote end, the blocking or permissive overreach scheme is considered.

To achieve an instantaneous trip, the carrier received signal (CR) must be received when the overreaching zone, Z2, is still starting . In some cases, due to a fault in current distribution, the overreaching zone can operate only after the fault has been cleared by the remote terminal. In this case, there is certain risk that in case the remote terminal is tripped directly by, for example, the zone Z1, the CS signal issued by the zone resets before the overreaching zone of the local end terminal has operated. To assure a sufficient duration of the CR signal, the CS signal can be prolonged by the time *Carrier Min Dur*. The recommended value of the *Carrier Min Dur* setting is "0.1" s.

The received communication signal is combined with the output from the local overreaching zone. Therefore, there is less concern for false signal causing an incorrect trip, and therefore the timer *Coordination time* is set to "0". A communication channel failure does not affect the selectivity, but delays the tripping at the other end for certain fault locations.

Setting guidelines for the permissive underreach scheme, PUTT:

Scheme type = "Permissive UR"

Coordination time = "0" s

Carrier Min Dur = "0.1" s

Permissive overreach scheme

In permissive overreach scheme, the permission to trip is obtained locally from an overreaching zone and sent to the remote end. The received signal is then combined with the local fault indication from the overreaching zone, resulting in trip command after a settable pick-up delay *Coordination time*.

In the permissive overreach scheme, the IED at either end of the feeder sends a permissive signal to trip the other end. Therefore the communication channel must be able to receive and transmit at the same time. A general requirement for the communication on permissive schemes is that it should be fast and secure.

In the permissive overreach scheme, the CS signal is issued based on the overreaching zone, Z2.

The permissive overreach scheme can be used for all feeder types and lengths.

In the permissive overreach scheme, the communication channel plays an essential role in obtaining a fast tripping at both ends. Typically, a lost communication channel does not cause false tripping. However, it delays the operation of the protection for the faults anywhere on the feeder.

The communication channel for a permissive overreach scheme must be fast and secure, but also dependable. Inadequate security can cause unwanted tripping for external faults. Inadequate speed or dependability can cause delayed tripping for internal faults.

In the permissive overreaching scheme, the CS signal can be issued in parallel both from the overreaching and underreaching zones. The CS signal from the overreaching zone must not be prolonged, while the CS signal from the underreaching zone must typically be prolonged. In parallel feeder applications, the scheme typically needs to be complemented by the current reversal logic. To ensure the correct operation in this case, the CS signal shall not be prolonged (*Carrier Min Dur* = "0" s). There is no need to delay the tripping while receiving the carrier signal, so set the timer *Coordination time* to "0".

Setting guidelines for the permissive overreaching transfer trip scheme, POTT:

Scheme type = "Permissive OR"

Coordination time = "0" s

Carrier Min Dur = "0.1" s

Carrier Min Dur = "0" s (in case of parallel lines and current reversal logic)

Directional comparison blocking scheme

In the blocking scheme, the reverse-looking zone, Z3, is used for sending a block signal to the remote end to block the overreaching zone.

The blocking scheme is very dependable because it operates on faults anywhere on the protected feeder, even if the communication channel is out of service. Conversely, it is less secure than a permissive scheme because it trips for external faults within the reach of the overreaching local zone, in case the communication channel is out of service and no block signal is received.

Inadequate speed or low dependability of the communication channel can cause spurious tripping for external faults.

To secure that the blocking signal has time to arrive before the local overreaching zone trips, the trip is delayed by the *Coordination time* setting. The *Coordination time* setting must be set longer than the maximal transmission time of the channel added by the start and response times of the IEDs sending and receiving the CS signal. A security margin of at least 10 ms should be considered. The time delay *Carrier Min Dur* for prolonging the CS signal is set to "0".

Setting guidelines for the blocking scheme, DCB:

Scheme type = "Blocking"

Coordination time = "0.1" s (10 ms + maximal transmission time)

Carrier Min Dur = "0" s

Directional comparison unblocking scheme

Metallic communication paths unfavourably affected by fault-generated noise or by other electrical phenomena, such as lightning, are not suitable for conventional permissive schemes that rely on the signal transmitted during a fault in the protected feeder. Principally, the communication media must be properly shielded or otherwise designed to provide an adequate performance during such conditions.

In general, to overcome the lower dependability of permissive schemes, the unblocking scheme can be used. The function is used at older, less reliable communication, where the signal has to be sent through the primary fault. The unblocking function uses a carrier guard signal (CRG) which must always be present, even when no CR signal is received. Due to the absence of the CRG signal during the security time, the *Loss of carrier time* setting is used as a CR signal. This also enables a permissive scheme to operate when the communication channel is temporarily lost during an internal fault.

Setting guidelines for the unblocking scheme, DCUB:

The unblocking function is configured with the *Unblock* setting:

- *Unblock* = “Off”: The unblocking function is disabled
- *Unblock* = “NoRestart”: If the CRG signal disappears for a longer time period defined in the *Loss of carrier time* setting, a logical carrier received signal (CRL) is generated. The CRL signal is kept up until the CRG signal is present.

The communication failure is not signalled by the LCG output. The *Loss of carrier time* setting is set to "35" ms.

- Unblock = “Restart”: If the CRG signal disappears for a longer time period than the *Loss of carrier time* setting, a CRL signal is generated. The CRL signal is kept up for 150 ms, after which a communication failure is signalled by the LCG output. The value of the LCG output is reset 200 ms after the CRG signal is present again. The *Loss of carrier time* setting is set to "35" ms.

5.7.6 Signals

Table 908: DSOCPSCH Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Signal for block of trip output from communication logic
BLK_CS	BOOLEAN	0	Block of carrier send in permissive OR and blocking schemes
CSBLK	BOOLEAN	0	Reverse directed distance protection zone signal
CACC	BOOLEAN	0	Permissive distance protection zone signal
CSOR	BOOLEAN	0	Overreaching distance protection zone signal
CSUR	BOOLEAN	0	Underreaching distance protection zone signal
CR	BOOLEAN	0	Carrier Signal Received
CRG	BOOLEAN	0	Carrier guard signal received

Table 909: DSOCPSCH Output signals

Name	Type	Description
OPERATE	BOOLEAN	Trip output
CS	BOOLEAN	Carrier Send signal
CRL	BOOLEAN	Carrier signal received or missing carrier guard signal
LCG	BOOLEAN	Loss of carrier guard signal

5.7.7 Settings

Table 910: DSOCPSCH Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Scheme type	Off Intertrip Permissive UR Permissive OR Blocking	-	-	Permissive UR	Scheme type
Coordination time	0.000 - 60.000	s	0.001	0.035	Communication scheme coordination time
Carrier Min Dur	0.000 - 60.000	s	0.001	0.100	Minimum duration of a carrier send signal

Table 911: DSOCPSCH Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Loss of carrier time	0.000 - 60.000	s	0.001	0.035	Security timer for loss of carrier guard detection
Unblock mode	Off NoRestart Restart	-	-	Off	Operation mode of unblocking logic

5.7.8 Measured values

Table 912: DSOCPSCH Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Signal for block of trip output from communication logic
BLK_CS	BOOLEAN	0	Block of carrier send in permissive OR and blocking schemes
CSBLK	BOOLEAN	0	Reverse directed distance protection zone signal
CACC	BOOLEAN	0	Permissive distance protection zone signal
CSOR	BOOLEAN	0	Overreaching distance protection zone signal
CSUR	BOOLEAN	0	Underreaching distance protection zone signal
CR	BOOLEAN	0	Carrier Signal Received
CRG	BOOLEAN	0	Carrier guard signal received

5.7.9 Monitored data

Table 913: DSOCPSCH Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Trip output
CS	BOOLEAN	0=FALSE 1=TRUE	-	Carrier Send signal
CRL	BOOLEAN	0=FALSE 1=TRUE	-	Carrier signal received or missing carrier guard signal
LCG	BOOLEAN	0=FALSE 1=TRUE	-	Loss of carrier guard signal

5.7.10 Technical data

Table 914: DSOCPSCH Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

5.8 Local acceleration logic DSTPLAL

5.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Local acceleration logic	DSTPLAL	LAL	LAL

5.8.2 Function block

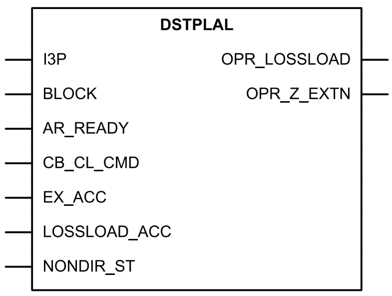


Figure 474: Function block

5.8.3 Functionality

The local acceleration logic function DSTPLAL is a complementary function to the distance protection function DSTPDIS. DSTPLAL is not intended for a stand-alone use.

The main purpose of DSTPLAL is to achieve a fast fault clearing which is independent of the fault location on the protected feeder when no communication channel is available between the local and remote terminals. DSTPLAL enables a fast fault clearing during certain conditions, but the function cannot completely replace the communication scheme logic.

DSTPLAL can be controlled either by the auto-recloser (zone extension logic), or by monitoring the loss of load currents (the loss of load logic). Both operation modes are enabled independently.

5.8.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the local acceleration logic function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

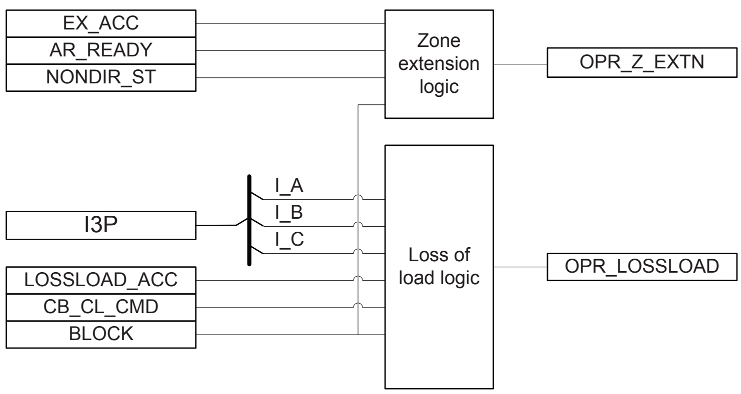


Figure 475: Functional module diagram

Zone extension logic

The zone extension logic is enabled with *Zone extension* = “Enabled”.

When the operation mode *Zone extension* is enabled, the auto-recloser (AR) function enables a fast fault clearance that covers the entire length of the protected feeder. This is achieved by allowing a time delayed overreaching zone to trip instantaneously when a fault occurs. For this purpose either a normal overreaching zone Z2 or a dedicated overreaching zone ZAR with an independently set reach can be used.

After instantaneously tripping for over reaching zone, the auto-reclose sequence starts. If the fault is transient the system may get restored in the first shot of AR. However, in case of persistant fault only the first trip of the AR sequence is accelerated by the zone extension logic. During the rest of the sequence, the zone extension logic is blocked and AR-initiation is performed selectively by the time graded distance zones

In case the fault is located on the adjacent feeder or bus within the reach of the overreaching zone, tripping and AR initiation will take place in an external fault.

The *Zone extension* operation mode setting can be described using a module diagram. All the modules in the diagram are explained in the next sections.

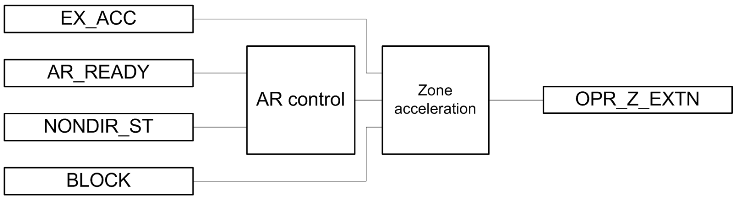


Figure 476: Functional module diagram of operation mode: Zone extension

AR control

The AR control module supervises the zone acceleration by monitoring the status of the AR_READY and NONDIR_ST input signals. The READY output signal from the autorecloser (AR) function which indicates the status of the autoreclosing is connected to the AR_READY input. The start signal from the non-directional zone is connected to the NONDIR_ST input. If the non-directional zone is not available for this, then the start output from the overreaching zone with the biggest reach or GFC can be used instead.

The permission for zone acceleration is given if AR_READY = TRUE, that is, the AR function is ready to start a new AR sequence. If the set reclaim time of the AR function expires before the fault is cleared, the NONDIR_ST input signal is used to block the activation of the zone acceleration. This ensures that the accelerated trip followed by the AR initiation is not repeated for the same fault regardless of the reclaim time setting and the reach of the overreaching zone connected to the EX_ACC input. Otherwise, this could lead to pumping of the circuit breaker, that is, the repetition of the first shot without being able to complete the desired AR sequence.

The AR control module blocks the zone acceleration module after the initiation of the first shot until the AR sequence has been completed, that is, until the AR_READY input signal changes its state back from FALSE to TRUE.

Zone acceleration

The start signal from the overreaching zone whose operation is to be accelerated is connected to the EX_ACC input. When the EX_ACC input is activated and simultaneously the AR control module gives a permission for acceleration, the operate signal from the zone extension logic is obtained from the OPR_Z_EXTN output, which is used to trip the circuit breaker and initiate the autoreclosing (the AR shot).

The activation of the BLOCK input blocks the OPR_Z_EXTN output.

Loss of load logic

The loss of load logic is enabled with *Loss of load Op* = “Enabled.”

When the *Loss of load Op* operation mode is enabled, a time-delayed overreaching zone is allowed to trip instantaneously if the loss of load current condition is detected.

The loss of load function does not operate in case of a three-phase fault as all the phases are faulty. Therefore, none of the current values drops below the *Minimum current* setting, meaning that the loss of load current condition cannot be detected.

The *Loss of load Op* setting mode can be described using a module diagram. All the modules in the diagram are explained in the next sections.

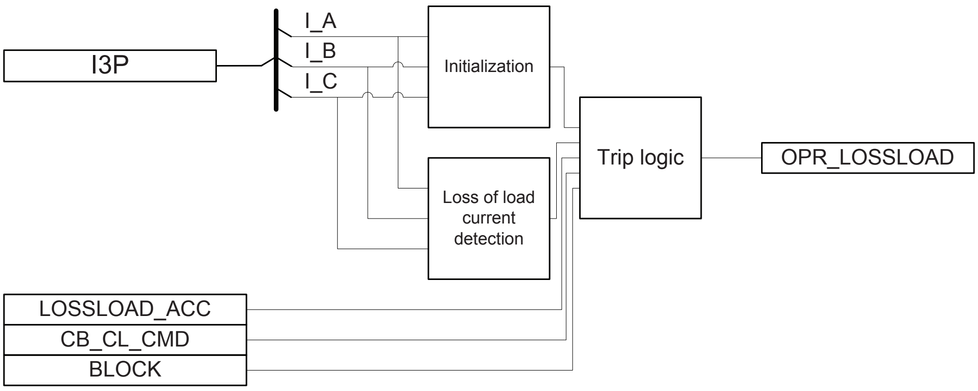


Figure 477: Functional module diagram of operation mode: Loss of load Op

Initialization

The initialization module gives an enabling signal to the trip logic module when the values of all three phase currents are above the set value of *Load current value* for more than the time set with *Load release on time*. The enabling signal has a drop-off delay defined with the *Load release off Tm* setting.

Loss of load current detection

The loss of load current detection module gives an enabling signal to the trip logic module if any of the phase current values drops below the *Minimum current* setting due to a remote end breaker opening and simultaneously the value of at least one phase current exceeds the value of the *Load current value* setting due to a fault. Such a condition has to be valid for longer than the *Minimum current time* setting.

Trip logic

The operate signal is obtained from the `OPR_LOSSLOAD` output if both initialization and loss of load current detection modules are activated and simultaneously a fault is seen by the overreaching zone connected to the `LOSSLOAD_ACC` input.

The activation of the `BLOCK` input blocks the `OPR_LOSSLOAD` output. Temporarily blocking is achieved using the circuit breaker close command pulse connected to the `CB_CL_CMD` input. It is used to prevent an unwanted operation due to initial transients after the breaker is closed, for example, in case of inrush currents.

5.8.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

5.8.6 Application

DSTPLAL is used in those applications when the conventional communication scheme logic cannot be applied (when no communication channel is available), but the user still requires a fast clearance for the faults on the entire feeder.

DSTPLAL enables a fast fault clearing during certain conditions. DSTPLAL is unable to replace the communication scheme logic completely due to a possible lack of selectivity during the first trip and AR initiation and also as the loss of load logic cannot operate for three-phase faults. DSTPLAL is controlled either by the auto-recloser (zone extension logic), or by monitoring the loss of load current (loss of load logic).

Zone extension logic

The *Zone extension* setting can be applied in cases when the auto-recloser function is in operation. When *Zone extension* is enabled, the auto-recloser (AR) function is used to enable the fast fault clearance independent of the fault location on the protected feeder. This is achieved by allowing a time delayed overreaching zone to trip instantly when a fault occurs. Also, in cases where there are tapped loads on the protected feeder, it is required to set a dedicated zone to initiate one or two shots as fast as possible before the protection devices of these taps clear. If the fault is still present after these shots, further tripping is delayed more in accordance with the other zones so that the operation becomes slower than the protection of the load taps, enabling it to clear. The final tripping that ends the sequence is always performed selectively according to a proper time grading of the zones.

If the fault is located on the adjacent feeder or bus within the reach of the overreaching zone, the tripping and the AR initiation takes place during an external fault.

Loss of load logic

The loss of load acceleration gives the overreaching zone a permission to operate instantly after the detection of a loss of load current condition.

The loss of load logic is unable to operate for three-phase faults.

Setting guidelines

The *Load current value* setting must be set below the minimum three-phase load current during the healthy state. A security factor of 0.5 is used:

$$\textit{Load current value} = 0.5 * I_{\text{minload}}$$

$I_{minload}$ the minimum load current during normal operation conditions.

The loss of load function is released after *Load release on time* is elapsed at the same time as the load current in all three phases has been above the *Load current value* setting. If the current values drop below the *Load current value* setting, the release condition stays activated until the drop-out delay time has expired (the *Load release off Tm* setting). The value of *Load release off Tm* is by default set to ”0.3 s". The *Load release on time* setting is used to increase the security of the loss of load function, for example in the case of transient inrush currents during the energizing of a power transformer. When there is no need for delaying the release, the *Load release on time* is set to zero in applications.

The *Minimum current* setting is used to detect the loss of load condition in healthy phases during the fault. The *Minimum current* setting is set to a value higher than the maximum current flowing in the healthy phases during the fault when the breaker at the remote end has been opened and the through flowing load has therefore been disconnected. This current can be, for example, due to the charging current of the phases or the load current of the tapped loads. At the same time, the *Minimum current* setting value is set below the *Load current value* setting. By default, the *Minimum current* setting value is set to “0.05 pu”.

The *Minimum current time* setting is used to provide the start delay for the loss of load current detection to avoid an unwanted release of the function. The value of *Minimum current time* is by default set to “0.2 s”.

5.8.7 Signals

Table 915: DSTPLAL Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
BLOCK	BOOLEAN	0	Block of function
AR_READY	BOOLEAN	0	Autoreclosure ready, releases function used for fast trip
CB_CL_CMD	BOOLEAN	0	CB close command
EX_ACC	BOOLEAN	0	Connected to function used for tripping at zone xtension
LOSSLOAD_ACC	BOOLEAN	0	Connected to function used for tripping at loss of load
NONDIR_ST	BOOLEAN	0	Non directional criteria used to prevent instantaneous trip

Table 916: DSTPLAL Output signals

Name	Type	Description
OPR_LOSSLOAD	BOOLEAN	Operate by loss of load
OPR_Z_EXTN	BOOLEAN	Operate by zone extension

5.8.8 Settings

Table 917: DSTPLAL Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Load current value	0.01 - 1.00	pu	0.01	0.10	Load current before disturbance
Minimum current	0.01 - 1.00	pu	0.01	0.05	Level taken as current loss due to remote CB trip
Minimum current time	0.000 - 60.000	s	0.001	0.200	Time delay on pick-up for Minimum current value
Load release on time	0.000 - 60.000	s	0.001	0.000	Time delay on pick-up for load current release
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
Load release off Tm	0.000 - 60.000	s	0.001	0.300	Time delay on drop off for load current release
Loss of load Op	Disabled Enabled	-	-	Disabled	Enable/Disable operation of Loss of load.
Zone extension	Disabled Enabled	-	-	Disabled	Enable/Disable operation of Zone extension

Table 918: DSTPLAL Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase

5.8.9 Measured values

Table 919: DSTPLAL Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0	Current amplitude phase A
I_AMPL_B	REAL	0	Current amplitude phase B
I_AMPL_C	REAL	0	Current amplitude phase C
BLOCK	BOOLEAN	0	Block of function
AR_READY	BOOLEAN	0	Autoreclosure ready, releases function used for fast trip
CB_CL_CMD	BOOLEAN	0	CB close command
EX_ACC	BOOLEAN	0	Connected to function used for tripping at zone xtension
LOSSLOAD_ACC	BOOLEAN	0	Connected to function used for tripping at loss of load
NONDIR_ST	BOOLEAN	0	Non directional criteria used to prevent instantaneous trip

5.8.10 Monitored data

Table 920: DSTPLAL Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_LOSSLOAD	BOOLEAN	0=FALSE 1=TRUE	-	Operate by loss of load
OPR_Z_EXTN	BOOLEAN	0=FALSE 1=TRUE	-	Operate by zone extension

5.8.11 Technical data

Table 921: DSTPLAL Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5% of the set value or $\pm 0.002 \times I_n$
Operate time accuracy	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

5.9 Communication logic for residual overcurrent RESCPSCH

5.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Communication logic for residual overcurrent	RESCPSCH	CLN	85N

5.9.2 Function block

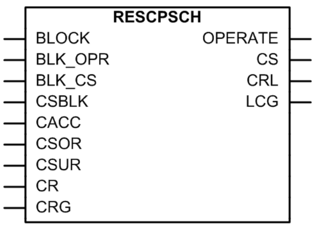


Figure 478: Function block

5.9.3 Functionality

The scheme communication logic for residual overcurrent protection RESCPSCH is provided to achieve an instantaneous fault clearing independent of the fault location on the protected feeder. The available communication scheme types are:

- Direct intertrip (DUTT)
- Permissive underreach (PUTT)
- Permissive overreach (POTT
- Directional comparison blocking (DCB)

The directional comparison unblocking scheme (DCUB) can also be provided by complementing the permissive schemes with an additional logic called the unblocking function, which is also included in RESCPSCH.

If the permissive overreaching scheme is used, some of the power system conditions requires additional special logic circuits, like current reversal logic and weak-end infeed (WEI) logic for distance protection, RCRWPSCH.

5.9.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the scheme communication logic function for residual overcurrent protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

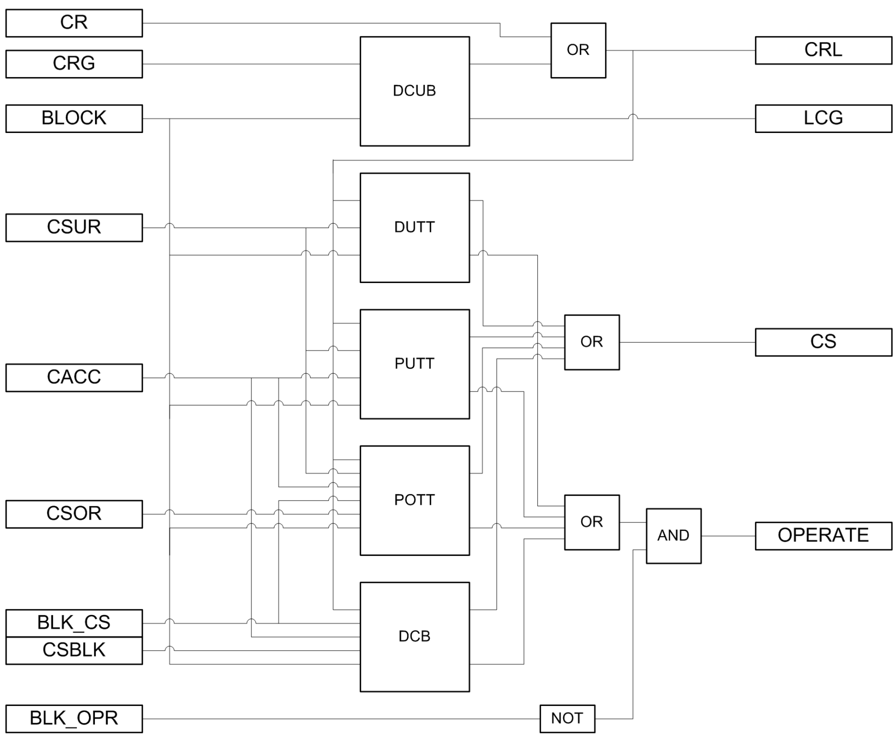


Figure 479: Functional module diagram

The applied communication scheme logic in RESCPSCH is selected with the *SchemeType* setting.

- If *SchemeType* = “Intertrip”, it is (DUTT)
- If *SchemeType* = “Permissive UR” , it is (PUTT)
- If *SchemeType* = “Permissive OR”, it is (POTT)
- If *SchemeType* = “Blocking” , it is (DCB)

The unblocking scheme (DCUB) is enabled with the *Unblock mode* setting.

Direct underreaching transfer trip scheme (DUTT)

The direct intertrip is enabled with *SchemeType* = “Intertrip”.

In the direct intertrip scheme, the start signal from the underreaching (instantaneous) residual overcurrent function DEFHPDEF, is connected to the `CSUR` input to create a carrier send (CS) signal. The duration of the `CSUR` input signal can be prolonged by the *Carrier Min Dur* setting to assure a sufficient duration for the CS signal.

The local circuit breaker is directly tripped (activation of the `OPERATE` output) with the carrier received (CR) signal after a settable pick-up delay *Coordination time* has elapsed without further local criteria.

The unblocking function (*Unblock* = “NoRestart” and *Unblock* = “Restart”) must not be enabled with the DUTT scheme, as the lost guard signal results in an immediate trip of the local circuit breaker.

The activation of the `BLOCK` input does a total blocking of the direct intertrip scheme. The activation of the `BLK_OPR` input blocks the `OPERATE` output.

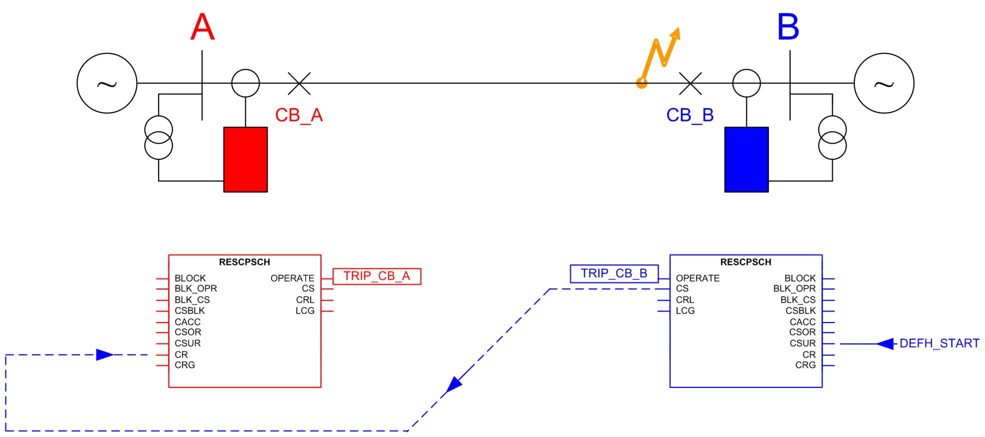


Figure 480: Simplified functional diagram of the direct intertrip scheme

Permissive underreaching transfer trip scheme (PUTT)

The permissive underreach is enabled with *SchemeType* = “Permissive UR”.

In the permissive underreach scheme, the start signal from the underreaching (instantaneous) residual overcurrent function DEFHPDEF, is connected to the `CSUR` input to create a CS signal. The duration of the `CSUR` input signal can be prolonged by the *Carrier Min Dur* setting to assure a sufficient duration of the CS signal.

In the permissive underreach scheme, the CR signal or CRL signal if unblocking function is enabled, is used to allow the overreaching residual overcurrent function DEFLPDEF, to trip (activation of the OPERATE output) after the pick-up delay *Coordination time*. The start signal from the overreaching function is connected to the CACC input. A general start signal in forward direction can also be connected to the CACC input.

The CS signal is also generated if the CR signal is received and the local carrier acceleration signal CACC is active.

Activating the BLOCK input blocks totally the permissive underreach scheme. Activating the BLK_OPR input blocks the OPERATE output.

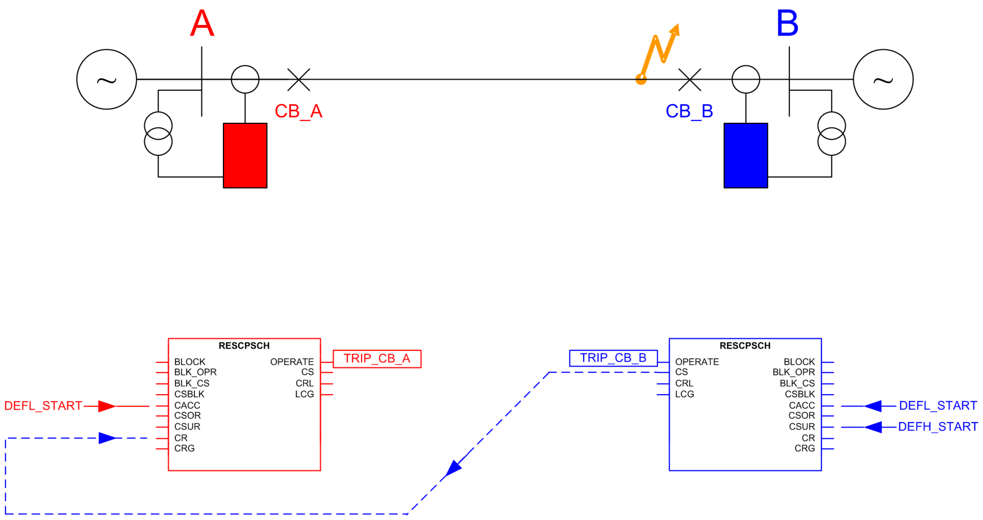


Figure 481: Simplified functional diagram of permissive underreach scheme

POTT (Permissive overrreaching transfer trip scheme)

The permissive overreach is enabled with *SchemeType* = “Permissive OR”.

In the permissive overreach scheme, the start signal from the overreaching residual overcurrent function DEFLPDEF, is connected to the CSOR input to create a CS signal. The CS signal can also be issued simultaneously from the underreaching residual overcurrent function DEFHPDEF. In this case, the start signal from the underreaching function is connected to the CSUR input. The duration of the CSUR input signal can be prolonged by the *Carrier Min Dur* setting, to assure a sufficient duration of the CS signal. The carrier send from CSOR can be blocked with the BLK_CS input.

In case of parallel feeders, and when the external current reversal logic (RCRWPSCH) is enabled, the CS signal is not prolonged and the value of *Carrier Min Dur* is set to zero to secure correct operation.

In the permissive overreach scheme, the received signal CR or CRL, if unblocking function is enabled used to allow the overreaching residual overcurrent function DEFLPDEF, to trip (activation of the OPERATE output) after the settable pick-up delay *Coordination time*. The start signal from the overreaching zone is connected to the CACC input.

The CS signal is also generated if the CR signal is received and the local carrier acceleration signal CACC is active.

Activating the BLOCK input blocks totally the permissive overreach scheme. Activating the BLK_OPR input blocks the OPERATE output.

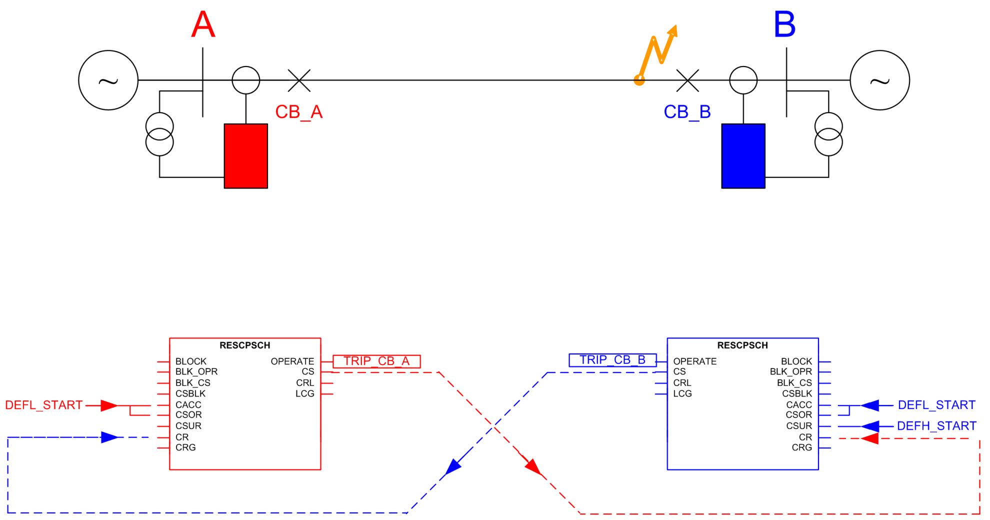


Figure 482: Simplified functional diagram of permissive overreach scheme

Directional comparison blocking scheme (DCB)

The directional comparison blocking scheme is enabled with *SchemeType* = “Blocking”.

In the blocking scheme, the start signal from the reverse looking residual overcurrent function DEFLPDEF set to operate for reverse direction earth fault, is connected to the CSBLK input to create a CS signal. The starting of the reverse looking function indicates that the fault is located outside the protected feeder. The duration of the CSBLK input signal can be prolonged with the *Carrier Min Dur* setting, to assure a sufficient duration of the CS signal. The CS signal from the CSBLK input can be blocked with the BLK_CS input.

The principal operation of the blocking scheme is that the forward looking overreaching residual overcurrent function is allowed to trip (activation of the

OPERATE output) after the settable *Coordination time* setting, and if no block signal is received from the remote terminal. To prevent a false trip in case of external faults, the CR signal must be received before the *Coordination time* has elapsed. The start signal from the overreaching residual overcurrent function DEFLPDEF, is connected to the CACC input.

The Coordination time setting in the blocking scheme depends, for example. on the communication system delay and on the terminal response times in transmitting a CS signal to the other feeder end. The *Coordination time* setting must not be zero.

Activating the BLOCK input blocks totally the permissive overreach scheme. Activating the BLK_OPR input blocks the OPERATE output.

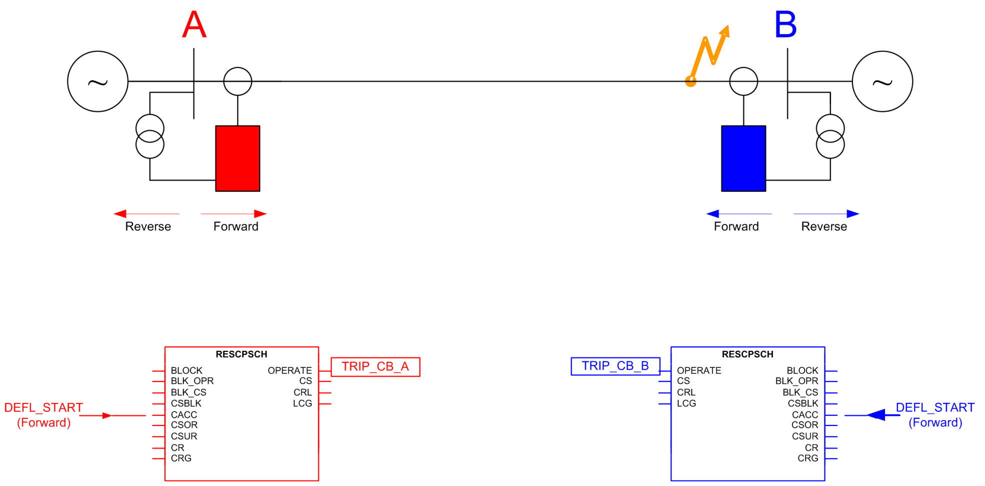


Figure 483: Simplified functional diagram of the blocking scheme, internal fault. The CS signal is not sent as the fault is not seen by the reverse-looking overreaching function.

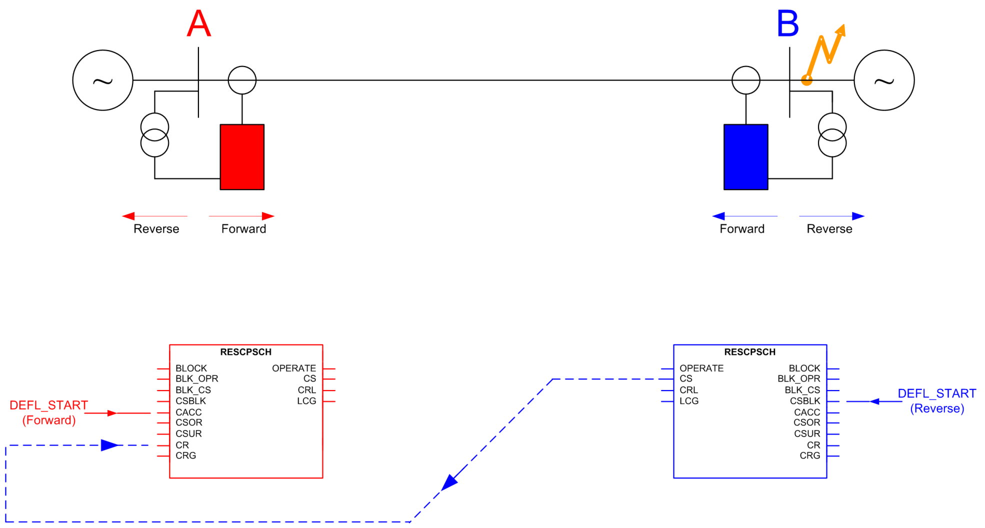


Figure 484: Simplified functional diagram of the blocking scheme, external fault. The IED at bus B sees the fault in the reverse direction and sends a blocking signal (CS) to the IED at bus A. There is no CB operation at either end.

The unblocking function used with the blocking function provides a possibility to supervise the communication channel. In this case, the `CRL` output signal is used as a local blocking signal.

The operation mode *Unblock* = “Restart” is not recommended as the blocking is activated only for 150 ms after the guard signal disappears. This results in an unwanted operation of the protection.

DCUB (Directional Comparison Unblocking)

The unblocking function is a complementary logic, which can be used together with the permissive communication schemes. In the unblocking scheme, the dependability of the permissive schemes is improved by using the loss of guard signal from the communication equipment to create locally a `CRL` output signal. This enables the permissive scheme to operate even if the communication channel is interrupted or lost.

The unblocking function uses a carrier guard signal (CRG), which must always be present. The absence of the CRG signal for a time longer than the value of the *Loss of carrier time* setting is used to generate a logical `CRL` signal. This enables the permissive scheme to operate despite the loss of the communication channel. A communication failure shorter than the value of the *Loss of carrier time* setting is always ignored.

The unblocking function is configured with the *Unblock* setting :

- *Unblock* = “Off”: The unblocking function is disabled.
- *Unblock* = “NoRestart”: If the CRG signal disappears for a longer time than defined in the *Loss of carrier time* setting. The logical CRL signal is generated. The CRL output signal is kept up until the CRG signal is present again. The communication failure is not signaled by the LCG output.
- *Unblock* = “Restart”: If the CRG signal disappears for a longer time than defined in the *Loss of carrier time* setting, theCRL output signal is generated. The CRL output signal is kept up for 150 ms, after which a communication failure is signaled by the LCG output. The LCG output is reset 200 ms after the CRG signal is present again. The purpose of this mode is to ensure tripping during a fixed delay of 150 ms after the loss of communication due to possible consequences of an internal fault. After this time, the accelerated tripping is allowed only if the actual CR signal is received again.

With operation modes *Unblock* = “NoRestart” and *Unblock* = “Restart” the created CRL output signal is internally ORed with the CR input to allow the permissive scheme to operate even when the communication channel has been interrupted or lost. The values of CRL and LCG output signals are also available through the monitored data view. Activating the BLOCK input blocks the CRL and LCG outputs.

5.9.5 Application

To achieve a fast fault clearing for a fault on the part of the protected feeder not covered by the instantaneous step of residual overcurrent protection, the directional residual overcurrent protection can be supported with RESCPSCH.

Applying RESCPSCH requires a communication channel capable of transmitting an "On" or "Off" signal in each direction. To enable fast tripping, the most important requirement for communication is the communication speed.

The performance of RESCPSCH function is directly related to the communication channel speed, and to the security against false or lost signals. Therefore, dedicated communication channels are recommended. A typical communication media is a simple pilot wire based on auxiliary power with short distances up to few kilometers, and fiber-optic cables utilizing digital data transmission up to distances of 150 km. To avoid false signals that could cause unwanted operation, the security of the communication channel should be emphasized. It is also important to pay attention to the dependability of the communication channel to ensure that the signals are reliably transmitted during power system faults.

The communication schemes supported by RESCPSCH are:

- Direct underreaching transfer trip, DUTT
- Permissive underreaching transfer trip, PUTT
- Permissive overreaching transfer trip, POTT
- Directional comparison blocking scheme, DCB
- Directional comparison unblocking scheme, DCUB

Depending on whether the communication channel is used for sending a block or a trip signal, the communication schemes can be divided into blocking schemes and permissive schemes.

In permissive schemes, the trip signals of the directional residual overcurrent protection are interchanged between the terminals to receive a permission to trip during an internal fault. The tripping of the local terminal depends on both the starting of its own forward looking function and on the received signal from the opposite terminal. In the underreaching scheme, no signals are sent during an external fault. However, during an external fault, a trip signal is also send to the opposite terminal, if the fault is seen in the forward direction and the overreaching scheme is used. However, in case of external faults, the tripping is always blocked either due to that no signal is received as the opposite terminal sees a reverse fault, or that the signal is received but locally the fault is seen in the reverse direction. In either case, the blocking is eventually not dependent on the received signal so that a lost communication channel would not result in false operation.

In the blocking scheme, a blocking signal is sent to the opposite terminal if the fault is locally seen in the reverse direction, that is, during an external fault. Thus, the blocking is dependent on the received signal, and there is typically a need to delay the tripping of the terminal receiving the blocking signal. This delay depends, for example, on the response times of the communication channel and terminals. During an internal fault, there is no signal transmission between the terminals, so the tripping does not depend on the received signal from the opposite terminal.

In conclusion, permissive schemes are inherently faster and have better security** against false tripping than a blocking scheme, since tripping in an external fault is not possible in case of a channel interruption. In a blocking scheme, a lost communication channel simultaneously with an external fault may lead to a false operation of the protection if the communication channel is not being supervised. On the other hand, as the fast trip of the permissive scheme depends on a received signal, its dependability*** is lower than that of the blocking scheme. [3] [4]

The unblocking scheme is also available to enhance the dependability of the permissive scheme. If the communication channel is interrupted, and simultaneously a fault occurs in the forward direction within that time, tripping is still possible either during a fixed time interval from the beginning of the interruption, or as long as the communication channel is lost. This is achieved by connecting the supervision output of the implemented communication functionality to the dedicated carrier guard signal input of RESCPSCH. In general, the

[3] ** security = The ability to block operation in case of an external fault
[4] *** dependability = The ability to operate in case of an internal fault

unblocking scheme also provides better security than the blocking scheme because tripping in external faults is only possible if the fault occurs within the above time.

The direct transfer trip scheme uses the underreaching function to trip the local breaker and to transfer the trip signal to the remote terminal. The remote terminal operates immediately based on the received transfer trip signal, without any additional conditions. This scheme is very simple, but its security is low, as a spurious signal results in false operation of the protection.

Direct intertrip

In some applications, there is a need to trip the remote end breaker immediately based on fault detection by the local measurements. This applies, for example, when the transformers or reactors are connected to the system without circuit-breakers, or for remote tripping following the operation of the local breaker failure protection (CBFP).

In the direct intertrip scheme (DUTT), the carrier send signal (CS) is initiated by the underreaching, or from the tripping signal of an external IED, such as transformer or reactor protection. At the remote end, the received signals initiates the breaker trip immediately without any further local protection criteria. To limit the risk for unwanted trip due to spurious sending of signals, the trip can be delayed by the *Coordination time* setting, which should be set to 10-30 ms, depending on the type of the communication channel. The general requirement for implementing the communication channel operating in direct intertripping applications is that it should be very secure and dependable.

Setting guidelines for intertrip scheme, DUTT:

Scheme type = "Intertrip"

Coordination time = "0.050" s (10 ms + maximal transmission time)

Carrier Min Dur = "0.1" s

Permissive underreach scheme

In the permissive underreach scheme, a permission to trip is obtained locally from the underreaching function and sent to the remote end. The received signal is then combined again with the local fault indication from the overreaching function resulting to trip command after a settable pick-up delay *Coordination time*.

In the permissive underreach scheme, the IED of either feeder end sends a permissive signal to trip the other end. The communication channel needs to be able to receive and transmit at the same time. In permissive schemes, a general requirement for the communication channel is that it must be fast and secure, but also the dependable. Inadequate security causes unwanted tripping for external faults. Inadequate speed or dependability causes delayed tripping for internal faults.

In the permissive underreach scheme, the CS signal is issued based on the underreaching residual overcurrent protection function.

The permissive scheme is not applicable on short feeder lengths due to the difficulties in the impedance measurement to distinguish between the internal and external faults in such cases.

It is possible that the residual overcurrent function starts only at one end due to the system conditions like weak zero sequence source at one end, or high fault resistance. It is still possible to achieve fast tripping from both ends by connecting a general forward start signal to `CACC`. So, even if the local overreaching residual overcurrent function has not picked up, the local `OPERATE` output would still be activated. The function also generates a CS signal by combining the carrier received (CR) signal from a remote end and also the local activation of `CACC`, giving the permission to a remote function to trip instantaneously.

The CR signal must be received when the overreaching residual overcurrent protection is still started to achieve an instantaneous trip. In some cases, due to the fault current distribution, the overreaching protection can operate only after the fault has been cleared by the remote terminal. In this case, there is a certain risk that if the remote terminal is tripped directly by the instantaneous underreaching function, the CS signal issued by it resets before the overreaching function of the local end terminal is operated. To assure a sufficient duration of the CR signal, the CS signal , can be prolonged by time *Carrier Min Dur*. The recommended value of the *Carrier Min Dur* setting is "0.1" s.

The received communication signal is combined with the output from the local overreaching function. Therefore, there is less concern for false signal causing an incorrect trip. Therefore, the timer *Coordination time* can be set to "0". A communication channel failure does not affect the selectivity, but delays the tripping at the other end for certain fault locations.

Setting guidelines for the permissive underreach scheme, PUTT:

Scheme type = "Permissive UR"

Coordination time = "0" s

Carrier Min Dur = "0.1" s

Permissive overreach scheme

In the permissive overreach scheme, permission to trip is obtained locally from an overreaching function and sent to the remote end. The received signal is then combined with the local fault indication from the overreaching function, resulting in trip command after a settable pick-up delay *Coordination time*.

In the permissive overreach scheme, the IED at either end of the feeder sends a permissive signal to trip the other end. Therefore the communication channel must be able to receive and transmit at the same time. A general requirement for the communication on permissive schemes is that it should be fast and secure.

In the permissive overreach scheme, the CS signal is issued based on the start of the overreaching residual overcurrent function.

It is possible that the residual overcurrent function start at one end due to system conditions like weak zero sequence source at one end, or high fault resistance. It is still possible to get fast tripping from both ends by connecting a general forward start signal to CACC. So, even if the local overreaching residual overcurrent function has not picked up, the local OPERATE would still be activated. The function also generates a CS signal by combining the CR signal from a remote end and local activation of CACC, giving permission to the remote function to trip instantaneously.

The permissive overreach scheme can be used for all feeder types and lengths.

In the permissive overreach scheme, the communication channel plays an essential role in obtaining a fast tripping at both ends. Typically, a lost communication channel does not cause false tripping. However, it delays the operation of the protection for the faults anywhere on the feeder.

The communication channel for a permissive overreach scheme must be fast and secure, but also dependable. Inadequate security can cause unwanted tripping for external faults. Inadequate speed or dependability can cause delayed tripping for internal faults.

In the permissive overreaching scheme, the CS signal can be issued in parallel both from the overreaching and underreaching functions. The CS signal from the overreaching function must not be prolonged, while the CS signal from the underreaching function must typically be prolonged. In parallel feeder applications, the scheme typically needs to be complemented by the current reversal logic. To ensure a correct operation in this case, the CS signal shall not be prolonged (*Carrier Min Dur* = "0" s). There is no need to delay the tripping when receiving the carrier signal, so set the time *Coordination time* to "0".

Setting guidelines for the permissive overreaching transfer trip scheme, POTT:

Scheme type = "Permissive OR"

Coordination time = "0" s

Carrier Min Dur = "0.1" s

Carrier Min Dur = "0" s (in case of parallel lines and current reversal logic)

Directional comparison blocking scheme

In the blocking scheme, the reverse-looking residual overcurrent function, is used for sending a block signal to the remote end to block the overreaching forward looking residual overcurrent function.

The blocking scheme is very dependable because it operates for faults anywhere on the protected feeder, even if the communication channel is out of service. Conversely, it is less secure than a permissive scheme because it trips for external faults within the reach of the overreaching local function, if the communication channel is out of service and no block signal is received.

Inadequate speed or low dependability of the communication channel can cause spurious tripping for external faults.

To secure that the blocking signal has time to arrive before the local overreaching function trips, the trip is delayed by the *Coordination time* setting. The *Coordination time* setting must be set longer than the maximal transmission time of the channel added by the start and response times of the IEDs sending and receiving the CS signal. A security margin of at least 10 ms should be considered. The time delay *Carrier Min Dur* for prolonging the CS signal is set to "0".

Setting guidelines for the blocking scheme:

Scheme type = "Blocking"

Coordination time = "0.1" s (10 ms + maximal transmission time)

Carrier Min Dur = "0" s

Directional comparison unblocking scheme

Metallic communication paths adversely affected by fault-generated noise or by other electrical phenomena, such as lightning, are not suitable for conventional permissive schemes that rely on signal transmitted during a fault in the protected feeder. Principally, the communication media must be properly shielded or otherwise designed to provide an adequate performance during such conditions.

In general, to overcome the lower dependability of permissive schemes, the unblocking scheme can be used. The function is used at older, less reliable communication, where the signal has to be sent through the primary fault. The unblocking function uses a carrier guard signal (CRG) which must always be present, even when no CR signal is received. Due to the absence of the CRG signal during the security time, the *Loss of carrier time* setting is used as a CR signal. This also enables a permissive scheme to operate when the communication channel is temporarily lost during an internal fault.

Setting guidelines for the unblocking scheme:

The unblocking function is configured with the *Unblock* setting:

- *Unblock* = “Off”: The unblocking function is disabled
- *Unblock* = “NoRestart”: If the CRG signal disappears for a longer time period defined in the *Loss of carrier time* setting, a logical carrier received signal (CRL) is generated. The CRL signal is kept up until the CRG signal is present. The communication failure is not signalled by the `LCG` output. The *Loss of carrier time* setting is set to "35" ms.
- Unblock = “Restart”: If the CRG signal disappears for a longer time period than the *Loss of carrier time* setting, a CRL signal is generated. The CRL signal is kept up for 150 ms, after which a communication failure is signalled by the `LCG` output. The value of the `LCG` output is reset 200 ms after the CRG signal is present again. The *Loss of carrier time* setting is set to "35" ms.

5.9.6 Signals

Table 922: RESCPSCH Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Signal for blocking trip due to communication logic
BLK_CS	BOOLEAN	0	Signal for blocking CS in Overreach and Blocking schemes
CSBLK	BOOLEAN	0	Reverse residual overcurrent signal for Carrier Send
CACC	BOOLEAN	0	Signal to be used for tripping by Communication Scheme
CSOR	BOOLEAN	0	Overreaching residual overcurrent signal for Carrier Send
CSUR	BOOLEAN	0	Underreaching residual overcurrent signal for Carrier Send
CR	BOOLEAN	0	Carrier Receive for Communication Scheme Logic
CRG	BOOLEAN	0	Carrier guard signal received

Table 923: RESCPSCH Output signals

Name	Type	Description
OPERATE	BOOLEAN	Trip by Communication Scheme Logic
CS	BOOLEAN	Carrier Send by Communication Scheme Logic
CRL	BOOLEAN	Carrier Receive from Communication Scheme Logic
LCG	BOOLEAN	loss of carrier guard signal

5.9.7 Settings

Table 924: RESCPSCH Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Scheme type	Off Intertrip Permissive UR Permissive OR Blocking	-	-	Permissive UR	Scheme type, Mode of Operation
Coordination time	0.000 - 60.000	s	0.001	0.035	Communication scheme coordination time
Carrier Min Dur	0.000 - 60.000	s	0.001	0.100	Minimum duration of a carrier send signal

Table 925: RESCPSCH Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Loss of carrier time	0.000 - 60.000	s	0.001	0.035	Security timer for loss of carrier guard detection
Unblock mode	Off NoRestart Restart	-	-	Off	Operation mode of unblocking logic

5.9.8 Measured values

Table 926: RESCPSCH Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPR	BOOLEAN	0	Signal for blocking trip due to communication logic
BLK_CS	BOOLEAN	0	Signal for blocking CS in Overreach and Blocking schemes
CSBLK	BOOLEAN	0	Reverse residual overcurrent signal for Carrier Send
CACC	BOOLEAN	0	Signal to be used for tripping by Communication Scheme
CSOR	BOOLEAN	0	Overreaching residual overcurrent signal for Carrier Send
CSUR	BOOLEAN	0	Underreaching residual overcurrent signal for Carrier Send
CR	BOOLEAN	0	Carrier Receive for Communication Scheme Logic
CRG	BOOLEAN	0	Carrier guard signal received

5.9.9 Monitored data

Table 927: RESCPSCH Monitored data

Name	Type	Values (Range)	Unit	Description
OPERATE	BOOLEAN	0=FALSE 1=TRUE	-	Trip by Communication Scheme Logic
CS	BOOLEAN	0=FALSE 1=TRUE	-	Carrier Send by Communication Scheme Logic
CRL	BOOLEAN	0=FALSE 1=TRUE	-	Carrier Receive from Communication Scheme Logic
LCG	BOOLEAN	0=FALSE 1=TRUE	-	loss of carrier guard signal

5.9.10 Technical data

Table 928: RESCPSCH Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

5.9.11 Technical revision history

Table 929: RESCPSCH technical revision history

Technical revision	Change
B	Default setting value changed from “Intertrip” to “Permissive UR” for *Scheme type* setting

5.10 Current reversal and WEI logic for residual overcurrent RCRWPSCH

5.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current reversal and weak-end infeed logic for residual overcurrent	RCRWPSCH	CLCRWN	85NCRW

5.10.2 Function block

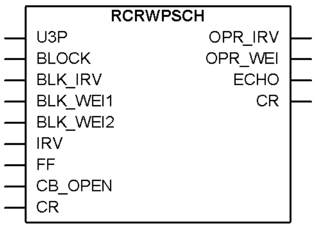


Figure 485: Function block

5.10.3 Functionality

The scheme communication logic for residual overcurrent protection RESCPSCH may require additional logics to operate correctly in all possible power system conditions. Such special logics include, for example, the current reversal and weak-end infeed logics which are combined to the RCRWPSCH function block.

Current reversal logic: In the parallel feeder applications, the direction of fault current on the healthy feeder can change when the circuit breaker on the faulty feeder opens to clear the fault. This can lead to an unwanted operation of the residual overcurrent protection on the healthy parallel feeder when RESCPSCH with the permissive overreach scheme is used. The main purpose of the current reversal logic is to prevent such unwanted operations.

The weak-end infeed (WEI) logic: Basically, the permissive communication schemes can operate only when the protection in the remote terminal can detect the fault. This detection requires a sufficient minimum fault current. If such current is not available due to too weak a remote end source, the WEI logic can be used to overcome the situation and trip the remote end breaker.

5.10.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of current reversal and weak-end infeed logics for residual overcurrent protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

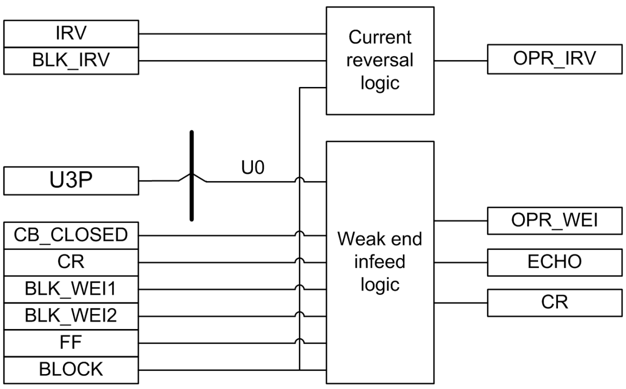


Figure 486: Functional module diagram

Current reversal logic

The current reversal logic is enabled by changing the value of the *Reversal mode* setting to “On”.

The current reversal logic uses the start signal of the reverse directional residual overcurrent function connected to the `IRV` input, which is used to recognize the fault being in the reverse direction, that is, in the parallel feeder. When the reverse directional residual overcurrent function is activated, after a start delay (setting *Reversal time*) the logic is ready to issue an `OPR_IRV` output signal. The `OPR_IRV` signal is connected to the `BLK_CS` input of the scheme communication logic function to block the sending of the carrier send signal (CS) and the activation of the OPERATE output of the communication logic. The OPR_IRV signal has a drop-off delay defined with the *Reversal reset time* setting.

An internal 10 ms drop-off timer is provided which secures the current reversal logic to be activated for short duration input signals, even if the *Reversal reset time* setting is set to zero.

The BLK_IRV input is used to block the activation of the OPR_IRV output. The BLK_IRV input is typically connected to the forward looking residual overcurrent function start signals within the terminal. General blocking is achieved by activating the BLOCK input.

Weak-end infeed (WEI) logic

The WEI logic is used in cases where the fault current infeed is too low due to, for example, high source impedance or fault current distribution between sources to activate the residual overcurrent protection function. When activated, the carrier receive (CR) signal is logically combined with the local criteria to initiate the tripping of the weak end breaker. The received signal is also echoed back to accelerate the tripping at the opposite end with the stronger source.

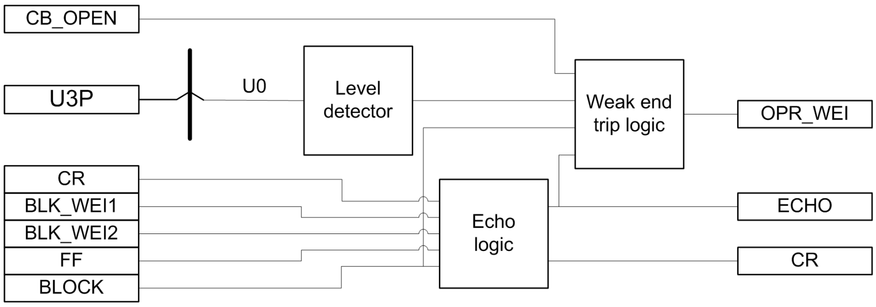


Figure 487: Functional module diagram of the weak-end infeed logic

The WEI logic is enabled using the *Wei mode* setting.

- If *Wei mode*= “Off,” the WEI logic is disabled.
- If *Wei mode*= “Echo,” the WEI logic is enabled without the trip function.
- If *Wei mode*= “Echo & Trip,” the WEI logic is enabled with the trip function.

Level detector

The level detector sends an enabling signal to the weak-end trip logic when the residual voltage is above the *Residual voltage Val* setting.

Echo logic

The WEI logic returns the received carrier signal with the ECHO output when it receives a carrier receive signal (CR) under the conditions that no fault has been detected by the forward and reverse directional residual overcurrent functions and that the duration of CR is longer than the coordination time delay (the setting *Wei Crd time*). The received carrier receive signal is also given as the CR output.

When the WEI logic is enabled at both feeder ends, a spurious signal can be looped round by the echo logics. To avoid a continuous lockup of the system, the duration of the echoed signal is limited to 200 ms.

The ECHO and CR outputs can be blocked by activating the BLOCK input. The FF, BLK_WEI1 and BLK_WEI2 inputs can be used to block the ECHO output. The FF input is usually connected to the functional output of the fuse failure function, and the BLK_WEI1 input is typically connected to the start signals of the forward and reverse directional residual overcurrent functions within the terminal. The BLK_WEI2 signal has an inbuilt 200 ms drop-off delay. The BLK_WEI2 input is usually connected to all the fault detection functions within the terminal except the residual overvoltage function.

Weak-end trip logic

The weak-end trip logic is activated if the level detector and echo logic are activated. Then a general trip signal OPR_WEI is activated. The tripping is blocked if the CB_OPEN input is activated.

The OPR_WEI output can be blocked by activating the BLOCK input.

5.10.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

5.10.6 Application

Current reversal logic

When the overreaching permissive communication schemes are used in parallel feeder applications, the current reversal can result in unselective tripping. Such a condition can occur in the healthy feeder when the fault is cleared in the faulty feeder. The tripping of the healthy parallel feeder can lead to the losing of the connection between the two buses. To avoid this situation, the current reversal logic (transient blocking logic) can be used.

In the current reversal condition, the relays Relay A1, Relay A2, Relay B1 and Relay B2 can be equipped with the scheme communication logic RESCPSCH and the permissive overreach scheme can be enabled.

A fault occurs at Feeder 1 close to the bus B. Relay A2 at the healthy feeder 2 recognizes the fault in the forward direction and sends a CS signal to Relay B2 according to the PUTT scheme. Relay B2 does not recognize the fault in the forward direction and hence does not send a permissive signal to Relay A2.

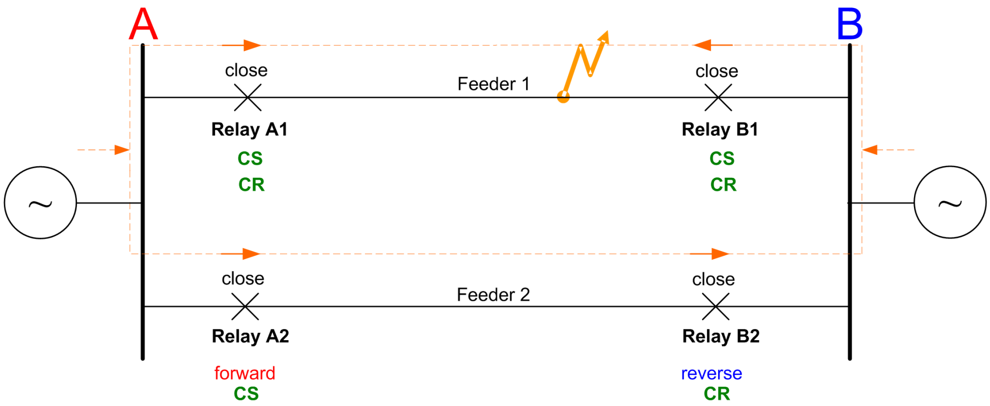


Figure 488: Fault occurs at one of the parallel lines. CS=carrier signal sending, CR=carrier signal receiving

In practice, the faulted feeder (Feeder 1) is not simultaneously tripped at both ends and it can occur that for example the circuit breaker closer to the fault at Relay B1 is tripped faster than the breaker at the bus A. The result is that when the breaker at Relay B1 opens, the direction of the fault current at the healthy feeder (Feeder 2) is reversed.

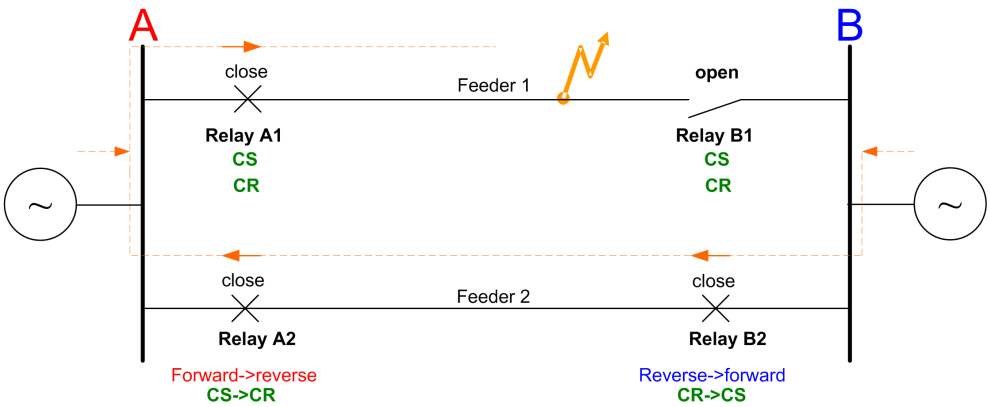


Figure 489: Circuit breaker at Relay B1 opens and creates a current reversal condition. CS=carrier signal sending, CR=carrier signal receiving.

The Relay A2 still sends the CS signal because of the reset time delay of forward direction residual overcurrent function of Relay A2 when the Relay B2 starts to recognize the fault in the forward direction, Relay B2 can mis-operate and trip the breaker of the healthy feeder.

This problem can be solved using the reverse directional residual overcurrent function to recognize the fault in reverse direction and temporarily block the operation of the scheme communication logic due to the current reversal condition. This is utilized in RCRWPSCH.

Weak-end infeed (WEI) logic

Avoid using the WEI function at both feeder ends. It can only be enabled at the weak end.

The WEI logic is recommended to be used only in the permissive schemes.

Setting guidelines for current reversal logic

Setting *Reversal reset time*: *Reversal reset time* can be set to the maximum reset time of the communication channel. A minimum setting of 40 ms is recommended. A long *Reversal reset time* setting increases the security against unwanted tripping, but delays the fault clearing if the fault develops from one feeder to involve the other. However, the probability of this type of fault is small.

Setting *Reversal time*: Set the start delay *reversal time* below 80 percent of the breaker operate time, but with a minimum of 20 ms.

Setting guidelines for Weak-End Infeed (WEI) logic

The WEI function returns the received carrier signal with the `ECHO` output when it receives the carrier signal (CR) under the condition that no fault has been detected by the forward and reverse directional measuring elements and that the duration is longer than the *Wei Crd time* coordination time delay setting. To prevent the spurious carrier received signals from activating the WEI logic and causing unwanted communications, the *Wei Crd time* setting can be set to “0.010 s”.

5.10.7 Signals

Table 930: RCRWPSCH Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block of function
BLK_IRV	BOOLEAN	0	Block of current reversal function
BLK_WEI1	BOOLEAN	0	Block of WEI Logic
BLK_WEI2	BOOLEAN	0	Block of WEI logic due to operation of other protections
IRV	BOOLEAN	0	Activation of current reversal logic
FF	BOOLEAN	0	Block of trip from WEI logic through fuse-failure function
CB_OPEN	BOOLEAN	0	Block of trip from WEI logic by an open breaker
CRL	BOOLEAN	0	POR Carrier receive for WEI logic

Table 931: RCRWPSCH Output signals

Name	Type	Description
OPR_IRV	BOOLEAN	Operation of current reversal logic
OPR_WEI	BOOLEAN	Operation of WEI logic
ECHO	BOOLEAN	Carrier send by WEI logic
CR	BOOLEAN	POR Carrier signal received from remote end

5.10.8 Settings

Table 932: RCRWPSCH Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Reversal mode	Off On	-	-	Off	Operating mode of Current Reversal Logic
Wei mode	Off Echo Echo & Trip	-	-	Off	Operating mode of WEI logic
Residual voltage Val	0.05 - 0.70	pu	0.01	0.25	Neutral voltage setting for fault conditions measurement
Reversal time	0.000 - 60.000	s	0.001	0.020	Pickup time for current reversal logic
Reversal reset time	0.000 - 60.000	s	0.001	0.060	Time Delay to prevent Carrier send and local trip
Wei Crd time	0.000 - 60.000	s	0.001	0.000	Coordination time for the WEI logic

Table 933: RCRWPSCH Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel Res	Residual Grp 1 Residual Grp 2 Residual Grp 3	-	-	Residual Grp 1	Base value selector, residual

5.10.9 Measured values

Table 934: RCRWPSCH Measured values

Name	Type	Default	Description
U0_AMPL	REAL	0	Residual voltage amplitude
BLOCK	BOOLEAN	0	Block of function
BLK_IRV	BOOLEAN	0	Block of current reversal function
BLK_WEI1	BOOLEAN	0	Block of WEI Logic
BLK_WEI2	BOOLEAN	0	Block of WEI logic due to operation of other protections
IRV	BOOLEAN	0	Activation of current reversal logic

Table continues on next page

Name	Type	Default	Description
FF	BOOLEAN	0	Block of trip from WEI logic through fuse-failure function
CB_OPEN	BOOLEAN	0	Block of trip from WEI logic by an open breaker
CRL	BOOLEAN	0	POR Carrier receive for WEI logic

5.10.10 Monitored data

Table 935: RCRWPSCH Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_IRV	BOOLEAN	0=FALSE 1=TRUE	-	Operation of current reversal logic
OPR_WEI	BOOLEAN	0=FALSE 1=TRUE	-	Operation of WEI logic
ECHO	BOOLEAN	0=FALSE 1=TRUE	-	Carrier send by WEI logic
CR	BOOLEAN	0=FALSE 1=TRUE	-	POR Carrier signal received from remote end

5.10.11 Technical data

Table 936: RCRWPSCH Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5% of the set value or ±0.002 × U_n
Operate time accuracy	±1.0% of the set value or ±20 ms

5.11 Emergency start function ESMGAPC

5.11.1 Identification

Functional description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Emergency start function	ESMGAPC	ESTART	ESTART

5.11.2 Function block

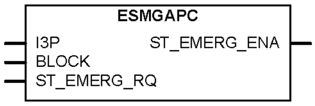


Figure 490: Function block

5.11.3 Functionality

An emergency condition can arise in cases where the motor needs to be started despite knowing that this can increase the temperature above limits or cause a thermal overload or some other condition that can damage the motor. The emergency start function ESMGAPC allows motor startups during such emergency conditions. ESMGAPC forces the IED to allow the restarting of the motor and keeps the trip limits 10 percent higher if the RTD temperature sensors are used. After the emergency input is activated, the motor can be started normally. ESMGAPC does not actually restart the motor.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

5.11.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the emergency start function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

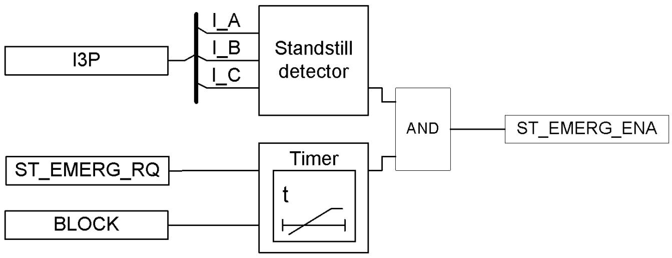


Figure 491: Functional module diagram

Standstill detector

The module detects if the motor is in a standstill condition. The standstill condition can be detected based on the phase current values. If all three phase currents are below the set value of *Motor standstill A*, the motor is considered to be in a standstill condition.

Timer

The timer is a fixed 10-minute timer that is activated when the ST_EMERG_RQ input is set high. The activation of the ST_EMERG_RQ input activates the ST_EMERG_ENA output, provided that the motor is in a standstill condition. The ST_EMERG_ENA output remains active for 10 minutes or as long as the ST_EMERG_RQ input is high, whichever takes longer.

The activation of the BLOCK input blocks the function and also resets the timer.

The function also provides the ST_EMERG_ENA output change date and time, T_ST_EMERG. The information is available in the monitored data view.

5.11.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

5.11.6 Application

If the motor needs to be started in an emergency condition at the risk of damaging the motor, all the external restart inhibits are ignored, allowing the motor to be restarted. Furthermore, if the calculated thermal level is higher than the restart inhibit level at an emergency start condition, the calculated thermal level is set slightly below the restart inhibit level. Also, if the register value of the cumulative startup time counter exceeds the restart inhibit level, the value is set slightly below the restart disable value to allow at least one motor startup. If RTDs are used, the set trip values are increased by 10 percent.

The activation of the ST_EMERG_RQ digital input allows to perform emergency start. The IED is forced to a state which allows the restart of motor, and the operator can now restart the motor. If RTDs are used, the operator should make sure that the RTD temperatures are low enough to restore the RTD trip level back to normal before the emergency start is deactivated. A new emergency start cannot be made until the 10 minute time-out has passed or until the emergency start is released, whichever takes longer.

The last change of the emergency start output signal is recorded.

5.11.7 Signals

Table 937: ESMGAPC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current inputs
BLOCK	BOOLEAN	0	Block signal to block the function.
ST_EMERG_RQ	BOOLEAN	0	Input emergency start signal from the operator.

Table 938: ESMGAPC Output signals

Name	Type	Description
ST_EMERG_ENA	BOOLEAN	Emergency start signal

5.11.8 Settings

Table 939: ESMGAPC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

Table 940: ESMGAPC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Motor standstill A	0.05 - 0.20	pu	0.01	0.12	Current limit to check for motor standstill condition

5.11.9 Measured values

Table 941: ESMGAPC Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0.0	TrueRMS motor current for phase A.
I_RMS_B	REAL	0.0	TrueRMS motor current for phase B.
I_RMS_C	REAL	0.0	TrueRMS motor current for phase C.
BLOCK	BOOLEAN	0	Block signal to block the function.
ST_EMERG_RQ	BOOLEAN	0	Input emergency start signal from the operator.

5.11.10 Monitored data

Table 942: ESMGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
ST_EMERG_ENA	BOOLEAN	0=FALSE 1=TRUE	-	Emergency start signal
T_ST_EMERG	INTEGER	-	-	Time when emergency start output signal was last activated / deactivated

5.11.11 Technical data

Table 943: ESMGAPC Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5% of the set value or ±0.002 × U_n

Section 6 Supervision functions

6.1 Trip circuit supervision TCSSCBR

6.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Trip circuit supervision	TCSSCBR	TCS	TCM

6.1.2 Function block

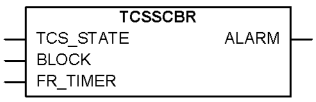


Figure 492: Function block

6.1.3 Functionality

The trip circuit supervision function TCSSCBR is designed to supervise the control circuit of the circuit breaker. The invalidity of a control circuit is detected by using a dedicated output contact that contains the supervision functionality. The failure of a circuit is reported to the TCSSCBR function by connecting the dedicated binary input HW channel of the PSM module to the corresponding TCSSCBR function block instance in the IED configuration.

The function starts and operates when TCS detects a trip circuit failure. The operating time characteristic for the function is DT. The function operates after a predefined operating time and resets when the fault disappears.

The function contains a blocking functionality. It is possible to block the function output or the timer itself, if desired.

6.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of trip circuit supervision can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

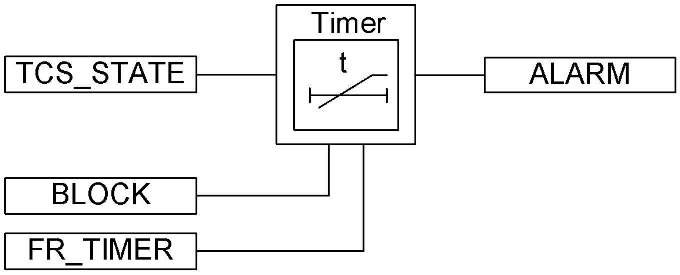


Figure 493: Functional module diagram

Timer

Once activated, the timer runs until the set value of *Operate delay time* has elapsed. The time characteristic is according to DT. When the operation timer has reached the maximum time value, the `ALARM` output is activated. If a drop-off situation occurs during the operate time up counting, the fixed 0.5 s reset timer is activated. After that time, the operation timer is reset.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates the `ALARM` output and resets the internal timers. The operation timer counting can be frozen to the prevailing value by activating the input signal `FR_TIMER`.

6.1.5 Application

TCSSCBR detects faults in the electrical control circuit of the circuit breaker. The function can supervise both open and closed coil circuits. This kind of supervision is necessary to find out the vitality of the control circuits continuously.

Figure 494 shows an application of the trip-circuit supervision function use. The best solution is to connect an external R_{ext} shunt resistor in parallel with the circuit breaker internal contact as shown with the dashed line. This way, although the circuit breaker internal contact is open, TCS can see the trip circuit through R_{ext}. The R_{ext} resistor should have such a resistance that the current through the circuit breaker coil remains small, that is, it does not harm or overload the circuit breaker's trip coil if the trip is latched or locked-out.

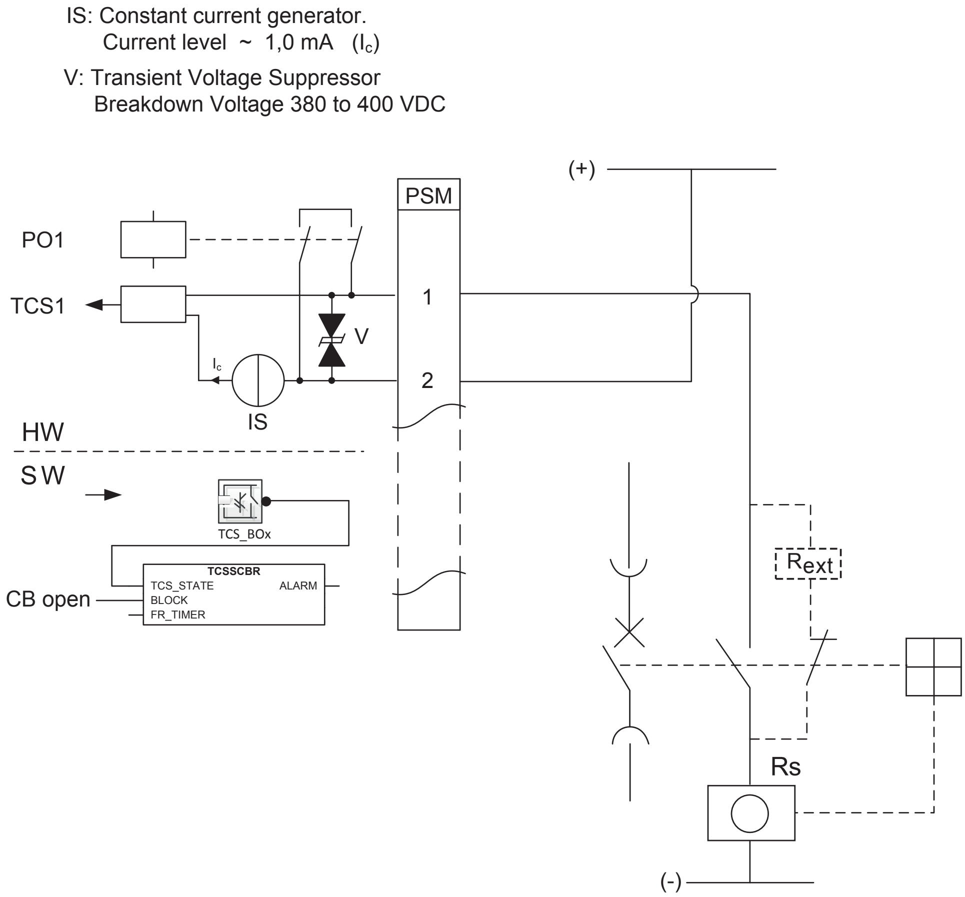


Figure 494: Operating principle of the trip-circuit supervision with an external resistor. When the CB is open, the TCSSCBR blocking is not required when the external resistor (Rext) is used.

If TCS is required only in a closed position, the external shunt resistance can be omitted. When the circuit breaker is in the open position, TCS sees the situation as a faulty circuit. One way to avoid TCS operation in this situation would be to block the supervision function whenever the circuit breaker is open.

Trip circuit supervision and other trip contacts

It is typical that the trip circuit contains more than one trip contact in parallel, for example in transformer feeders where the trip of a Buchholz relay is connected in parallel with the feeder terminal and other relays involved.

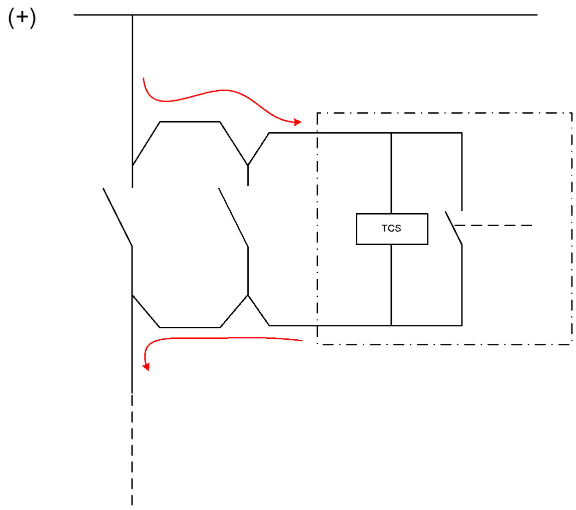


Figure 495: Constant test current flow in parallel trip contacts and trip-circuit supervision

Several trip circuit supervision functions parallel in circuit

Not only the trip circuit often have parallel trip contacts, it is also possible that the circuit has multiple TCS circuits in parallel. Each TCS circuit causes its own supervising current to flow through the monitored coil and the actual coil current is a sum of all TCS currents. This must be taken into consideration when determining the resistance of R_{ext}.

Setting the TCS function in a protection IED "Off" does not affect the supervising current injection.

Trip circuit supervision with auxiliary relays

Many retrofit projects are carried out partially, that is, the old electromechanical relays are replaced with new ones but the circuit breaker is not replaced. This creates a problem that the coil current of an old type circuit breaker can be too high for the protection IED trip contact to break.

The circuit breaker coil current is normally cut by an internal contact of the circuit breaker. In case of a circuit breaker failure, there is a risk that the protection IED trip contact is destroyed since the contact is obliged to disconnect high level of electromagnetic energy accumulated in the trip coil.

An auxiliary relay can be used between the protection IED trip contact and the circuit breaker coil. This way the breaking capacity question is solved, but the TCS circuit in the protection IED monitors the healthy auxiliary relay coil, not the circuit breaker coil. The separate trip circuit supervision relay is applicable for this to supervise the trip coil of the circuit breaker.

Dimensioning of the external resistor

Under normal operating conditions, the applied external voltage is divided between the relay’s internal circuit and the external trip circuit so that at the minimum 10 V (3...10 V) remains over the relay’s internal circuit. Should the external circuit’s resistance be too high or the internal circuit’s too low, for example due to welded relay contacts, the fault is detected.

Mathematically, the operation condition can be expressed as:

$$U_c - (R_{ext} + R_s) \times I_c \geq 10V\ DC$$

(Equation 152)

U_c	Operating voltage over the supervised trip circuit
I_c	Measuring current through the trip circuit, appr. 1.0 mA (0.85...1.20 mA)
R_{ext}	external shunt resistance
R_s	trip coil resistance

If the external shunt resistance is used, it has to be calculated not to interfere with the functionality of the supervision or the trip coil. Too high a resistance causes too high a voltage drop, jeopardizing the requirement of at least 10 V over the internal circuit, while a resistance too low can enable false operations of the trip coil.

Table 944: Values recommended for the external resistor R_{ext}

Operating voltage U_c	Shunt resistor R_{ext}
48 V DC	10 kΩ, 5 W
60 V DC	22 kΩ, 5 W
110...130 V DC	33 kΩ, 5 W
220...250 V DC	68 kΩ, 5 W

Due to the requirement that the voltage over the TCS contact must be 10 V or higher, the correct operation is not guaranteed with auxiliary operating voltages lower than 48 V DC because of the voltage drop in R_{ext} and the operating coil or even voltage drop of the feeding auxiliary voltage system which can cause too low voltage values over the TCS contact. In this case, erroneous alarming can occur.

At lower (<48 V DC) auxiliary circuit operating voltages, it is recommended to use the circuit breaker position to block unintentional operation of TCS. The use of the position indication is described earlier in this chapter.

6.1.6 Signals

Table 945: TCSSCBR Input signals

Name	Type	Default	Description
TCS_STATE	BOOLEAN	0	Trip circuit supervision from TCS hardware circuit
BLOCK	BOOLEAN	0	Blocking signal of the trip circuit supervision
FR_TIMER	BOOLEAN	0	Blocking signal to freeze operating counter

Table 946: TCSSCBR Output signals

Name	Type	Description
ALARM	BOOLEAN	Trip circuit fault indication

6.1.7 Settings

Table 947: TCSSCBR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On

Table 948: TCSSCBR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Operate delay time	0.020 - 300.000	s	0.001	3.000	Operate Delay Time

6.1.8 Measured values

Table 949: TCSSCBR Measured values

Name	Type	Default	Description
TCS_STATE	BOOLEAN	0	Trip circuit supervision from TCS hardware circuit
BLOCK	BOOLEAN	0	Blocking signal of the trip circuit supervision
FR_TIMER	BOOLEAN	0	Blocking signal to freeze operating counter

6.1.9 Monitored data

Table 950: TCSSCBR Monitored data

Name	Type	Values (Range)	Unit	Description
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Trip circuit fault indication

6.1.10 Technical data

Table 951: TCSSCBR Technical data

Characteristic	Value
Time accuracy	±1.0% of the set value or ±40 ms

6.2 Current circuit supervision CCRDIF

6.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current circuit supervision	CCRDIF	MCS 3I	MCS 3I

6.2.2 Function block

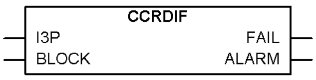


Figure 496: Function block

6.2.3 Functionality

The current circuit supervision function CCRDIF is used for monitoring current transformer secondary circuits.

CCRDIF calculates internally the sum of phase currents (I_A, I_B and I_C) and compares the sum against the measured single reference current (I_REF). The reference current must originate from other three-phase CT cores than the phase currents (I_A, I_B and I_C) and it is to be externally summated, that is, outside the IED.

CCRDIF detects a fault in the measurement circuit and issues an alarm or blocks the protection functions to avoid unwanted tripping.

It must be remembered that the blocking of protection functions at an occurring open CT circuit means that the situation remains unchanged and extremely high voltages stress the secondary circuit.

6.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of current circuit supervision can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

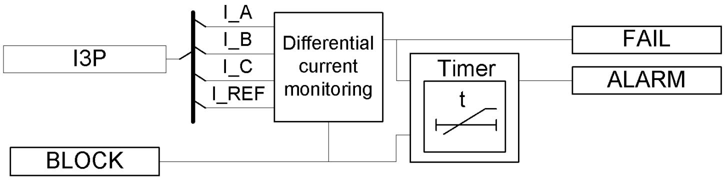


Figure 497: Functional module diagram. Group signal I3P is used for feeding the necessary analog signals to the function.

Differential current monitoring

Differential current monitoring supervises the difference between the summed phase currents I_A, I_B and I_C and the reference current I_REF.

The current operating characteristics can be selected with the *Start value* setting. When the highest phase current is less than 1.0 × In, the differential current limit is defined with *Start value*. When the highest phase current is more than 1.0 × In, the differential current limit is calculated with the formula:

$$MAX(I\_A, I\_B, I\_C) \times Start\ value$$

(Equation 153)

The differential current is limited to 1.0 × In.

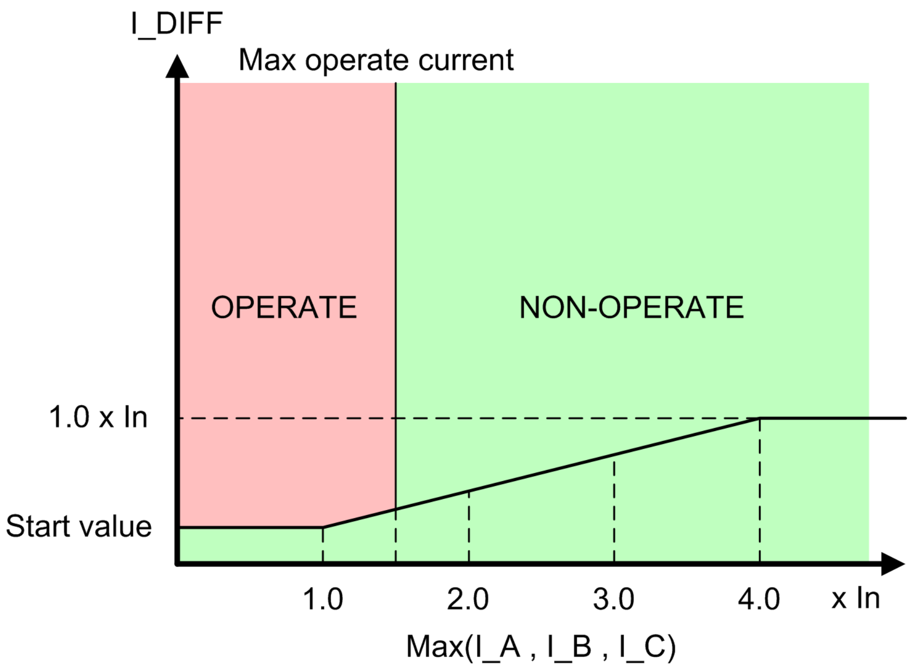


Figure 498: CCRDIF operating characteristics

When the differential current I_DIFF is in the operating region, the FAIL output is activated.

The function is internally blocked if any phase current is higher than the set *Max operate current*. When the internal blocking activates, the FAIL output is deactivated immediately. The internal blocking is used for avoiding false operation during a fault situation when the current transformers are saturated due to high fault currents.

The value of the differential current is available in the monitored data view on the LHMI or through other communication tools. The value is calculated with the formula:

$$I\_DIFF = \left|\overline{I\_A} + \overline{I\_B} + \overline{I\_C}\right| - \left|\overline{I\_REF}\right|$$

(Equation 154)

The *Start value* setting is given in units of × In of the phase current transformer. The possible difference in the phase and reference current transformer ratios is internally compensated by scaling I_REF with the value derived from the *Primary current* setting values. These setting parameters can be found in the Basic functions section.

The activation of the BLOCK input deactivates the FAIL output immediately.

Timer

The timer is activated with the FAIL signal. The ALARM output is activated after a fixed 200 ms delay. FAIL needs to be active during the delay.

When the internal blocking is activated, the FAIL output deactivates immediately, however the ALARM output deactivates after a fixed delay of three seconds.

The function resets when the differential current is below start value and highest phase current is more than five percent of the nominal current (0.05 × In).

If the current falls to zero when FAIL or ALARM outputs are active, then deactivation of FAIL and ALARM outputs are prevented.

The activation of the BLOCK input deactivates the ALARM output.

6.2.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase*

Grp 3". One of the groups to be used with the *Base value Sel phase* setting must be selected.

6.2.6 Application

Open or short-circuited current transformer cores can cause unwanted operation in many protection functions such as differential, earth-fault current and negative sequence current functions. When currents from two independent three-phase sets of CTs or CT cores measuring the same primary currents are available, reliable current circuit supervision can be arranged by comparing the currents from the two sets. When an error in any CT circuit is detected, the protection functions concerned can be blocked and an alarm given.

In case of high currents, the unequal transient saturation of CT cores with a different remanence or saturation factor may result in differences in the secondary currents from the two CT cores. Unwanted blocking of protection functions during the transient stage must then be avoided.

The supervision function must be sensitive and have a short operate time in order to prevent unwanted tripping from fast-acting, sensitive numerical protections in case of faulty CT secondary circuits.

Open CT circuits create extremely high voltages in the circuits, which may damage the insulation and cause further problems. This must be taken into consideration especially when the protection functions are blocked.

When the reference current is not connected to the IED, the function should be turned off. Otherwise, the `FAIL` output is activated when unbalance occurs in the phase currents even if there was nothing wrong with the measurement circuit.

Reference current measured with core-balanced current transformer

The function compares the sum of phase currents to the current measured with the core-balanced CT.

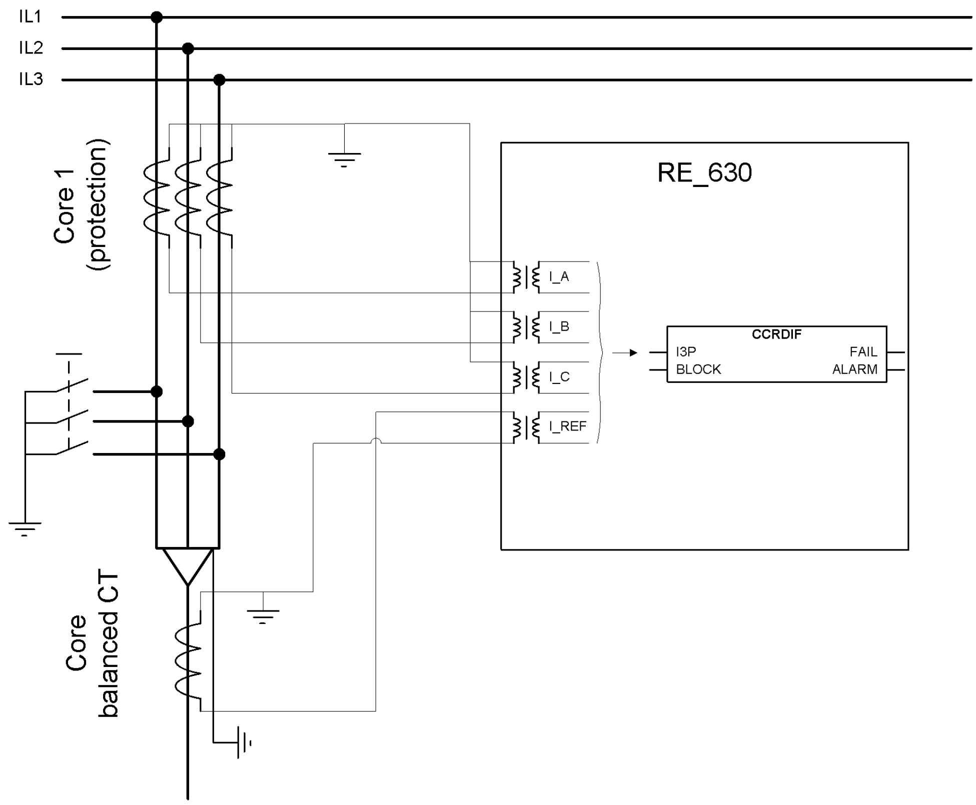


Figure 499: Connection diagram for reference current measurement with core-balanced current transformer

Current measurement with two independent three-phase sets of CT cores

Figure 500 and Figure 501 show diagrams of connections where the reference current is measured with two independent three-phase sets of CT cores.

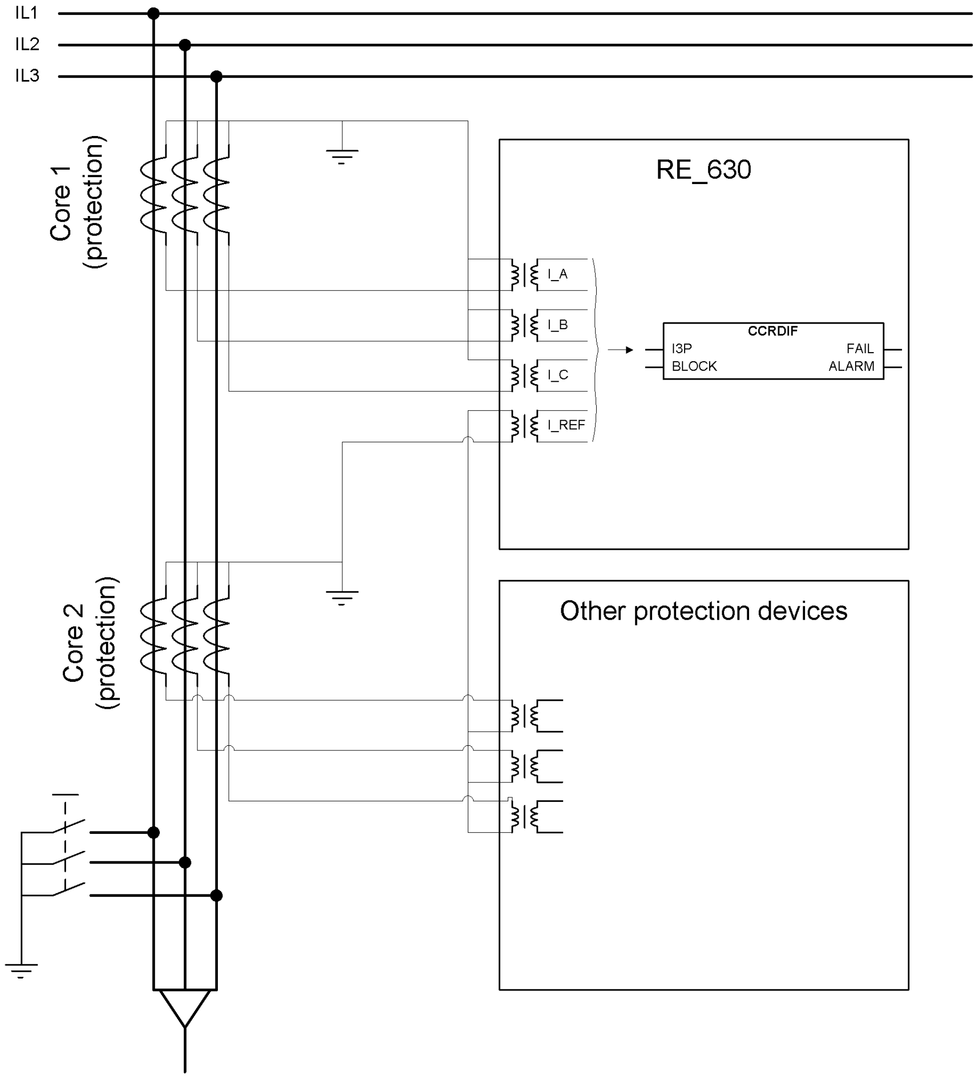


Figure 500: Connection diagram for current circuit supervision with two sets of three-phase current transformer protection cores

When using the measurement core for reference current measurement, it should be noted that the saturation level of the measurement core is much lower than with the protection core. This should be taken into account when setting the current circuit supervision function.

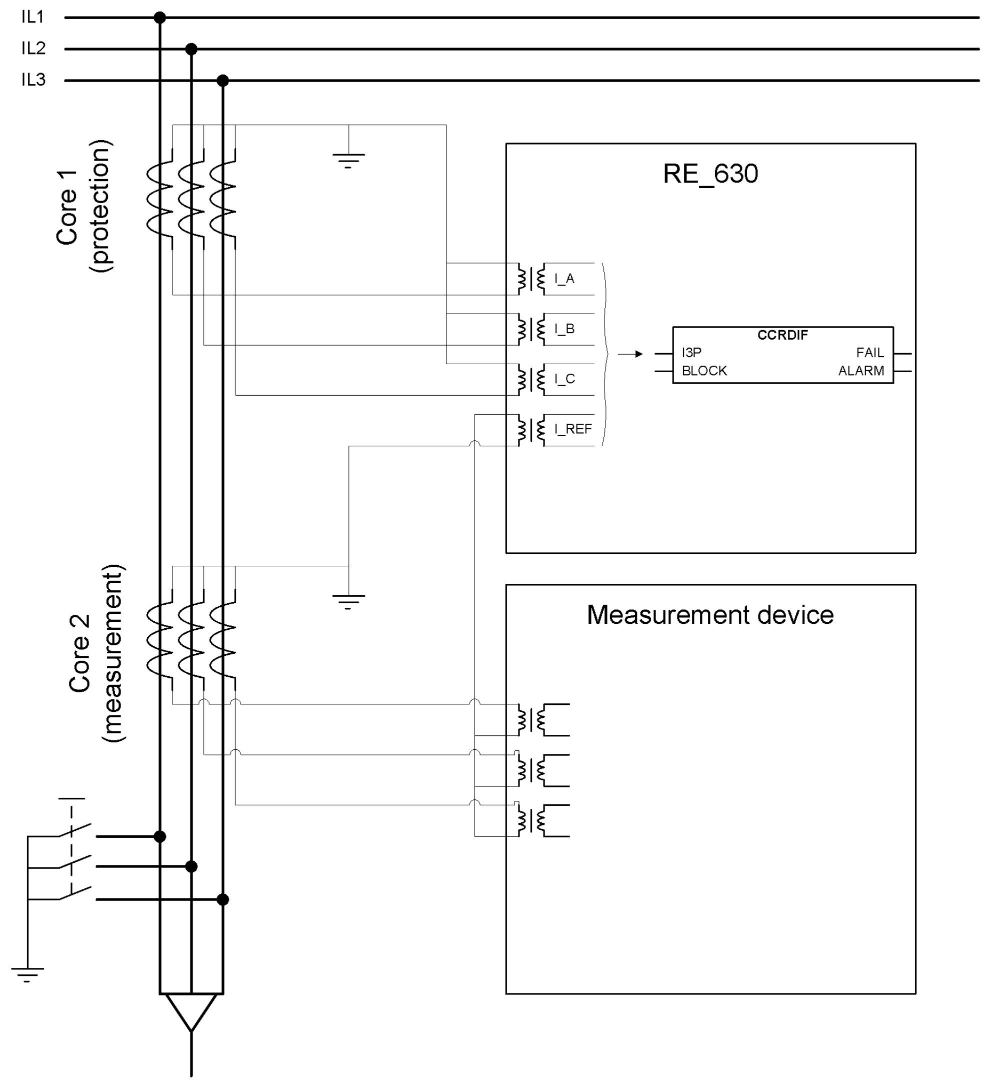


Figure 501: Connection diagram for current circuit supervision with two sets of three-phase current transformer cores (protection and measurement)

Example of incorrect connection

The currents must be measured with two independent cores, that is, the phase currents must be measured with a different core than the reference current. A connection diagram shows an example of a case where the phase currents and the reference currents are measured from the same core.

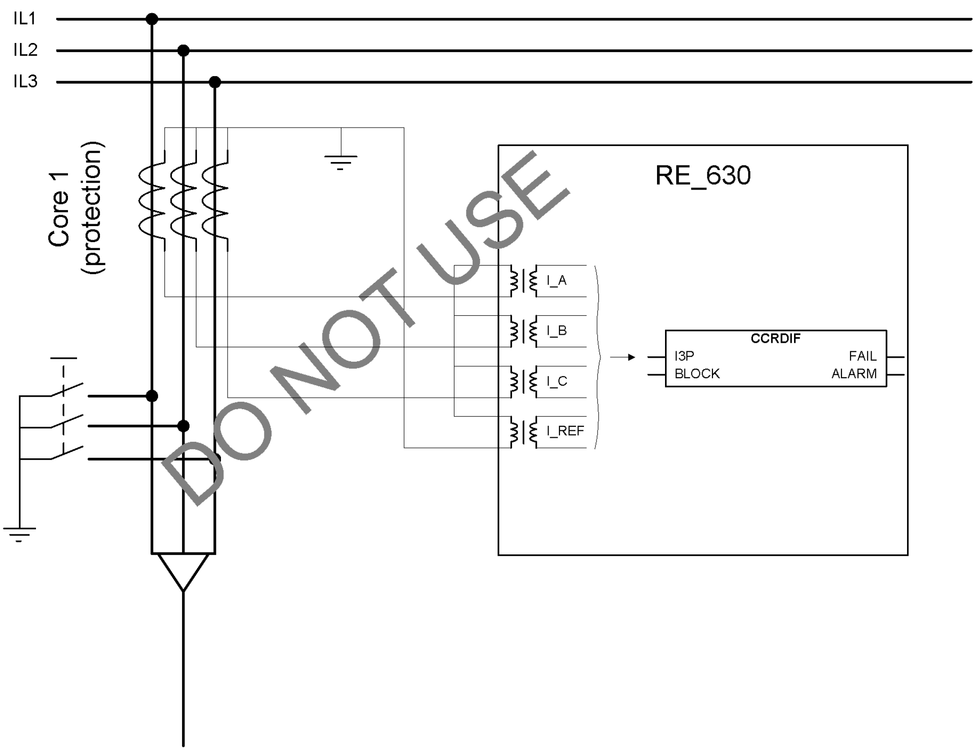


Figure 502: Example of incorrect reference current connection

6.2.7 Signals

Table 952: CCRDIF Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
BLOCK	BOOLEAN	0	Block of function

Table 953: CCRDIF Output signals

Name	Type	Description
FAIL	BOOLEAN	Detection of current circuit failure
ALARM	BOOLEAN	Alarm for current circuit failure

6.2.8 Settings

Table 954: CCRDIF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Start value	0.05 - 2.00	pu	0.01	0.20	Minimum operate current differential level

Table 955: CCRDIF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Max operate current	0.05 - 5.00	pu	0.01	1.50	Block of the function at high phase current

6.2.9 Measured values

Table 956: CCRDIF Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function

6.2.10 Monitored data

Table 957: CCRDIF Monitored data

Name	Type	Values (Range)	Unit	Description
FAIL	BOOLEAN	0=FALSE 1=TRUE	-	Detection of current circuit failure
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Alarm for current circuit failure

6.2.11 Technical data

Table 958: CCRDIF Technical data

Characteristic	Value
Operate time1)	<30 ms

1) Including the delay of the output contact

6.3 Fuse failure supervision SEQRFUF

6.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fuse failure supervision	SEQRFUF	FUSEF	60

6.3.2 Function block

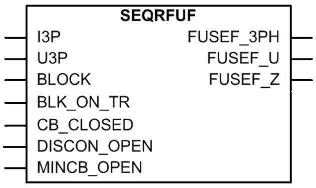


Figure 503: Function block

6.3.3 Functionality

The fuse failure supervision function SEQRFUF is used to block the voltage measuring functions at failures in the secondary circuits between the voltage transformer and IED to avoid misoperations of the voltage protection functions.

SEQRFUF has two algorithms, a negative sequence-based algorithm and a delta current and delta voltage algorithm.

A criterion based on the delta current and the delta voltage measurements can be activated to detect three-phase fuse failures which usually are more associated with the voltage transformer switching during station operations.

6.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the fuse failure supervision function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

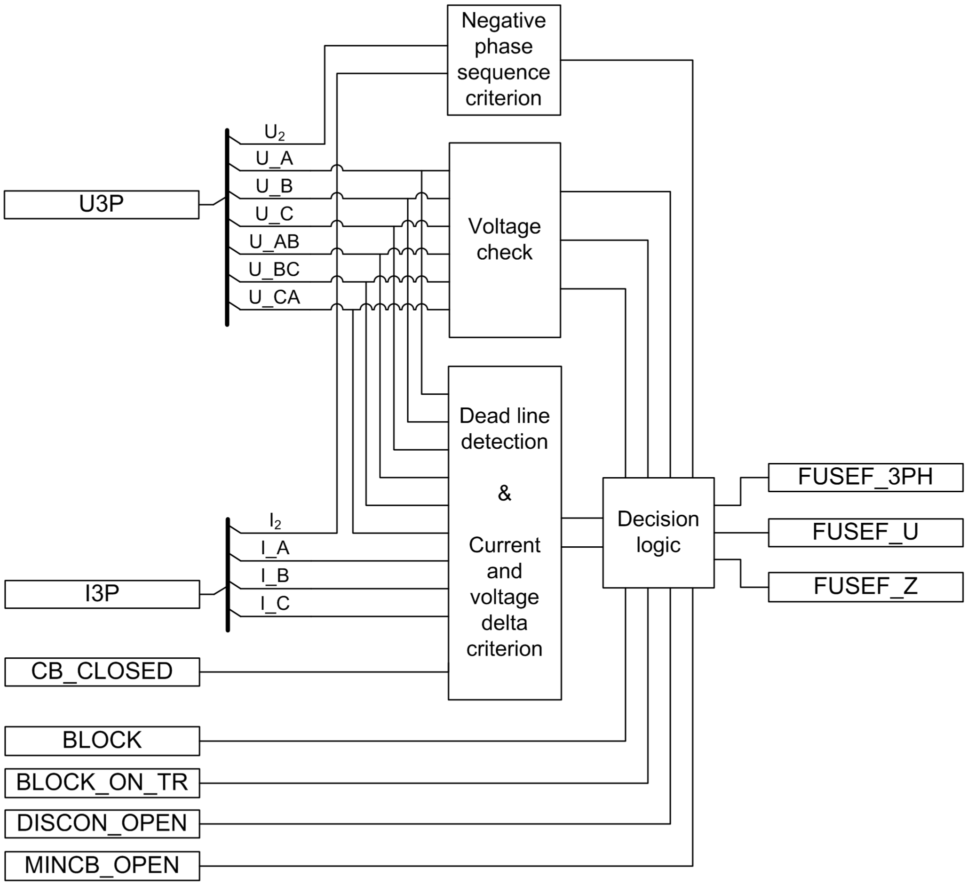


Figure 504: Functional module diagram

Negative phase-sequence criterion

A fuse failure based on negative-sequence criterion is detected if the measured negative-sequence voltage exceeds the set *Neg Seq voltage Lev* value and the measured negative-sequence current is below the set *Neg Seq current Lev* value. The detected fuse failure is reported to the decision logic module.

Voltage check

The phase voltage magnitude is checked when deciding whether the fuse failure is a three-, two- or a single-phase fault.

The module makes a phase-specific comparison between each voltage input and the *Seal in voltage* setting. If the input voltage is lower than the setting, the corresponding phase is reported to the decision logic module.

Dead-line detection

The dead-line detection function is activated from the dead-line condition when the voltage and current in at least one phase are below the respective set values of *Voltage dead Lin Val* and *Current dead Lin Val*. This prevents the blocking of the impedance protection by fuse failure detection during the dead-line condition. This also occurs during single pole autoreclosing. The 200 ms drop-off timer prolongs the dead-line condition after the line energization to prevent the blocking of the impedance protection for unequal pole closing.

Current and voltage delta criterion

The delta function can be activated by setting the *Change rate enable* parameter to "Yes". Once the function is activated, it operates in parallel with the negative sequence-based algorithm. The current and voltage are continuously measured in all three phases for calculations.

- Change of voltage dU/dt
- Change of current dI/dt

The calculated delta quantities are compared to the respective set values of the *Current change rate* and *Voltage change rate* settings.

The delta current and delta voltage algorithms detect a fuse failure if there is a sufficient negative change in the voltage amplitude without a sufficient change in the current amplitude in each phase separately. This is performed when the circuit breaker is closed. Information about the circuit breaker position is connected to the `CB_CLOSED` input.

There are two conditions for activating the current and voltage delta function.

- The magnitude of dU/dt exceeds the corresponding value of the *Voltage change rate* setting and the magnitude of dI/dt is below the value of the *Current change rate* setting in any phase at the same time due to the closure of the circuit breaker (`CB_CLOSED` = TRUE).
- The magnitude of dU/dt exceeds the value of the *Voltage change rate* setting and the magnitude of dI/dt is below the *Current change rate* setting in any phase at the same time since the magnitude of the phase current in the same phase exceeds the *Min Op current delta* setting.

The first condition requires the delta criterion to be fulfilled in any phase at the same time as the circuit breaker is closed. Opening the circuit breaker at one end and energizing the line from the other end onto a fault could lead to an improper operation of SEQRFUF with an open breaker. If this is considered to be an important disadvantage, the `CB_CLOSED` input is to be connected to FALSE. This way, only the second criterion can activate the delta function

The second condition requires the delta criterion to be fulfilled in one phase together with high current for the same phase. The measured phase current is used to reduce the risk of a false fuse failure detection. If the current on the protected line is low, a voltage drop in the system (not caused by the fuse failure) is not followed by a current change and a false fuse failure can occur. To prevent this, the minimum phase current criterion is checked.

The fuse failure detection is active until the voltages return above the *Min Op voltage delta* setting. If a voltage in a phase is below the *Min Op voltage delta* setting, a new fuse failure detection for that phase is not possible until the voltage returns above the setting value.

Decision logic

The fuse failure detection outputs FUSEF_U and FUSEF_3PH are controlled according to the detection criteria or external signals.

Table 959: Fuse failure output control

Fuse failure detection criterion	Conditions and function response
Negative sequence criterion	If a fuse failure is detected based on the negative sequence criterion, the FUSEF_U output is activated. The FUSEF_Z output is also activated if the internal dead-line detection is not activated at the same time.
	If the fuse failure detection is active for more than five seconds and at the same time all the phase voltage values are below the set value of the *Seal in voltage* setting with *Enable seal in* turned to "True", the function activates the FUSE_3PH output signal.
	The FUSEF_U output signal is also activated if all the phase voltages are above the *Seal in voltage* setting for more than 60 seconds and at the same time the negative sequence voltage is above *Neg Seq voltage Lev* for more than 5 seconds, all the phase currents are below the *Current dead Lin Val* setting and the circuit breaker is closed, that is,CB_CLOSED is TRUE.
Current and voltage delta function criterion	If the current and voltage delta criterion detects a fuse failure condition, but all the voltages are not below the *Seal in voltage* setting, only the FUSEF_U output is activated. The FUSEF_Z output is also activated if the internal dead-line detection is not activated at the same time.
	If the fuse failure detection is active for more than five seconds and at the same time all the phase voltage values are below the set value of the *Seal in voltage* setting with *Enable seal in* turned to "True", the function activates the FUSE_3PH output signal.
External fuse failure detection	The MINCB_OPEN input signal is supposed to be connected through an IED binary input to the N.C. auxiliary contact of the miniature circuit breaker protecting the VT secondary circuit. The MINCB_OPEN signal sets the FUSEF_U and FUSEF_Z output signals to block all the voltage-related functions when MCB is in the open state.
	The DISCON_OPEN input signal is supposed to be connected through an IED binary input to the N.C. auxiliary contact of the line disconnector. The DISCON_OPEN signal sets the FUSEF_U output signal to block the voltage-related functions when the line disconnector is in the open state.

6.3.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

6.3.6 Application

Some protection functions operate on the basis of the measured voltage value in the IED point. These functions can fail if there is a fault in the measuring circuits between the voltage transformers and the IED.

A fault in the voltage measuring circuit is referred to as a fuse failure. This term is misleading since a blown fuse is just one of the many possible reasons for a broken circuit. Since incorrectly measured voltage can result in a faulty operation of some of the protection functions, it is important to detect the fuse failures. A fast fuse failure detection is one of the means to block voltage-based functions before they operate.

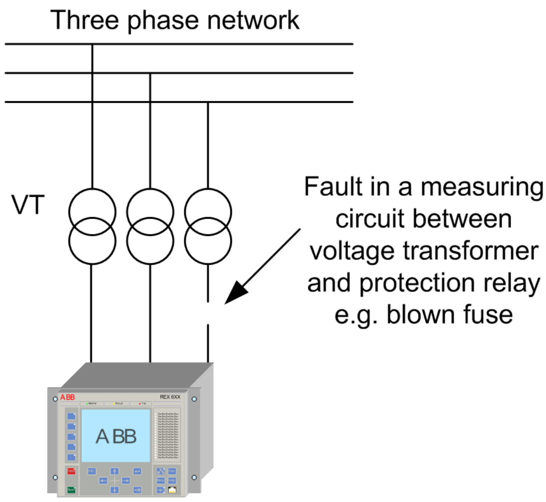


Figure 505: Fault in a circuit from the voltage transformer to the IED

A fuse failure occurs due to blown fuses, broken wires or intended substation operations. The negative sequence component-based function can be used to detect different types of single-phase or two-phase fuse failures. However, at least one of the three circuits from the voltage transformers must not be broken. The supporting delta-based function can also detect a fuse failure due to three-phase interruptions.

In the negative sequence component-based part of the function, a fuse failure is detected by comparing the calculated value of the negative sequence component voltage to the negative sequence component current. The sequence entities are calculated from the measured current and voltage data for all three phases. The purpose of this function is to block voltage-dependent functions when a fuse failure is detected. Since the voltage dependence differs between these functions, SEQRFUF has two outputs for this purpose.

Other functions, such as the impedance-based functions, can be allowed to operate despite a fuse failure, for example when the fuse failure occurs during the dead-line condition. The `FUSEF_Z` output is based on more restricted criteria and intended to block these functions.

6.3.7 Signals

Table 960: SEQRFUF Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	3-phase current group
U3P	GROUP SIGNAL	-	3-phase voltage group
BLOCK	BOOLEAN	0	Block of function
BLK_ON_TR	BOOLEAN	0	Block operation of function. Fuse failure is not detected
CB_CLOSED	BOOLEAN	0	Active when curcuit breaker is closed
DISCON_OPEN	BOOLEAN	0	Active when line disconnector is open
MINCB_OPEN	BOOLEAN	0	Active when external MCB opens protected voltage circuit

Table 961: SEQRFUF Output signals

Name	Type	Description
FUSEF_3PH	BOOLEAN	Three-phase start of function
FUSEF_U	BOOLEAN	General start of function
FUSEF_Z	BOOLEAN	Start of current and voltage controlled function

6.3.8 Settings

Table 962: SEQRFUF Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 963: SEQRFUF Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Neg Seq current Lev	0.10 - 0.50	pu	0.01	0.10	Operate level of neg seq undercurrent element
Neg Seq voltage Lev	0.10 - 0.50	pu	0.01	0.30	Operate level of neg seq over-voltage element
Current change rate	0.10 - 0.50	pu	0.01	0.15	Operate level of change in phase current
Voltage change rate	0.50 - 0.90	pu	0.01	0.60	Operate level of change in phase voltage
Min Op voltage delta	0.01 - 1.00	pu	0.01	0.70	Minimum operate level of phase voltage for delta calculation
Min Op current delta	0.01 - 1.00	pu	0.01	0.10	Minimum operate level of phase current for delta calculation
Current dead Lin Val	0.05 - 1.00	pu	0.01	0.05	Operate level for open phase current detection
Voltage dead Lin Val	0.10 - 1.00	pu	0.01	0.60	Operate level for open phase voltage detection
Seal in voltage	0.01 - 1.00	pu	0.01	0.70	Operate level of seal-in phase voltage
Enable seal in	No Yes	-	-	Yes	Enabling seal in functionality
Change rate enable	No Yes	-	-	No	Enabling operation of change based function

6.3.9 Monitored data

Table 964: SEQRFUF Monitored data

Name	Type	Values (Range)	Unit	Description
FUSEF_3PH	BOOLEAN	0=FALSE 1=TRUE	-	Three-phase start of function
FUSEF_U	BOOLEAN	0=FALSE 1=TRUE	-	General start of function
FUSEF_Z	BOOLEAN	0=FALSE 1=TRUE	-	Start of current and voltage controlled function

6.3.10 Technical data

Table 965: SEQRFUF Technical data

Characteristic		Value	
Operation accuracy		At the frequency f = f_n	
		Current: ±1.5% of the set value or ±0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n	
Operate time[1]	• NPS function	U_{Fault} = 1.1 × set *Neg Seq voltage Lev* U_{Fault} = 5.0 × set *Neg Seq voltage Lev*	Typically 35 ms (±15 ms) Typically 25 ms (±15 ms)
	• Delta function	ΔU = 1.1 × set *Voltage change rate* ΔU = 2.0 × set *Voltage change rate*	Typically 35 ms (±15 ms) Typically 28 ms (±15 ms)

1) Includes the delay of the signal output contact, f_n = 50 Hz, fault voltage with nominal frequency injected from random phase angle

6.4 Station battery supervision SPVNZBAT

6.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Station battery supervision	SPVNZBAT	U<>	U<>

6.4.2 Function block

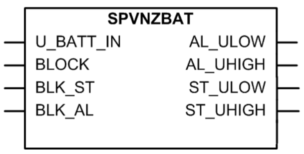


Figure 506: Function block

6.4.3 Functionality

The station battery supervision function SPVNZBAT is used for monitoring battery terminal voltage.

SPVNZBAT activates the start and alarm outputs when the battery terminal voltage exceeds the set upper limit or drops below the set lower limit. A time delay for the overvoltage and undervoltage alarms can be set according to definite time characteristics.

In the definite time (DT) mode, SPVNZBAT operates after a predefined operate time and resets when the battery undervoltage or overvoltage condition disappears.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

6.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The function execution requires that at least one of the function outputs is connected in configuration.

The operation of the station battery supervision function can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

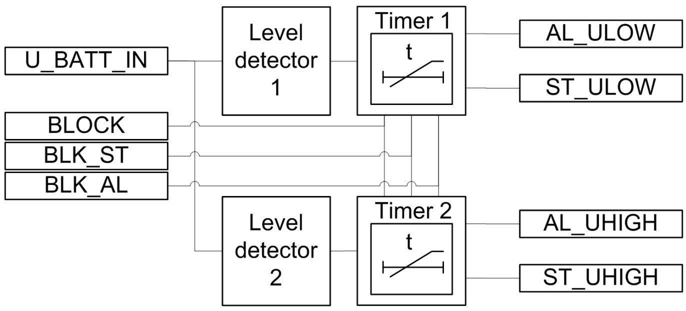


Figure 507: Functional module diagram

The battery rated voltage is set with the *Battery voltage Rtg* setting. The value of the *Low battery value* and *High battery value* settings are given in relative per unit to the *Battery voltage Rtg* setting.

The battery voltage to be connected to the input U_BATT_IN is available as analog Input BATTAMPL from power source (PSM) hardware module.

Level detector 1

The level detector compares the battery voltage U_BATT_IN to the set value of the *Low battery value* setting. If the value of U_BATT_IN input drops below the value of the *Low battery value* setting, the level detector sends an enabling signal to the timer 1 module.

The measured voltage between the battery terminals U_BATT is available in monitored data view.

Level detector 2

The level detector compares the battery voltage U_BATT_IN to the set value of the *High battery value* setting. If the value of U_BATT_IN exceeds the set value of the *High battery value* setting, the level detector sends an enabling signal to the timer 2 module.

Timer 1

Once activated, the timer activates the ST_ULOW output for undervoltage condition. When the operate timer has reached the value set by the *Alarm delay time* setting, the AL_ULOW output is activated. If the voltage returns to normal value before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the ST_ULOW output is deactivated.

The activation of the BLOCK input resets the timer and deactivates the ST_ULOW and AL_ULOW outputs. The activation of BLK_ST and BLK_AL blocks the individual start and alarm outputs respectively.

Timer 2

Once activated, the timer activates ST_UHIGH for overvoltage condition. When the operate timer has reached the value set by the *Alarm delay time* setting, the AL_UHIGH output is activated. If the voltage returns to normal value before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the ST_UHIGH output is deactivated.

The activation of the BLOCK input signal resets the timer and deactivates the ST_UHIGH and AL_UHIGH outputs. The activation of BLK_ST and BLK_AL blocks the individual alarm and operate outputs respectively.

6.4.5 Application

Usually, the load on the DC system is a constant resistance load, for example, lamps, LEDs, electronic instruments and electromagnetic contactors in a steady state condition. A transient RL load exists when breakers are tripped or closed.

The battery voltage has to be continuously monitored as the batteries can withstand moderate overvoltage and undervoltage only for a short period of time.

- If the battery is subjected to a prolonged or frequent overvoltage, it leads to the ageing of the battery, which may lead to the earlier failure of the battery. The other occurrences may be the thermal runaway, generation of heat or increased amount of hydrogen gas and the depletion of fluid in case of valve regulated batteries.

- If the value of the charging voltage drops below the minimum recommended float voltage of the battery, the battery does not receive sufficient charging current to offset internal losses, resulting in a gradual loss of capacity.
    - If a lead acid battery is subjected to a continuous undervoltage, heavy sulfation occurs on the plates, which leads to the loss of the battery capacity.

6.4.6 Signals

Table 966: SPVNZBAT Input signals

Name	Type	Default	Description
U_BATT_IN	REAL	0.00	Battery terminal voltage
BLOCK	BOOLEAN	0	Block of function
BLK_AL	BOOLEAN	0	Blocks the alarm signals
BLK_ST	BOOLEAN	0	Blocks the start signals

Table 967: SPVNZBAT Output signals

Name	Type	Description
AL_ULOW	BOOLEAN	Alarm when voltage has been below lower limit for a set time
AL_UHIGH	BOOLEAN	Alarm when voltage has exceeded higher limit for a set time
ST_ULOW	BOOLEAN	Start signal when battery voltage drops below lower limit
ST_UHIGH	BOOLEAN	Start signal when battery voltage exceeds upper limit

6.4.7 Settings

Table 968: SPVNZBAT Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
Battery voltage Rtg	20.00 - 250.00	V	1.00	110.00	Battery rated voltage
Low battery value	0.60 - 1.40	pu	0.01	0.70	Lower limit for the battery terminal voltage
High battery value	0.60 - 1.40	pu	0.01	1.20	Upper limit for the battery terminal voltage
Alarm delay time	0.100 - 60.000	s	0.001	0.200	Delay time for alarm

Table 969: SPVNZBAT Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Reset delay time	0.000 - 60.000	s	0.001	0.000	Reset time provided to reset the timers

6.4.8 Measured values

Table 970: SPVNZBAT Measured values

Name	Type	Default	Description
U_BATT_IN	REAL	0.00	Battery terminal voltage
BLOCK	BOOLEAN	0	Block of function
BLK_AL	BOOLEAN	0	Blocks the alarm signals
BLK_ST	BOOLEAN	0	Blocks the start signals

6.4.9 Monitored Data

Table 971: SPVNZBAT Monitored data

Name	Type	Values (Range)	Unit	Description
U_BATT	REAL	-	kV	Service value of the battery terminal voltage
AL_ULOW	BOOLEAN	0=FALSE 1=TRUE	-	Alarm when voltage has been below lower limit for a set time
AL_UHIGH	BOOLEAN	0=FALSE 1=TRUE	-	Alarm when voltage has exceeded higher limit for a set time
ST_ULOW	BOOLEAN	0=FALSE 1=TRUE	-	Start signal when battery voltage drops below lower limit
ST_UHIGH	BOOLEAN	0=FALSE 1=TRUE	-	Start signal when battery voltage exceeds upper limit

6.4.10 Technical data

Table 972: SPVNZBAT Technical data

Characteristic	Value
Operation accuracy	±1.0% of the set value
Operate time accuracy	±1.0% of the set value or ±40 ms

6.5 Tap position TPOSSLTC

6.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Tap position	TPOSSLTC	TPOSM	84M

6.5.2 Function block

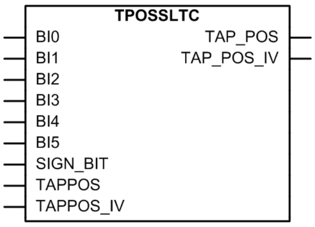


Figure 508: Function block

6.5.3 Functionality

The binary converter function TPOSSLTC is used for converting binary-coded tap position inputs to their decimal equivalent when a tap position indication is received from the I/O board with the help of the coded binary inputs. Optionally, the tap position can be read directly from the `RTD` input.

There are three user-selectable conversion modes available for the 7–bit binary inputs where MSB is used as the SIGN bit: the natural binary-coded boolean input to the signed integer output, binary coded decimal BCD input to the signed integer output and binary reflected GRAY coded input to the signed integer output.

6.5.4 Operation principle

The operation of tap position indication function can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

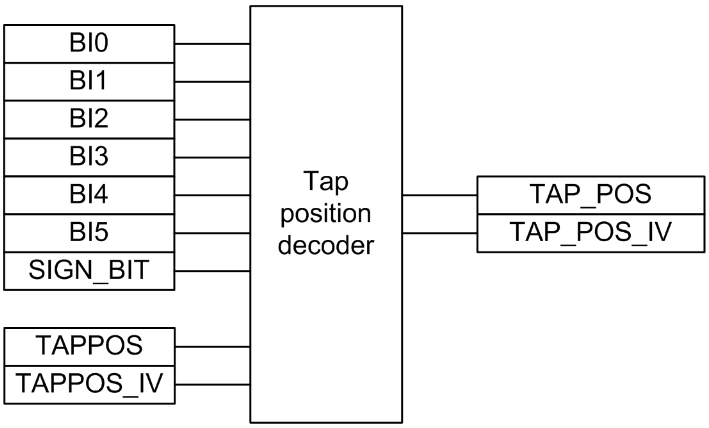


Figure 509: Functional module diagram

Tap position decoder

The function has four alternative user selectable operation modes: "BIN," "BCD," "GRAY" and "Input TAPPOS". The operation mode is selected with the *Operation* *mode* parameter. Each operation mode can be used to convert the maximum of a 6–bit coded input to an 8–bit signed short integer output. For less than the 6–bit input (usually 19 positions with 5 bits when the BCD coding is used), the rest of the bits can be set to FALSE (0).

The operation mode “BIN” is selected when the natural binary coding is used for showing the position of the transformer tap changer. The basic principle of the natural binary coding is to calculate the sum of the bits set to TRUE (1). LSB has the factor 1. Each following bit has the previous factor multiplied by 2. This is also called dual coding.

The operation mode “BCD” is selected when the binary-coded decimal coding is used for showing the position of the transformer tap changer. The basic principle of the binary coded decimal coding is to calculate the sum of the bits set to TRUE (1). The four bits nibble (BI3...BI0) have a typical factor to the natural binary coding. The sum of the values should not be more than 9. If the nibble sum is greater than 9, the tap position validity output TAP_POS_IV is set to FALSE (0).

The operation mode “GRAY” is selected when the binary-reflected Gray coding is used for showing the position of the transformer tap changer. The basic principle of the Gray coding is that only one actual bit changes value with consecutive numbers. This function is based on the common binary-reflected Gray code, which is used with some tap changers. Changing the bit closest to the right side bit gives a new pattern.

An additional separate input, SIGN_BIT, can be used for negative values. If the values are positive, the input should be set to FALSE (0). If SIGN_BIT is set to TRUE (1) making the number negative, the remaining bits are identical to those of the coded positive number.

The tap position validity output TAP_POS_IV is set to TRUE (1) in all valid cases. The output is set to FALSE (0) in invalid combinations in the binary inputs. For example, when the “BCD” mode is selected and the input binary combination is “0001101”, TAP_POS_IV is set to FALSE (0) and the TAP_POS output is in this case “9”. For negative values, when SIGN_BIT is set to TRUE (1) and the input binary combination is “1011011”, TAP_POS_IV is set to FALSE (0) and the TAP_POS output is in this case “-19”.

When *Operation mode* is set to “Input TAPPOS” (4), the RTD card output REAL value is used for showing the position of the transformer tap changer. The invalidity information from the RTD card is connected through the TAPPOS_IV input. The TAP_POS and TAP_POS_IV outputs are then set according to the inputs from RTD. The tap position value is also converted from REAL to INT according to rounding rules.

Table 973: Truth table of the decoding modes

Inputs							TAP_POS outputs		
SIGN_ BIT	BI5	BI4	BI3	BI2	BI1	BI0	BIN	BCD	GRAY
...		...		...		...	...	...	...
1	0	0	0	0	1	1	—3	—3	—3
1	0	0	0	0	1	0	—2	—2	—2
1	0	0	0	0	0	1	—1	—1	—1
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	1	1	1
0	0	0	0	0	1	0	2	2	3
0	0	0	0	0	1	1	3	3	2
0	0	0	0	1	0	0	4	4	7
0	0	0	0	1	0	1	5	5	6
0	0	0	0	1	1	0	6	6	4
0	0	0	0	1	1	1	7	7	5
0	0	0	1	0	0	0	8	8	15
0	0	0	1	0	0	1	9	9	14
0	0	0	1	0	1	0	10	9	12
0	0	0	1	0	1	1	11	9	13
0	0	0	1	1	0	0	12	9	8
0	0	0	1	1	0	1	13	9	9
0	0	0	1	1	1	0	14	9	11
0	0	0	1	1	1	1	15	9	10
0	0	1	0	0	0	0	16	10	31
0	0	1	0	0	0	1	17	11	30
0	0	1	0	0	1	0	18	12	28
0	0	1	0	0	1	1	19	13	29
0	0	1	0	1	0	0	20	14	24
0	0	1	0	1	0	1	21	15	25
0	0	1	0	1	1	0	22	16	27
0	0	1	0	1	1	1	23	17	26
0	0	1	1	0	0	0	24	18	16
0	0	1	1	0	0	1	25	19	17
0	0	1	1	0	1	0	26	19	19
0	0	1	1	0	1	1	27	19	18
0	0	1	1	1	0	0	28	19	23
0	0	1	1	1	0	1	29	19	22
0	0	1	1	1	1	0	30	19	20
0	0	1	1	1	1	1	31	19	21
Table continues on next page									

Inputs							TAP_POS outputs		
0	1	0	0	0	0	0	32	20	63
0	1	0	0	0	0	1	33	21	62
0	1	0	0	0	1	0	34	22	60
0	1	0	0	0	1	1	35	23	61
0	1	0	0	1	0	0	36	24	56
...		...		...		...	...	...	...

6.5.5 Application

TPOSSLTC provides tap position information for other functions as a signed integer value that can be fed to the tap position input.

The position information of the tap changer can be coded in various methods for many applications, for example, the differential protection algorithms. In this function, the binary inputs in the transformer terminal connector are used as inputs to the function. The coding method can be chosen by setting the mode parameter. The available coding methods are BCD, Gray and Natural binary coding. Since the number of binary inputs is limited to seven, the coding functions are limited to seven bits including the sign bit and thus the six bits are used in the coding functions. The position limits for the tap positions at BCD, Gray and Natural binary coding are ±39, ±63 and ±63 respectively.

In this example, the transformer tap changer position indication is wired as a mA signal from the corresponding measuring transducer. The position indication is connected to RTD analog input 1 (`RTD_3.AI1`). The tap changer operating range from the minimum to maximum turns of the tap and a corresponding mA signal for the tap position are set in HW configuration for `RTD_3`. When there is a wired connection to the `TAP_POS` connector, the corresponding tap changer position is seen as the `TAP_POS` output value that is fed to other functions, for example, OLATCC1. When there is no wired connection to the `TAP_POS` connector, the binary inputs are expected to be used for the tap changer position information. The invalidity information from the RTD card is connected through the `TAPPOS_IV` input.

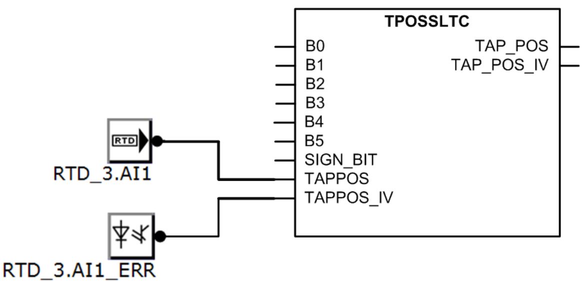


Figure 510: RTD/analog input configuration example

6.5.6 Signals

Table 974: TPOSSLTC Input signals

Name	Type	Default	Description
BI0	BOOLEAN	0	Input bit B0
BI1	BOOLEAN	0	Input bit B1
BI2	BOOLEAN	0	Input bit B2
BI3	BOOLEAN	0	Input bit B3
BI4	BOOLEAN	0	Input bit B4
BI5	BOOLEAN	0	Input bit B5
SIGN_BIT	BOOLEAN	0	Input sign as TRUE for negative values
TAPPOS	REAL	0	Input tap position real value from RTD
TAPPOS_IV	BOOLEAN	0	TAPPOS invalidity status from RTD card

Table 975: TPOSSLTC Output signals

Name	Type	Description
TAP_POS	INTEGER	Tap position value as integer
TAP_POS_IV	BOOLEAN	TAP_POS invalidity status

6.5.7 Settings

Table 976: TPOSSLTC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On / Off
Operation mode	BIN BCD Gray Input TAPPOS	-	-	BCD	Operation mode seletion

6.5.8 Measured values

Table 977: TPOSSLTC Measured values

Name	Type	Default	Description
BI0	BOOLEAN	0	Input bit B0
BI1	BOOLEAN	0	Input bit B1
BI2	BOOLEAN	0	Input bit B2
BI3	BOOLEAN	0	Input bit B3
BI4	BOOLEAN	0	Input bit B4
BI5	BOOLEAN	0	Input bit B5
Table continues on next page			

Name	Type	Default	Description
SIGN_BIT	BOOLEAN	0	Input sign as TRUE for negative values
TAPPOS	REAL	0	Input tap position real value from RTD
TAPPOS_IV	BOOLEAN	0	TAPPOS invalidity status from RTD card

6.5.9 Monitored data

Table 978: TPOSSLTC Monitored data

Name	Type	Values (Range)	Unit	Description
TAP_POS	INTEGER	-	-	Tap position value as integer
TAP_POS_IV	BOOLEAN	0=FALSE 1=TRUE	-	TAP_POS invalidity status

6.5.10 Technical data

Table 979: TPOSSLTC Technical data

Descrpition	Value
Response time for binary inputs	Typically 100 ms

6.6 Runtime counter for machines and devices MDSOPT

6.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Runtime counter for machines and devices	MDSOPT	OPTS	OPTM

6.6.2 Function block

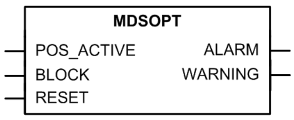


Figure 511: Function block

6.6.3 Functionality

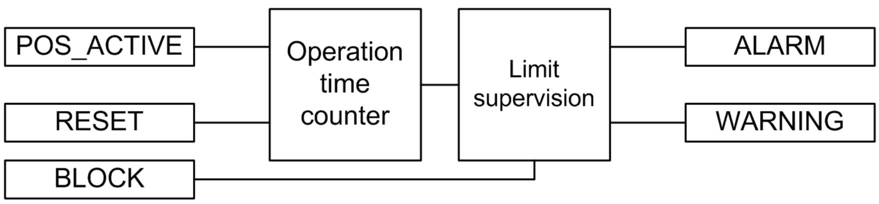
The runtime counter for machines and devices MDSOPT calculates and presents the accumulated operation time of a machine or device as the output. The unit of time for accumulation is hour. The function generates a WARNING and an ALARM when the accumulated operation time exceeds the set limits. It utilizes a binary input to indicate the active operation condition.

The accumulated operation time is one of the parameters for scheduling a service on the equipment like motors. It indicates the use of the machine and hence the mechanical wear and tear. Generally, the equipment manufacturers provide a maintenance schedule based on the number of hours of service.

6.6.4 Operation principle

The *Operation* setting is used to enable or disable the function. When "On" is selected, the function is enabled and when "Off" is selected, the function is disabled.

The operation of the generic runtime counter for machines and devices is described using a module diagram. All the modules in the diagram are explained in the next sections.



Operation time counter

This module counts the operation time. When POS_ACTIVE is active, the count is continuously added to the time duration until it is deactivated. The OPR_TIME output is the total duration for which POS_ACTIVE is active. The unit of time duration count for OPR_TIME is hour. The value is available through the monitored data view.

The OPR_TIME output is a continuously increasing value and it is stored in a nonvolatile memory. When POS_ACTIVE is active, the OPR_TIME count starts increasing from the previous value. The count of OPR_TIME saturates at the final value of 299999, that is, no further increment is possible. The activation of RESET, resets the count to the *Initial value* setting.

Limit Supervision

This module compares the motor run-time count to the set values of *Warning value* and *Alarm value* to generate the WARNING and ALARM outputs when the counts exceed the levels.

The activation of the WARNING and ALARM outputs depends on the *Operating time mode* setting. If *Operating time mode* is set to “Immediate”, both WARNING and ALARM occur immediately after the conditions are met, if *Operating time mode* is set to “Timed Warn”, WARNING is activated within the next 24 hours at the time of the day set using the *Operating time hour* setting. If *Operating time mode* is set to “Timed Warn Alm”, the WARNING and ALARM outputs are activated at the time of day set using *Operating time hour*.

The *Operating time hour* setting is used to set the hour of day in Coordinated Universal Time (UTC). The setting has to be adjusted according to the local time and local daylight-saving time.

The function contains a blocking functionality. Activation of the BLOCK input blocks both WARNING and ALARM.

6.6.5 Application

The machine operating time since commissioning indicates the use of the machine. For example, the mechanical wear and lubrication requirement for the shaft bearing of the motors depend on the use hours.

If a motor is used for long duration runs, it might require frequent servicing, while for a motor that is not used regularly the maintenance and service are scheduled less frequently. The accumulated operating time of a motor together with the appropriate settings for warning can be utilized to trigger the condition based maintenance of the motor.

The operating time counter combined with the subsequent reset of the operating time count can be used to monitor the motor's run time for a single run. Both the long term accumulated operating time and the short term single run duration provide valuable information about the condition of the machine and device. The information can be co-related to other process data to provide diagnoses for the process where the machine or device is applied.

6.6.6 Signals

Table 980: MDSOPT Input signals

Name	Type	Default	Description
POS_ACTIVE	BOOLEAN	0	When active indicates the equipment is in operation
BLOCK	BOOLEAN	0	Blocks all binary outputs of the function
RESET	BOOLEAN	0	Reset of function

Table 981: MDSOPT Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm accumulated operation time exceeds Alarm value
WARNING	BOOLEAN	Warning accumulated operation time exceeds Warning value

6.6.7 Settings

Table 982: MDSOPT Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On
Warning value	0 - 299999	Hour	1	8000	Warning value for operation time supervision
Alarm value	0 - 299999	Hour	1	10000	Alarm value for operation time supervision

Table 983: MDSOPT Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Initial value	0 - 299999	Hour	1	0	Initial value for operation time supervision
Operating time hour	0 - 23	Hour	1	0	Time of day in hour when alarm and warning will occur
Operating time mode	Immediate Timed Warn Timed Warn Alm	-	-	Immediate	Mode for time activation of binary outputs

6.6.8 Measured values

Table 984: MDSOPT Measured values

Name	Type	Default	Description
POS_ACTIVE	BOOLEAN	0	When active indicates the equipment is in operation
BLOCK	BOOLEAN	0	Blocks all binary outputs of the function
RESET	BOOLEAN	0	Reset of function

6.6.9 Monitored data

Table 985: MDSOPT Monitored data

Name	Type	Values (Range)	Unit	Description
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Alarm accumulated operation time exceeds Alarm value
WARNING	BOOLEAN	0=FALSE 1=TRUE	-	Warning accumulated operation time exceeds Warning value
OPR_TIME	INTEGER	-	-	Accumulated operation time of machine or equipment

6.6.10 Technical data

Table 986: MDSOPT Technical data

Characteristic	Value
Motor run-time measurement accuracy 1)	±0.5%

1) Of the reading, for a stand-alone protection relay without time synchronization

Section 7 Condition monitoring functions

7.1 Circuit breaker condition monitoring SSCBR

7.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit breaker condition monitoring	SSCBR	CBCM	CBCM

7.1.2 Function block

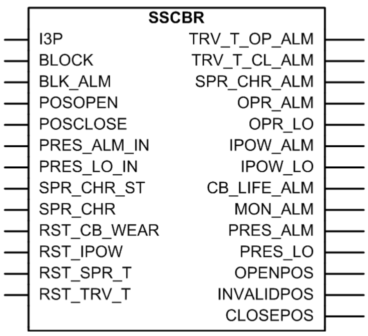


Figure 512: Function block

7.1.3 Functionality

The circuit breaker condition monitoring function SSCBR is used to monitor different parameters of the circuit breaker. The breaker requires maintenance when the number of operations has reached a predefined value. The energy is calculated from the measured input currents as a sum of $I^y t$ values. Alarms are generated when the calculated values exceed the threshold settings.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

7.1.4 Operation principle

The circuit breaker condition monitoring function includes different metering and monitoring subfunctions. The functions can be enabled and disabled with the

Operation setting. The corresponding parameter values are “On” and “Off”. The operation counters are cleared when *Operation* is set to “Off”.

The operation of the functions can be described with a module diagram. All the modules in the diagram are explained in the next sections.

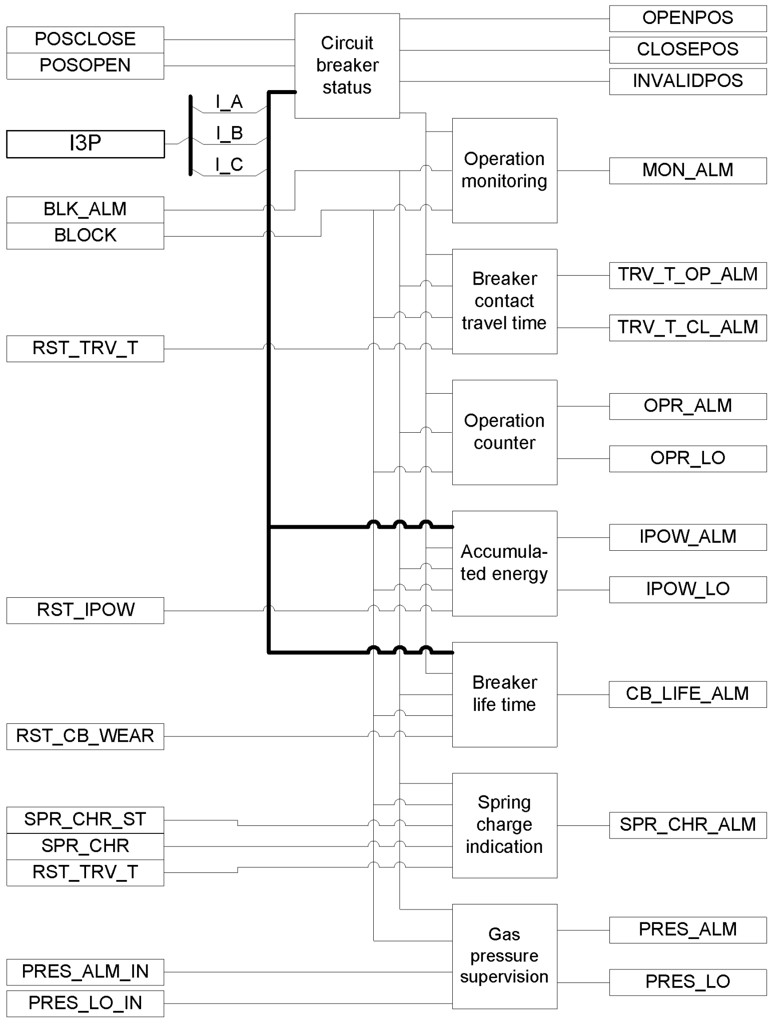


Figure 513: Functional module diagram

7.1.4.1 Circuit breaker status

The circuit breaker status subfunction monitors the position of the circuit breaker, that is, whether the breaker is in an open, closed or intermediate position. The operation of the breaker status monitoring can be described with a module diagram. All the modules in the diagram are explained in the next sections.

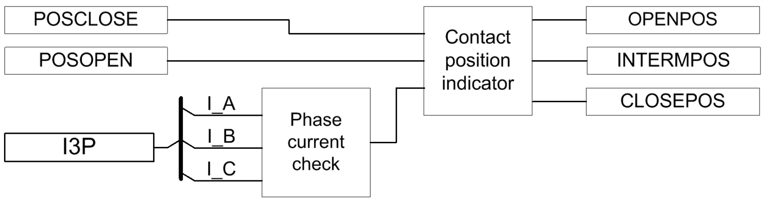


Figure 514: Functional module diagram for monitoring circuit breaker status

Phase current check

This module compares the three phase currents with the setting *Acc stop current*. If the current in a phase exceeds the set level, information about phase is reported to the contact position indicator module.

Contact position indicator

The circuit breaker status is open if the auxiliary input contact POSCLOSE is low, the POSOPEN input is high and the current is zero. The circuit breaker is closed when the POSOPEN input is low and the POSCLOSE input is high. The breaker is in the intermediate position if both the auxiliary contacts have the same value, that is, both are in the logical level "0", or if the auxiliary input contact POSCLOSE is low and the POSOPEN input is high, but the current is not zero.

The status of the breaker is indicated with the binary outputs OPENPOS, INTERMPOS and CLOSEPOS for open, intermediate and closed position respectively.

7.1.4.2 Circuit breaker operation monitoring

The purpose of the circuit breaker operation monitoring subfunction is to indicate if the circuit breaker has not been operated for a long time.

The operation of the circuit breaker operation monitoring can be described with a module diagram. All the modules in the diagram are explained in the next sections.

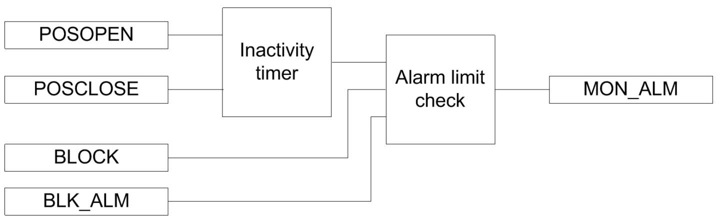


Figure 515: Functional module diagram for calculating inactive days and alarm for circuit breaker operation monitoring

Inactivity timer

The module calculates the number of days the circuit breaker has remained inactive, that is, has stayed in the same open or closed state. The calculation is done by monitoring the states of the POSOPEN and POSCLOSE auxiliary contacts.

The inactive days INA_DAYS is available in the monitored data view. It is also possible to set the initial inactive days with the *Ini inactive days* parameter.

Alarm limit check

When the inactive days exceed the limit value defined with the *Inactive Alm days* setting, the MON_ALM alarm is initiated. The time in hours at which this alarm is activated can be set with the *Inactive Alm hours* parameter as coordinates of UTC. The alarm signal MON_ALM can be blocked by activating the binary input BLOCK.

7.1.4.3 Breaker contact travel time

The breaker contact travel time module calculates the breaker contact travel time for the closing and opening operation. The operation of the breaker contact travel time measurement can be described with a module diagram. All the modules in the diagram are explained in the next sections.

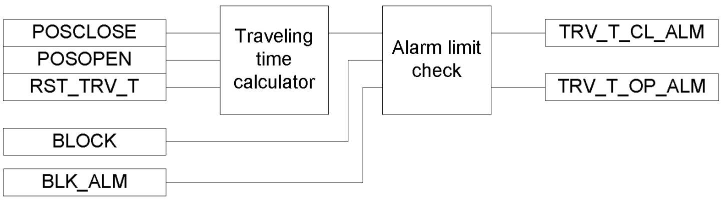


Figure 516: Functional module diagram for breaker contact travel time

Traveling time calculator

The contact travel time of the breaker is calculated from the time between auxiliary contacts' state change. The opening travel time is measured between the opening of the POSCLOSE auxiliary contact and the closing of the POSOPEN auxiliary contact. Travel time is also measured between the opening of the POSOPEN auxiliary contact and the closing of the POSCLOSE auxiliary contact.

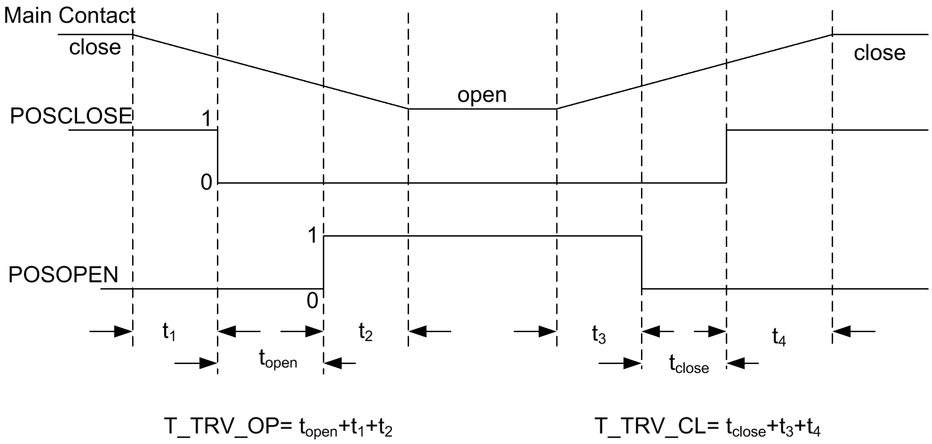


Figure 517: Travel time calculation

There is a time difference t_1 between the start of the main contact opening and the opening of the POSCLOSE auxiliary contact. Similarly, there is a time gap t_2 between the time when the POSOPEN auxiliary contact opens and the main contact is completely open. Therefore, to incorporate the time t_1+t_2, a correction factor needs to be added with t_{open} to get the actual opening time. This factor is added with the *Opening time Cor* ($=t_1+t_2$) setting. The closing time is calculated by adding the value set with the *Closing time Cor* (t_3+t_4) setting to the measured closing time.

The last measured opening travel time T_TRV_OP and the closing travel time T_TRV_CL are available in the monitored data view on the LHMI or through tools via communications.

Alarm limit check

When the measured opening travel time is longer than the value set with the *Open alarm time* setting, the TRV_T_OP_ALM output is activated. Respectively, when the measured closing travel time is longer than the value set with the *Close alarm time* setting, the TRV_T_CL_ALM output is activated.

It is also possible to block the TRV_T_CL_ALM and TRV_T_OP_ALM alarm signals by activating the BLOCK input.

7.1.4.4 Operation counter

The operation counter subfunction calculates the number of breaker operation cycles. The opening and closing operations are both included in one operation cycle. The operation counter value is updated after each opening operation.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

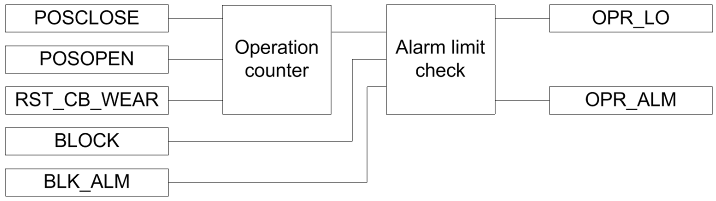


Figure 518: Functional module diagram for counting circuit breaker operations

Operation counter

The operation counter counts the number of operations based on the state change of the binary auxiliary contacts inputs POSCLOSE and POSOPEN.

The number of operations NO_OPR is available in the monitored data view on the LHMI or through tools via communications. The old circuit breaker operation counter value can be taken into use by writing the value to the *Counter initial Val* parameter and by setting the parameter *CB wear values* in the clear menu from WHMI or LHMI.

Alarm limit check

The OPR_ALM operation alarm is generated when the number of operations exceeds the value set with the *Alarm Op number* threshold setting. However, if the number of operations increases further and exceeds the limit value set with the *Lockout Op number* setting, the OPR_LO output is activated.

The binary outputs OPR_LO and OPR_ALM are deactivated when the BLOCK input is activated.

7.1.4.5 Accumulation of $I^y t$

Accumulation of the $I^y t$ module calculates the accumulated energy.

The operation of the module can be described with a module diagram. All the modules in the diagram are explained in the next sections.

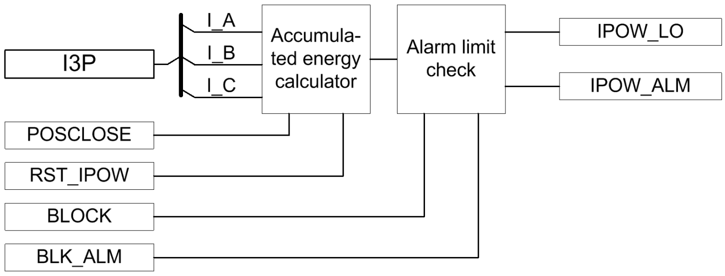


Figure 519: Functional module diagram for calculating accumulative energy and alarm

Accumulated energy calculator

This module calculates the accumulated energy $I^y t$ [$(kA)^y s$]. The factor y is set with the *Current exponent* setting.

The calculation is initiated with the POSCLOSE input opening events. It ends when the RMS current becomes lower than the *Acc stop current* setting value.

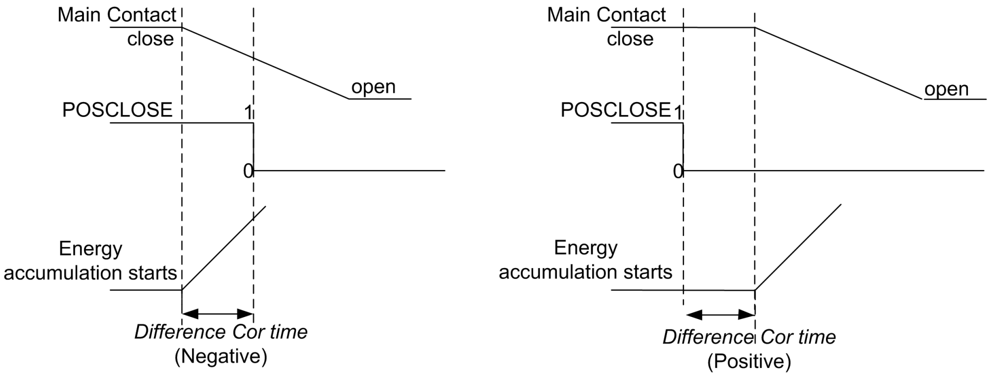


Figure 520: Significance of theDifference Cor time setting

The *Difference Cor time* setting is used instead of the auxiliary contact to accumulate the energy from the time the main contact opens. If the setting is positive, the calculation of energy starts after the auxiliary contact has opened and when the delay is equal to the value set with the *Difference Cor time* setting. When the setting is negative, the calculation starts in advance by the correction time before the auxiliary contact opens.

The accumulated energy outputs IPOW_A (_B, _C) are available in the monitored data view on the LHMI or through tools via communications. The values can be reset by setting the parameter *CB accum. currents power* setting to true in the clear menu from WHMI or LHMI.

Alarm limit check

The IPOW_ALM alarm is activated when the accumulated energy exceeds the value set with the *Alm Acc currents Pwr* threshold setting. However, when the energy exceeds the limit value set with the *LO Acc currents Pwr* threshold setting, the IPOW_LO output is activated.

The IPOW_ALM and IPOW_LO outputs can be blocked by activating the binary input BLOCK.

7.1.4.6 Remaining life of the circuit breaker

Every time the breaker operates, the life of the circuit breaker reduces due to wearing. The wearing in the breaker depends on the tripping current, and the remaining life of the breaker is estimated from the circuit breaker trip curve provided by the manufacturer. The remaining life is decremented at least with one when the circuit breaker is opened.

The operation of the remaining life of the circuit breaker subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

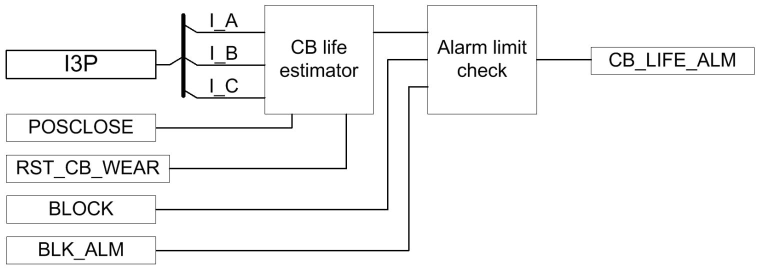


Figure 521: Functional module diagram for estimating the life of the circuit breaker

Circuit breaker life estimator

The circuit breaker life estimator module calculates the remaining life of the circuit breaker. If the tripping current is less than the rated operating current set with the *Rated Op current* setting, the remaining operation of the breaker reduces by one operation. If the tripping current is more than the rated fault current set with the *Rated fault current* setting, the possible operations are zero. The remaining life of the tripping current in between these two values is calculated based on the trip curve given by the manufacturer. The *Op number rated* and *Op number fault* parameters set the number of operations the breaker can perform at the rated current and at the rated fault current, respectively.

The remaining life is calculated separately for all three phases and it is available as a monitored data value `CB_LIFE_A (_B,_C)`. The values can be cleared by setting the parameter *CB wear values* in the clear menu from WHMI or LHMI.

Clearing *CB wear values* also resets the operation counter.

Alarm limit check

When the remaining life of any phase drops below the *Life alarm level* threshold setting, the corresponding circuit breaker life alarm `CB_LIFE_ALM` is activated.

It is possible to deactivate the `CB_LIFE_ALM` alarm signal by activating the binary input `BLOCK`. The old circuit breaker operation counter value can be taken into use by writing the value to the *Initial CB Rmn life* parameter and resetting the value via the clear menu from WHMI or LHMI.

7.1.4.7 Circuit breaker spring-charged indication

The circuit breaker spring-charged indication subfunction calculates the spring charging time.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

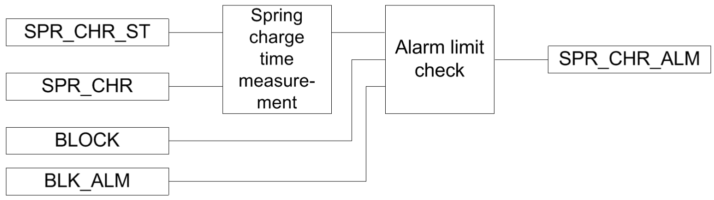


Figure 522: Functional module diagram for circuit breaker spring-charged indication and alarm

Spring charge time measurement

Two binary inputs, SPR_CHR_ST and SPR_CHR, indicate spring charging started and spring charged, respectively. The spring-charging time is calculated from the difference of these two signal timings.

The spring-charging time T_SPR_CHR is available in the monitored data view.

Alarm limit check

If the time taken by the spring to charge is more than the value set with the *Spring charge time* setting, the subfunction generates the SPR_CHR_ALM alarm.

It is possible to block the SPR_CHR_ALM alarm signal by activating the BLOCK binary input.

7.1.4.8 Gas pressure supervision

The gas pressure supervision subfunction monitors the gas pressure inside the arc chamber.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

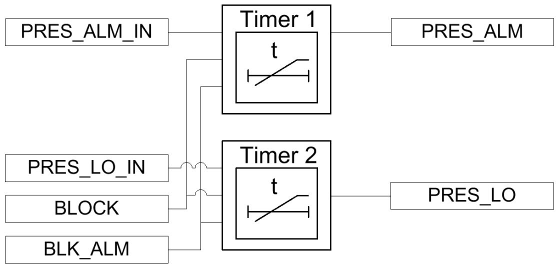


Figure 523: Functional module diagram for circuit breaker gas pressure alarm

The gas pressure is monitored through the binary input signals PRES_LO_IN and PRES_ALM_IN.

Timer 1

When the PRES_ALM_IN binary input is activated, the PRES_ALM alarm is activated after a time delay set with the *Pressure alarm time* setting. The PRES_ALM alarm can be blocked by activating the BLOCK input.

Timer 2

If the pressure drops further to a very low level, the PRES_LO_IN binary input becomes high, activating the lockout alarm PRES_LO after a time delay set with the *Pres lockout time* setting. The PRES_LO alarm can be blocked by activating the BLOCK input.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers. The alarm signals from the function can be blocked by activating the binary input BLK_ALM.

7.1.5 Application

SSCBR includes different metering and monitoring subfunctions.

Circuit breaker status

Circuit breaker status monitors the position of the circuit breaker, that is, whether the breaker is in an open, closed or intermediate position.

Circuit breaker operation monitoring

The purpose of the circuit breaker operation monitoring is to indicate that the circuit breaker has not been operated for a long time. The function calculates the number of days the circuit breaker has remained inactive, that is, has stayed in the same open or closed state. There is also the possibility to set an initial inactive day.

Breaker contact travel time

High travelling times indicate the need for maintenance of the circuit breaker mechanism. Therefore, detecting excessive travelling time is needed. During the opening cycle operation, the main contact starts opening. The auxiliary contact A opens, the auxiliary contact B closes, and the main contact reaches its opening position. During the closing cycle, the first main contact starts closing. The auxiliary contact B opens, the auxiliary contact A closes, and the main contact reaches its close position. The travel times are calculated based on the state changes of the auxiliary contacts and the adding correction factor to consider the time difference of the main contact's and the auxiliary contact's position change.

Operation counter

Routine maintenance of the breaker, such as lubricating breaker mechanism, is generally based on a number of operations. A suitable threshold setting, to raise an alarm when the number of operation cycle exceeds the set limit, helps preventive maintenance. This can also be used to indicate the requirement for oil sampling for dielectric testing in case of an oil circuit breaker.

The change of state can be detected from the binary input of the auxiliary contact. There is a possibility to set an initial value for the counter which can be used to initialize this functionality after a period of operation or in case of refurbished primary equipment.

Accumulation of I^yt

Accumulation of I^yt calculates the accumulated energy ΣI^yt where the factor y is known as the current exponent. The factor y depends on the type of the circuit breaker. For oil circuit breakers the factor y is normally 2. In case of a high-voltage system, the factor y can be 1.4...1.5.

Remaining life of the breaker

Every time the breaker operates, the life of the circuit breaker reduces due to wearing. The wearing in the breaker depends on the tripping current, and the remaining life of the breaker is estimated from the circuit breaker trip curve provided by the manufacturer.

Example for estimating the remaining life of a circuit breaker

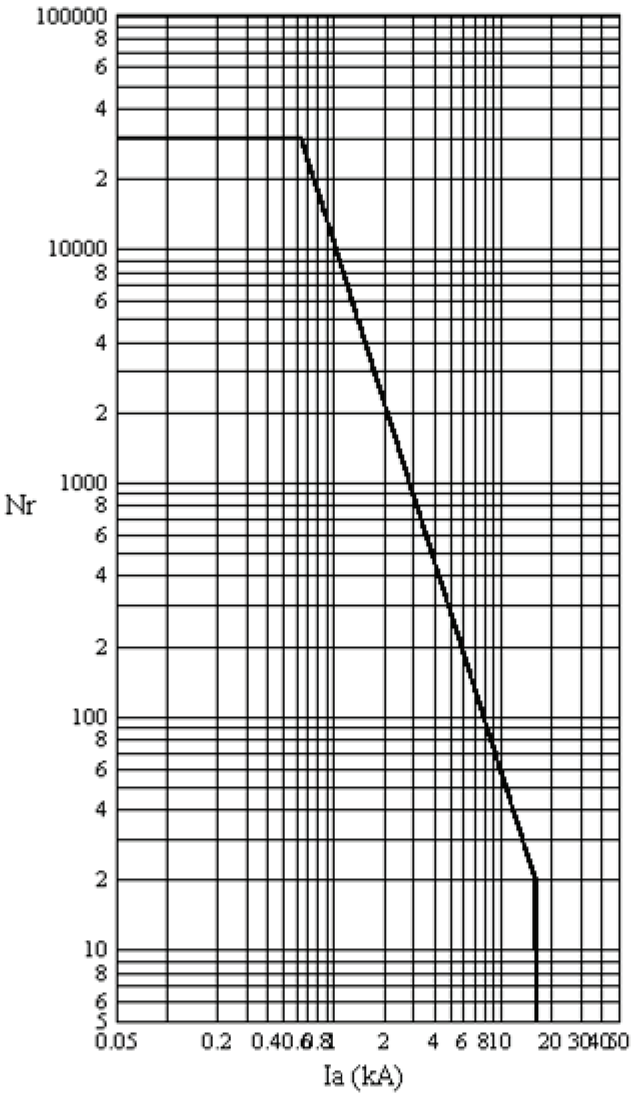


Figure 524: Trip Curves for a typical 12 kV, 630 A, 16 kA vacuum interrupter

Nr	the number of closing-opening operations allowed for the circuit breaker
Ia	the current at the time of tripping of the circuit breaker

Calculation of Directional Coef

The directional coefficient is calculated according to the formula:

$$Directional\,Coef = \frac{\log\left(\frac{B}{A}\right)}{\log\left(\frac{I_f}{I_r}\right)} = -2.2609$$

(Equation 155)

I_r	Rated operating current = 630 A
I_f	Rated fault current = 16 kA
A	Op number rated = 30000
B	Op number fault = 20

Calculation for estimating the remaining life

The equation shows that there are 30,000 possible operations at the rated operating current of 630 A and 20 operations at the rated fault current 16 kA. Therefore, if the tripping current is 10 kA, one operation at 10 kA is equivalent to 30,000/60=500 operations at the rated current. It is also assumed that prior to this tripping, the remaining life of the circuit breaker is 15,000 operations. Therefore, after one operation of 10 kA, the remaining life of the circuit breaker is 15,000-500=14,500 at the rated operating current.

Spring-charged indication

For normal operation of the circuit breaker, the circuit breaker spring should be charged within a specified time. Therefore, detecting long spring-charging time indicates that it is time for the circuit breaker maintenance. The last value of the spring-charging time can be used as a service value.

Gas pressure supervision

The gas pressure supervision monitors the gas pressure inside the arc chamber. When the pressure becomes too low compared to the required value, the circuit breaker operations are locked. A binary input is available based on the pressure levels in the function, and alarms are generated based on these inputs.

7.1.6 Signals

Table 987: SSCBR Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
BLOCK	BOOLEAN	0	Block all the alarm and lockout indication
BLK_ALM	BOOLEAN	0	Block all the alarms
POSOPEN	BOOLEAN	0	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0	Signal for close position of apparatus from I/O
PRES_ALM_IN	BOOLEAN	0	Binary pressure alarm input
Table continues on next page			

Name	Type	Default	Description
PRES_LO_IN	BOOLEAN	0	Binary pressure input for lockout indication
SPR_CHR_ST	BOOLEAN	0	CB spring charging started input
SPR_CHR	BOOLEAN	0	CB spring charged input
RST_CB_WEAR	BOOLEAN	0	Reset input for CB remaining life and operation counter
RST_IPOW	BOOLEAN	0	Reset accumulated currents power
RST_SPR_T	BOOLEAN	0	Reset input for the charging time of the CB spring
RST_TRV_T	BOOLEAN	0	Reset input for CB closing and opening travel times

Table 988: SSCBR Output signals

Name	Type	Description
TRV_T_OP_ALM	BOOLEAN	CB open travel time exceeded set value
TRV_T_CL_ALM	BOOLEAN	CB close travel time exceeded set value
SPR_CHR_ALM	BOOLEAN	Spring charging time has crossed the set value
OPR_ALM	BOOLEAN	Number of CB operations exceeds alarm limit
OPR_LO	BOOLEAN	Number of CB operations exceeds lockout limit
IPOW_ALM	BOOLEAN	Accumulated currents power (Iyt),exceeded alarm limit
IPOW_LO	BOOLEAN	Accumulated currents power (Iyt),exceeded lockout limit
CB_LIFE_ALM	BOOLEAN	Remaining life of CB reduced to Life alarm level
MON_ALM	BOOLEAN	CB 'not operated for long time' alarm
PRES_ALM	BOOLEAN	Pressure below alarm level
PRES_LO	BOOLEAN	Pressure below lockout level
OPENPOS	BOOLEAN	CB is in open position
INVALIDPOS	BOOLEAN	CB is in invalid position (not positively open or closed)
CLOSEPOS	BOOLEAN	CB is in closed position

7.1.7 Settings

Table 989: SSCBR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Acc stop current	5.00 - 500.00	A	0.01	10.00	RMS current setting below which energy acm stops
Current exponent	0.00 - 2.00	-	0.01	2.00	Current exponent setting for energy calculation
Rated fault current	500.00 - 75000.00	A	0.01	5000.00	Rated fault current of the breaker
Rated Op current	100.00 - 5000.00	A	0.01	1000.00	Rated operating current of the breaker
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
Alm Acc currents Pwr	0.00 - 20000.00	-	0.01	2500.00	Setting of alarm level for accumulated currents power
LO Acc currents Pwr	0.00 - 20000.00	-	0.01	2500.00	Lockout limit setting for accumulated currents power
Op number rated	1 - 99999	-	1	10000	Number of operations possible at rated current
Op number fault	1 - 10000	-	1	1000	Number of operations possible at rated fault current
Alarm Op number	0 - 9999	-	1	200	Alarm limit for number of operations
Lockout Op number	0 - 9999	-	1	300	Lockout limit for number of operations
Open alarm time	0 - 200	ms	1	40	Alarm level setting for open travel time
Close alarm time	0 - 200	ms	1	40	Alarm level setting for close travel time
Spring charge time	0.00 - 60.00	s	0.01	1.00	Setting of alarm for spring charging time
Inactive Alm days	0 - 9999	Day	1	2000	Alarm limit value of the inactive days counter
Initial CB Rmn life	0 - 9999	-	1	5000	Initial value for the CB remaining life estimates

Table 990: SSCBR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Directional Coef	-3.00 - -0.50	-	0.01	-1.50	Directional coefficient for CB life calculation
Life alarm level	0 - 99999	-	1	5000	Alarm level for CB remaining life
Opening time Cor	0 - 100	ms	1	10	Correction factor for open travel time
Closing time Cor	0 - 100	ms	1	10	Correction factor for close travel time
Difference Cor time	-10 - 10	ms	1	5	Correction factor for time difference in auxiliary and main contacts open time
Pressure alarm time	0.00 - 60.00	s	0.01	0.10	Time delay for gas pressure alarm
Pres lockout time	0.00 - 60.00	s	0.01	0.10	Time delay for gas pressure lockout
Inactive Alm hours	0 - 23	Hour	1	0	Alarm time of the inactive days counter in hours
Counter initial Val	0 - 9999	-	1	0	Operation numbers counter initialization value
Ini inactive days	0 - 9999	Day	1	0	Initial value of the inactive days counter
Ini Acc currents Pwr	0.00 - 9999.99	-	0.01	0.00	Initial value for accumulation energy (Iyt)

7.1.8 Measured values

Table 991: SSCBR Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0	RMS Current input phase A
I_RMS_B	REAL	0	RMS Current input phase B
I_RMS_C	REAL	0	RMS Current input phase C
BLOCK	BOOLEAN	0	Block all the alarm and lockout indication
BLK_ALM	BOOLEAN	0	Block all the alarms
POSOPEN	BOOLEAN	0	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0	Signal for close position of apparatus from I/O
PRES_ALM_IN	BOOLEAN	0	Binary pressure alarm input
PRES_LO_IN	BOOLEAN	0	Binary pressure input for lockout indication
SPR_CHR_ST	BOOLEAN	0	CB spring charging started input
SPR_CHR	BOOLEAN	0	CB spring charged input
RST_CB_WEAR	BOOLEAN	0	Reset input for CB remaining life and operation counter
RST_IPOW	BOOLEAN	0	Reset accumulated currents power
RST_SPR_T	BOOLEAN	0	Reset input for the charging time of the CB spring
RST_TRV_T	BOOLEAN	0	Reset input for CB closing and opening travel times

7.1.9 Monitored data

Table 992: SSCBR Monitored data

Name	Type	Values (Range)	Unit	Description
TRV_T_OP_ALM	BOOLEAN	0=FALSE 1=TRUE	-	CB open travel time exceeded set value
TRV_T_CL_ALM	BOOLEAN	0=FALSE 1=TRUE	-	CB close travel time exceeded set value
T_TRV_OP	REAL	-	ms	Travel time of the CB during opening operation
T_TRV_CL	REAL	-	ms	Travel time of the CB during closing operation
SPR_CHR_ALM	BOOLEAN	0=FALSE 1=TRUE	-	Spring charging time has crossed the set value
T_SPR_CHR	REAL	-	s	The charging time of the CB spring
OPR_ALM	BOOLEAN	0=FALSE 1=TRUE	-	Number of CB operations exceeds alarm limit
OPR_LO	BOOLEAN	0=FALSE 1=TRUE	-	Number of CB operations exceeds lockout limit

Table continues on next page

Name	Type	Values (Range)	Unit	Description
NO_OPR	INTEGER	-	-	Number of CB operation cycle
IPOW_ALM	BOOLEAN	0=FALSE 1=TRUE	-	Accumulated currents power (Iyt),exceeded alarm limit
IPOW_LO	BOOLEAN	0=FALSE 1=TRUE	-	Accumulated currents power (Iyt),exceeded lockout limit
CB_LIFE_ALM	BOOLEAN	0=FALSE 1=TRUE	-	Remaining life of CB reduced to Life alarm level
MON_ALM	BOOLEAN	0=FALSE 1=TRUE	-	CB 'not operated for long time' alarm
INA_DAYS	INTEGER	-	-	The number of days CB has been inactive
PRES_ALM	BOOLEAN	0=FALSE 1=TRUE	-	Pressure below alarm level
PRES_LO	BOOLEAN	0=FALSE 1=TRUE	-	Pressure below lockout level
CB_LIFE_A	INTEGER	-	-	CB Remaining life phase A
CB_LIFE_B	INTEGER	-	-	CB Remaining life phase B
CB_LIFE_C	INTEGER	-	-	CB Remaining life phase C
IPOW_A	REAL	-	-	Accumulated currents power (Iyt), phase A
IPOW_B	REAL	-	-	Accumulated currents power (Iyt), phase B
IPOW_C	REAL	-	-	Accumulated currents power (Iyt), phase C
OPENPOS	BOOLEAN	0=FALSE 1=TRUE	-	CB is in open position
INVALIDPOS	BOOLEAN	0=FALSE 1=TRUE	-	CB is in invalid position (not positively open or closed)
CLOSEPOS	BOOLEAN	0=FALSE 1=TRUE	-	CB is in closed position

7.1.10 Technical data

Table 993: SSCBR Technical data

Characteristic	Value
Current measuring accuracy	At the frequency f = f_n
	±1.5% or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% (at currents in the range of 10…40 × I_n)
Operate time accuracy	±1.0% of the set value or ±20 ms
Traveling time measurement	±10 ms

7.1.11 Technical revision history

Table 994: SSCBR technical revision history

Technical revision	Change
B	Output data objects PosCls and PosOpn removed from being in data set by default
C	Internal improvements

7.2 Hot-spot and insulation ageing rate monitoring for transformers HSARSPTR

7.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Hot-spot and insulation ageing rate monitoring for transformers	HSARSPTR	3Ihp>T	26/49HS

7.2.2 Function block

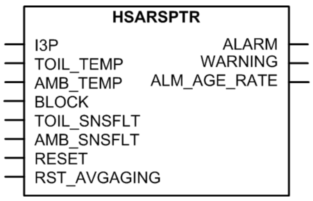


Figure 525: Function block

7.2.3 Functionality

HSARSPTR is used for online monitoring of transformers. The function monitors the hot-spot temperature of the transformer winding and the ageing rate of the insulation caused by thermal stress. The function can be applied for new transformers as well as for transformers already in service.

The hot-spot temperature and loss of life of transformer are calculated for one winding of the transformer from three phase currents and RTD inputs for top oil temperature and ambient temperature.

The hot-spot temperature and the momentary ageing rate are calculated based on the IEC 60076-7 or the IEEE C57.91-2011 standard, depending upon a user defined setting. The total ageing and loss of transformer insulation life is calculated in years.

The function generates `WARNING` and `ALARM` signals, if the calculated hot-spot temperature exceeds the set value.

7.2.4 Operation principle

The *Operation* setting is used to enable or disable the function. When "On" is selected, the function is enabled and when "Off" is selected, the function is disabled.

The operation of HSARSPTR can be described using a module diagram. All modules in the diagram are explained in the next sections.

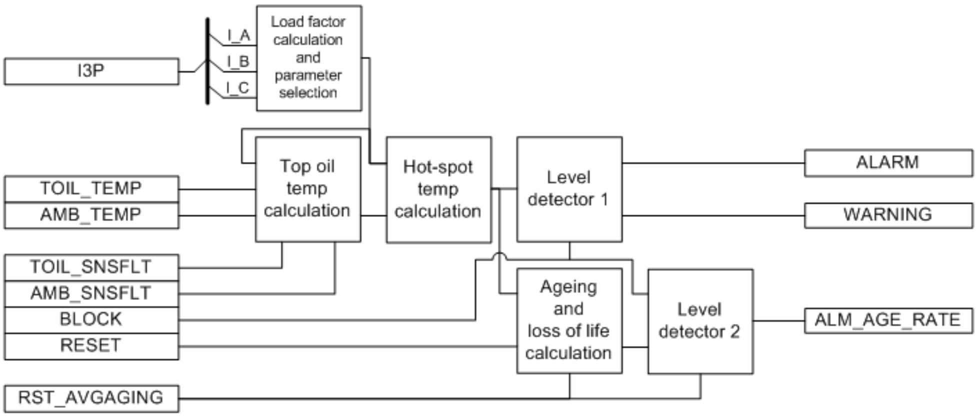


Figure 526: Functional module diagram

Load factor calculation and parameter selection

The transformer top oil and hot-spot temperatures are dependent on the load factor, the winding conductor properties and the cooling oil properties of the transformer. This module calculates the load factor based on the measured phase currents and selects the transformer parameters based on user defined settings.

Load factor calculation

Load factor is a ratio of the load current to the rated current. Since the thermal content of all the three phase currents influence the temperature inside the transformer, the load factor is calculated as a ratio of the root of sum of squared phase currents to three times the rated current.

$$K = \sqrt{\frac{I\_A^2 + I\_B^2 + I\_C^2}{3 \times I_{rated}^2}}$$

(Equation 156)

Where

K	Load factor
I_A, I_B and I_C	RMS value of input phase currents (Amperes)
I_{rated}	Rated current (Amperes)

If *Transformer type* is set to “Single phase”, the denominator consists only of I^2_{rated} instead of $3 \times I^2_{rated}$.

The *Transformer rating* setting and the value of the rated current are obtained from the *SBase* and *IBase* settings of the IED respectively. Equation 156 assumes that voltage is constant and tap changer position is not considered.

For a start-delta transformer, it is recommended to use the function on the star winding, since the circulating zero sequence currents (in case of unbalance) cannot be measured on the delta winding of the transformer.

Transformer parameter selection

The transformer parameters are selected based on the *Parm select method*, *Cooling mode*, *Transformer type*, and *Transformer rating* settings.

If the *Parm select method* setting is set to “IEC”, the transformer parameters' values are automatically selected as per the IEC 60076-7 guidelines based on Table 995.

Table 995: Constants based IEC guidelines

	Distribution Transformers	Medium and Large power transformers			
Cooling mode	ONAN	ONAN	ONAF	OFAF	ODAF
Oil Exponent (x)	0.8	0.8	0.8	1.0	1.0
Winding Exponent (y)	1.6	1.3	1.3	1.3	2.0
Constant K11 (k_{11})	1.00	0.50	0.50	1.00	1.00
Constant K21 (k_{21})	1.00	2.00	2.00	1.30	1.00
Constant K22 (k_{22})	2.00	2.00	2.00	1.00	1.00
Oil Time Constant (τ_0) [minutes]	180	210	150	90	90
Winding Tm Constant (τ_w) [minutes]	4	10	7	7	7

If *Parm select method* is set to “IEEE”, the constants are selected as per the IEEE C57.91™-2011 standard based on Table 996.

Table 996: Constants based on IEEE guidelines

	Distribution Transformers	Medium and Large power transformers			
Cooling mode	ONAN	ONAN	ONAF	OFAF	ODAF
Oil Exponent (x)	0.8	0.8	0.8	0.8	1.0
Winding Exponent (y)	0.8	0.8	0.9	0.9	1.0
Constant K11 (k_{11})	1.00	1.00	1.00	1.00	1.00
Constant K21 (k_{21})	1.00	1.00	1.00	1.00	1.00
Constant K22 (k_{22})	1.00	1.00	1.00	1.00	1.00
Oil Time Constant (τ_0) [minutes]	180	210	150	90	90
Winding Tm Constant (τ_w) [minutes]	4	10	7	7	7

A transformer is a distribution transformer if the *Transformer rating* setting < 2.5 MVA and *Transformer type* is set to “Three phase” or if the *Transformer rating* setting < 0.833 MVA and *Transformer type* is set to “Single phase”.

Transformer parameters vary with the material used for winding and insulating oil. The *Parm select method* setting can be set to “Manual” and the constants can be set individually through the *Oil exponent*, *Winding exponent*, *Constant K11*, *Constant K21*, *Constant K22*, *Oil time constant* and *Winding Tm constant* settings.

If *Parm select method* is set to “Manual”, the *Cooling mode* setting has no effect on the transformer parameters.

Since there is no direct *Cooling mode* based time constants' selection mentioned in the IEEE Std C57.91™- 2011 standard, the oil time constant (τ_0) and winding time constant (τ_w) in the Table 996 are kept same as in the Table 995.
For more accuracy, the values of the constants can be entered manually by setting *Parm select method* to “Manual”.

Top oil temp calculation

The function receives two sensor inputs for measuring top oil temperature and ambient temperature.

The top oil temperature of the tank is obtained through a sensor placed at the upper inner turn of the winding. If the top oil temperature sensor status `TOIL_SNSFLT` is FALSE, the top oil temperature is directly obtained from the `TOIL_TEMP` input.

If the status of `TOIL_SNSFLT` is TRUE, indicating that the sensor is faulty, the top oil temperature is calculated with the help of measured ambient temperature.

The status of the ambient temperature sensor is obtained through the AMB_SNSFLT binary input. If AMB_SNSFLT is FALSE, indicating the healthy status of the sensor, the ambient temperature is directly measured through the AMB_TEMP input. Else, if AMB_SNSFLT is TRUE, the ambient temperature is taken from the *Avg ambient Temp* setting.

The formula for calculating the top oil temperature from the measured or set ambient temperature is shown in Equation 157.

$$D\theta_{0(n)} = \frac{Dt}{(k_{11} \times \tau_o)} \times \left(\left[\frac{1+(K^2 \times R)}{1+R} \right]^x \times \Delta\theta_{or} - \left[\theta_{0(n-1)} - \theta_a \right] \right)$$

(Equation 157)

Where

$\theta_{0(n)}$	Top oil temperature in the tank at n^{th} time step
θ_a	Ambient temperature [°C]
$\Delta\theta_{or}$	Top oil temperature rise over ambient temperature at rated load, given by the setting *Rated TO Temp rise*
R	Ratio of losses at rated current to no load losses, given by the setting *Ratio of losses*

k_{11}, τ_0, K and x are as defined in the Parameter selection module in Figure 526.

The D operator implies a difference in the associated variable that corresponds to each time step Dt. At each time step, the n^{th} value of $D\theta_{0(n)}$ is calculated from the $(n-1)^{th}$ value.

The initial conditions are calculated by setting the time derivative equal to zero in $D\theta_{0(n)}$ equation, resulting in the following equations.

$$\theta_{0(0)} = \left[\frac{1+(K^2 \times R)}{1+R} \right]^x \times \Delta\theta_{or} + \theta_a$$

(Equation 158)

The top oil temperature at the n^{th} time step is calculated as shown below.

$$TOPOIL\_TEMP = \theta_{0(n-1)} + D\theta_{0(n)}$$

(Equation 159)

The measured/calculated top oil temperature TOPOIL_TEMP is available in the monitored data view.

If the top oil temperature sensor is valid, the `TOPOIL_TEMP` output is equal to the measured top oil temperature `TOIL_TEMP` input.

Hot-spot temp calculation

Winding hot-spot temperature depends on the winding temperature rise due to the load factor and oil flow. These two factors act complimentary to each other in the influence of temperature rise.

The differential equations for hot-spot temperature rise above top oil temperature is solved as the sum of two differential equations.

$$\Delta\theta_{h(n)} = \Delta\theta_{h1(n)} - \Delta\theta_{h2(n)}$$

(Equation 160)

The two differential equations are shown in the Equation 161 and Equation 162.

$$D\Delta\theta_{h1(n)} = \frac{Dt}{(k_{22} \times \tau_w)} \times \left(k_{21} \times \Delta\theta_{hr} \times K^y - \Delta\theta_{h1(n-1)}\right)$$

(Equation 161)

$$D\Delta\theta_{h2(n)} = \frac{Dt}{\left(\left(\frac{1}{k_{22}}\right) \times \tau_o\right)} \times \left(\left(k_{21} - 1\right) \times \Delta\theta_{hr} \times K^y - \Delta\theta_{h2(n-1)}\right)$$

(Equation 162)

Where

$\Delta\theta_{hr}$	Hot-spot-to-top-oil gradient at rated current [°C]

The constants τ_w, k_{21}, k_{22} and y are varying according to the *Cooling mode* setting and are obtained from the Load factor calculation and parameter selection module.

The rated hot-spot to top oil gradient, HS_TOIL_GRA ($\Delta\theta_{hr}$), is calculated using the formula as shown in the Equation 163.

$$\Delta\theta_{hr} = \frac{Rated\ HS\ Temp\ rise - Rated\ TO\ Temp\ rise}{\left(Current\ type\ test\ /\ I_{rated}\right)^y}$$

(Equation 163)

Where

I_{rated}	Rated current of the transformer
Rated HS Temp rise	Hot-spot temperature rise over ambient at rated current
Current type test	Current applied in type testing to reach rated hot-spot temperature

At each time step, the n^{th} value of $D\Delta\theta_{h1(n)}$ and $D\Delta\theta_{h2(n)}$ are calculated from the (n-1) value; the solutions of which are combined in accordance with the hot-spot temperature rise equation.

$$\Delta\theta_{h1(n)} = \Delta\theta_{h1(n-1)} + D\Delta\theta_{h1(n)}$$

(Equation 164)

$$\Delta\theta_{h2(n)} = \Delta\theta_{h2(n-1)} + D\Delta\theta_{h2(n)}$$

(Equation 165)

The initial conditions are calculated by setting the time derivative equal to zero in $D\Delta\theta_{h1(n)}$ and $D\Delta\theta_{h2(n)}$ equations, resulting in the following equations.

$$\Delta\theta_{h1(0)} = k_{21} \times \Delta\theta_{hr} \times K^{y}$$

(Equation 166)

$$\Delta\theta_{h2(0)} = (k_{21} - 1) \times \Delta\theta_{hr} \times K^{y}$$

(Equation 167)

The final hot-spot temperature is calculated as the sum of top oil temperature and the rise of hot-spot temperature over the top oil temperature.

The hot-spot temperature at the nth time step is calculated as shown in the Equation 168.

$$HOTSPOT\_TEMP = \theta_{o(n)} + \Delta\theta_{h(n)}$$

(Equation 168)

The calculated hot-spot temperature HOTSPOT_TEMP and rated hot-spot to top oil gradient, HS_TOIL_GRA are available in the monitored data view.

Level detector 1

This module compares the calculated hot-spot temperature, HOTSPOT_TEMP value with the *Alarm level* and *Warning level* settings.

If HOTSPOT_TEMP is greater than the *Warning level*, the module activates the `WARNING` output after a settable *Warning delay time*.

If HOTSPOT_TEMP is greater than the *Alarm level*, the module activates the `ALARM` output after a settable *Alarm delay time*.

Assuming existing conditions, as long as the alarm/warning conditions are not reached, the module calculates the available load reserve in percentage to reach the alarm condition `LD_RSV_ALM` and to reach the warning condition, `LD_RSV_WRN`. These outputs can be obtained from the monitored data view.

If the warning condition is reached, the `LD_RSV_WRN` output is forced to zero and if the alarm condition is reached, `LD_RSV_ALM` is forced to zero.

The load reserve outputs are only indicative and are calculated based on rated current, assuming the same ambient temperature and cooling modes.
If, for any reason, the load reserve calculation is not feasible, the load reserve outputs are shown as zero.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates WARNING and ALARM outputs and resets the internal timers.

Ageing and loss of life calculation

This module calculates the rate at which transformer insulation ageing is accelerating compared with the ageing rate at rated hot-spot temperature and equivalent ageing over a time period.

If transformer insulation paper is not upgraded, that is, if setting *Insul paper type* is set to “Normal”, the setting *Ageing rate method* selects between the IEC and IEEE methods of calculation. If *Ageing rate method* is set to “IEC method”, the relative ageing rate is calculated as shown in the Equation 169.

$$V_{IEC} = 2^{\frac{(\theta_h - 98)}{6}}$$

(Equation 169)

If the setting *Ageing rate method* is set to “IEEE method”, the ageing rate is calculated as shown in the Equation 170.

$$V_{IEEE} = e^{\frac{15000}{110+273} - \frac{15000}{\theta_h + 273}}$$

(Equation 170)

Where

V_{IEC}	Momentary ageing rate as per IEC method
V_{IEEE}	Momentary ageing rate as per IEEE method
θ_h	The calculated hot-spot temperature

If the setting *Insul paper type* is set to “Upgraded”, the IEEE method is used for calculating the ageing rate irrespective of the value of *Ageing rate method* setting.

The calculated value of the relative ageing rate, AGEING_RATE is given as an output in the monitored data view.

The module also calculates the average ageing rate, AVG_AGE_RATE, over a specified time period given by the *Avg Age Rte period* setting. The setting *Avg Age Rte period* can be set to “Day”, “Week”, “Month” or “Year”.

For example, if the *Avg Age rate period* is set to “Month”, the output AVG_AGE_RATE is updated every day with the average ageing rate since the day the calculation started. Once a month is completed, the AVG_AGE_RATE is calculated over the previous 30 days. That is, after the 31st day, the average ageing rate is calculated from day 2 to day 31 and so on.

If the *Avg Age rate period* is set to “Day”, “Week” or “Month”, the calculated AVG_AGE_RATE is refreshed every day at 12:00 hours, but, if it is set to “Year”, the AVG_AGE_RATE is refreshed once in 30 days.

The calculated AVG_AGE_RATE is given as an output in the monitored data view.

The function considers month as 30 days and correspondingly a year as 12 months or 360 days.

Loss of life calculation

The momentary loss of life can be calculated as the product of the momentary ageing rate and the time step over which the momentary ageing is calculated.

$$DL_n = V_n \times Dt$$

(Equation 171)

The total loss of life is the sum of the momentary loss of life and the total loss of life until time, n-1.

$$L_n = L_{n-1} + DL_n$$

(Equation 172)

The initial loss of life L_0, is taken from the setting *Initial loss of life*.

For new transformer installations, the *Initial loss of life* setting should be “0”. For previously installed transformers, the *Initial loss of life* can be set to the consumed transformer life in months.

The calculated value of the loss of life in years, LOSS_OF_LIFE, is given as an output in the monitored data view.

The calculated value of LOSS_OF_LIFE can be reset through the input RESET.

Level detector 2

This module compares the AVG_AGE_RATE output with the setting *Alarm level age Rte*.

If the calculated AVG_AGE_RATE over the *Avg Age Rte period* setting is greater than *Alarm level Age Rte*, the module activates the binary output ALM_AGE_RATE.

The binary input RST_AVGAGING can be used to reset the output ALM_AGE_RATE and also the calculated value of AVG_AGE_RATE.

Once the RST_AVGAGING input is active, the average ageing rate values stored over the *Avg Age rate period* setting is erased and the calculation of AVG_AGE_RATE is restarted.

If the *Avg Age Rte period* is set to “Year”, the output AVG_AGE_RATE is refreshed once in 30 days starting from the time the relay is installed or since the last activation of binary input RST_AVGAGING.

The activation of the BLOCK input deactivates the ALM_AGE_RATE output.

7.2.5 Base value

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values. For example, the values are given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example, “Phase Grp 1”, “Phase Grp 2” and “Phase Grp 3”. Select one of the groups to be used with the *Base value Sel phase* settings.

7.2.6 Application

The insulation used in transformer windings is paper oil insulation that can degrade over a period of time. The deterioration of insulation is a time function of temperature, moisture and oxygen content. With modern oil preservation systems, the moisture and oxygen contributions to insulation deterioration can be minimized, leaving insulation temperature as the controlling parameter.

Since, in most of the transformers the temperature distribution is not uniform, the part that is operating at the highest (hot-spot) temperature normally undergoes the greatest deterioration. Hot-spot temperature of winding needs to be monitored continuously in order to not exceed the flashover value of transformer insulation oil. The first step in monitoring the insulation age is the calculation of hot-spot temperature of the transformer.

A simplified representation of the variation of temperature inside the transformer is shown in the Figure 527 (IEC 60076-7).

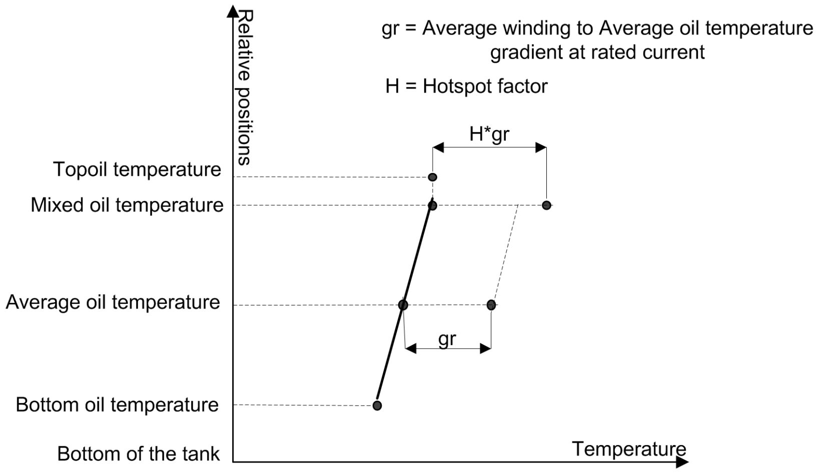


Figure 527: Transformer thermal diagram

The winding hot-spot temperature depends on the load losses, type of cooling and ambient temperature. Usually the conductors near the top of the winding experience the maximum leakage field and the highest surrounding oil temperature (due to convection effect). It is natural to consider that the top conductors contain the hottest spot. Measurements have shown that the hottest spot can also be moved to lower conductors.

Direct measurement of hot-spot temperature with fiber optic probes became available in mid 1980s. Experience has shown that there might be gradients of more than 10 °C between different locations at the top of a transformer winding. It is unlikely that the insertion of one to three sensors detect the real hot-spot. Direct measurement of hot-spot temperature is difficult and it is calculated using the empirical formulae.

The hot-spot temperature calculation is dependent upon the thermal properties of the winding material, cooling oil and the cooling mode of the transformer. The thermal model may also differ from IEC and IEEE markets, though the underlying principle of temperature calculation remains the same. The transformer constants are decided based on a user defined setting to select the preferred type of thermal model (IEC, IEEE or Manual).

For most transformers in service, the top oil temperature inside a winding is difficult to measure. On the other hand, the top oil temperature at the top of the tank is well known, either by measurement or by calculation. The winding hot-spot temperature rise above the top oil temperature is calculated. By adding this value to the measured or calculated top oil temperature, the winding hot-spot temperature is obtained. A pictorial representation of the location of top oil temperature sensor is shown in the Figure 528.

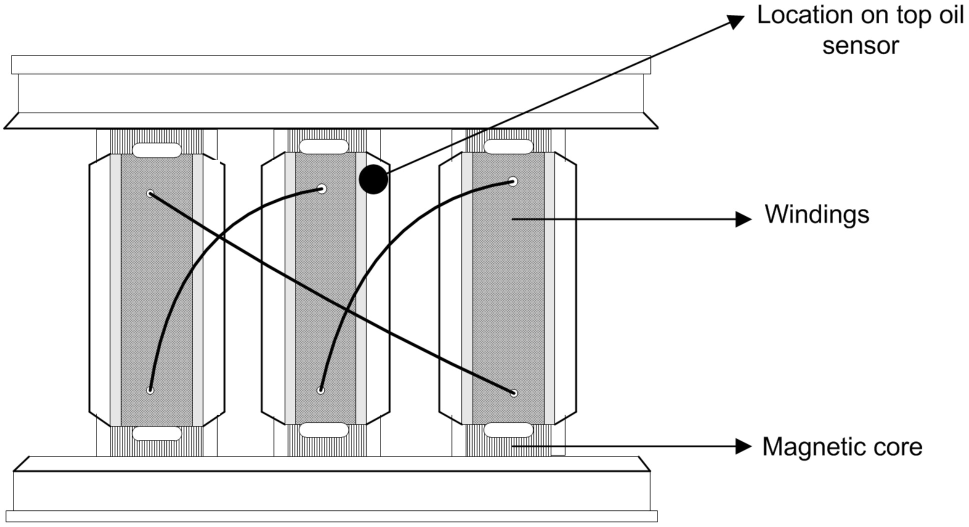


Figure 528: Location of top oil sensor

`WARNING` and `ALARM` signals are provided for the operator to take corrective actions to reduce the temperature inside the transformer. Corrective actions include switching on coolers, reducing the load on the transformers and so on.

Normally, warning level is set to indicate if the temperature is nearing the limiting value and alarm is generated when the limiting condition has reached. Hence, alarm level is set at a higher value than the warning level.

The function only calculates hot-spot temperature based on the load factor of the winding. This function does not calculate the rise in actual hot-spot temperature, which occurs due to oil flow blockage or malfunction of cooler groups. That said, the set oil and winding properties can be updated manually to indicate this change.

Based on the calculated hot-spot temperature, the function calculates the relative ageing, that is, the accelerated or decelerated ageing of the insulation at current load compared to its ageing at rated load. The variation of ageing acceleration factor with respect to the hot-spot temperature for a sample transformer is plotted in Figure 529. Here, 110 °C is taken as the rated hot-spot temperature at which point an ageing acceleration factor of 1.0 is achieved.

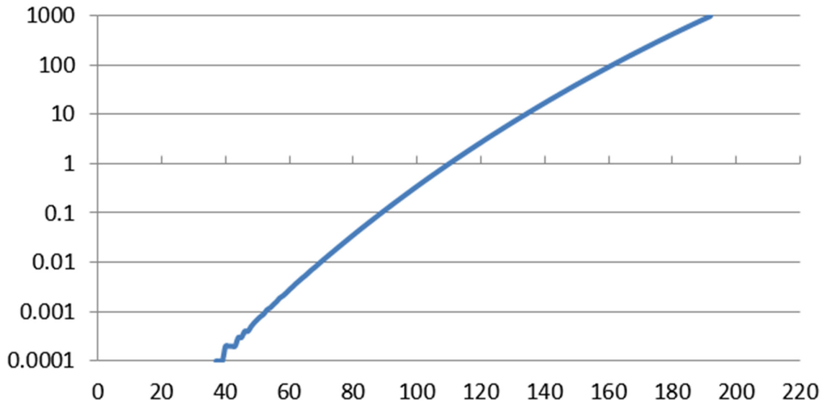


Figure 529: Variation of insulation ageing factor with hot-spot temperature (Graph produced using values from Table 11 of IEEE Std. C57.91-1995)

The variation of insulation life with respect to the hot-spot temperature depends upon the type of insulation paper used. Thermally upgraded insulation paper neutralizes the production of acids caused by the hydrolysis of the material over the lifetime of the transformer and slows down insulation ageing when compared to the normal insulation paper (IEC 60076-7). The proper selection of insulation paper type is needed for better accuracy of loss of life calculation.

In certain cases, it is necessary to monitor the loading of the transformer over a defined time period. For example, during a planned overloading of a transformer for a period of one month. In such cases it is important to know the ageing rate during that period of overload rather than the overall loss of life transformer. Hence, an additional output on average ageing rate over a settable average ageing period is provided in the function.

The function can be applied for new transformers and also for transformers already in service using the initial loss of life setting.

7.2.7 Signals

Table 997: HSARSPTR Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group signal for current input
TOIL_TEMP	REAL	0.0	Measured top oil temperature
AMB_TEMP	REAL	0.0	Measured ambient temperature
BLOCK	BOOLEAN	0	Block all binary outputs
TOIL_SNSFLT	BOOLEAN	0	Top oil temperature sensor fault status
AMB_SNSFLT	BOOLEAN	0	Ambient temperature sensor fault status
RESET	BOOLEAN	0	Reset loss of life calculation
RST_AVGAGING	BOOLEAN	0	Reset average ageing rate calculation

Table 998: HSARSPTR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm signal
WARNING	BOOLEAN	Warning signal
ALM_AGE_RATE	BOOLEAN	Alarm signal for average ageing rate over set time period

7.2.8 Settings

Table 999: HSARSPTR Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Cooling mode	ONAN ONAF OFAF ODAF	-	-	ONAN	Transformer cooling method
Alarm level	50.0 - 350.0	Deg C	0.1	120.0	Alarm level for hotspot temperature
Warning level	50.0 - 350.0	Deg C	0.1	100.0	Warning level for hotspot temperature
Alarm level Age Rte	0.10 - 5.00	-	0.01	1.00	Alarm level for average ageing rate over set time period
Avg ambient Temp	-20.00 - 70.00	Deg C	0.01	20.00	Average ambient temperature
Alarm delay time	0.00 - 3600.00	s	0.01	10.00	Time delay for hotspot temperature alarm
Warning delay time	0.00 - 3600.00	s	0.01	10.00	Time delay for hotspot temperature warning

Table 1000: HSARSPTR Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Avg Age rate period	Day Week Month Year	-	-	Month	Time period over which average ageing rate is calculated

Table 1001: HSARSPTR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 1002: HSARSPTR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Transformer type	Single phase Three phase	-	-	Three phase	Number of phases of the transformer
Parm select method	IEC IEEE Manual	-	-	IEC	Transformer parameter selection method
Insul paper type	Normal Upgraded	-	-	Normal	Type of transformer paper insulation
Ageing rate method	IEC IEEE	-	-	IEC	Ageing rate calculation method
Initial loss of life	0 - 1000	Month	1	0	Initial value for winding insulation loss of life in months
Rated HS Temp rise	50.0 - 350.0	Deg C	1.0	80.0	Hotspot temperature rise over ambient at rated load
Rated TO Temp rise	50.0 - 350.0	Deg C	0.1	65.0	Top oil temperature rise over ambient at rated load
Current type test	0.01 - 2.00	pu	0.01	1.00	Current applied during type test to reach rated hotspot Temp
Ratio of losses	0.1 - 500000.0	-	0.1	25.0	Ratio of load losses at rated load to no-load losses
Oil exponent	0.10 - 10.00	-	0.01	0.10	User defined value for Oil exponent
Winding exponent	0.10 - 10.00	-	0.01	0.10	User defined value for Winding exponent
Constant K11	0.01 - 10.00	-	0.01	1.00	User defined value of thermal model constant K11
Constant K21	0.01 - 10.00	-	0.01	1.00	User defined value of thermal model constant K21
Constant K22	0.01 - 10.00	-	0.01	2.00	User defined value of thermal model constant K22
Oil time constant	1 - 20000	s	1	10800	user defined oil time constant in seconds
Winding Tm constant	1 - 20000	s	1	240	user defined winding time constant in seconds

7.2.9 Measured values

Table 1003: HSARSPTR Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0.0	RMS value of input current phase A
I_RMS_B	REAL	0.0	RMS value of input current phase B
I_RMS_C	REAL	0.0	RMS value of input current phase C
TOIL_TEMP	REAL	0.0	Measured top oil temperature
AMB_TEMP	REAL	0.0	Measured ambient temperature
BLOCK	BOOLEAN	0	Block all binary outputs
Table continues on next page			

Name	Type	Default	Description
TOIL_SNSFLT	BOOLEAN	0	Top oil temperature sensor fault status
AMB_SNSFLT	BOOLEAN	0	Ambient temperature sensor fault status
RESET	BOOLEAN	0	Reset loss of life calculation
RST_AVGAGING	BOOLEAN	0	Reset average ageing rate calculation

7.2.10 Monitored data

Table 1004: HSARSPTR Monitored data

Name	Type	Values (Range)	Unit	Description
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal
WARNING	BOOLEAN	0=FALSE 1=TRUE	-	Warning signal
ALM_AGE_RATE	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal for average ageing rate over set time period
HOTSPOT_TEMP	REAL	-	deg	Calculated value of hot spot temperature
TOPOIL_TEMP	REAL	-	deg	Calculated value of top oil temperature
LOSS_OF_LIFE	REAL	-	-	Loss of life in years
LD_RSV_WRN	REAL	-	%	Percentage load reserve for reaching warning condition
LD_RSV_ALM	REAL	-	%	Percentage load reserve for reaching alarm condition
AGEING_RATE	REAL	-	-	Momentary relative ageing rate
AVG_AGE_RATE	REAL	-	-	Average ageing rate over set time period

7.2.11 Technical data

Table 1005: HSARSPTR technical data

Characteristic	Value
Warning/alarm time accuracy	±1.0% of the set value or ±0.50 s

Section 8 Measurement functions

8.1 Basic measurements

8.1.1 Functions

The three-phase current measurement function CMMXU is used for monitoring and metering the phase currents of the power system.

The three-phase voltage measurement functions VPHMMXU and VPPMMXU are used for monitoring and metering the phase and line voltage of the power system.

The residual current measurement function RESCMMXU is used for monitoring and metering the residual current of the power system.

The residual voltage measurement function RESVMMXU is used for monitoring and metering the residual voltage of the power system.

The sequence current measurement CSMSQI is used for monitoring and metering the phase sequence currents.

The sequence voltage measurement VSMSQI is used for monitoring and metering the phase sequence voltages.

The three phase power measurement PWRMMXU is used for monitoring and metering the active power, reactive power, apparent power, power factor and the frequency. PWRMMXU calculates these quantities by using the fundamental frequency phasors, for example, the DFT values of the measured current and voltage signals.

The information of the measured quantity is available in the monitored data view on the LHMI or through tools via communication.

RESVMMXU has two outputs for the residual voltages. One corresponds to the true RMS value and the other is the fundamental component amplitude. The service value U0_RMS_DB provides the true RMS value. However, if a fundamental component with an angle is required, U0_MAG_DB and U0_ANGL_INST should be monitored.

8.1.2 Measurement functionality

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

Zero-point clamping

Each measured signal has a separate zero-point clamping function. The active clamping function forces the actual measurement value to zero if the measured value goes below the zero-point clamping limit. This helps in the elimination of the noise from the input signal.

Table 1006: Settings for the zero-point clamping

Function	Settings for zero clamping
Three phase current measurement (CMMXU)	*A Zer deadband PhA, A Zer deadband PhB* and *A zer deadband PhC*
Three phase voltage measurement (VPHMMXU)	*V Zer deadband PhA, V Zer deadband PhB* and *V Zer deadband PhC*
Three phase-to-phase voltage measurement (VPPMMXU)	*V Zer deadband PhAB, V Zer deadband PhBC* and *V Zer deadband PhCA*
Residual current measurement (RESCMMXU)	*A Zer deadband res*
Residual voltage measurement (RESVMMXU)	*V RMS deadband res* and *V Mag deadband res*
Phase sequence current measurement (CSMSQI)	*Ps Seq A Zero Db* and *Ng Seq A Zero Db*
Phase sequence voltage measurement (VSMSQI)	*Ps Seq V Zero Db* and *Ng Seq V Zero Db*
Three phase power measurement (PWRMMXU)	*Tot VA zero deadband, Tot W zero deadband, Tot VAr zeroDb, Av PF zero deadband* and *Hz zero deadband*

Example for CMMXU

A minimum PhA = 0.0 A

A maximum PhA = 500.0 A

A Zer deadband PhA = 500 m%

Zero-point clamping limit for phase A = (A maximum PhA - A minimum PhA) × A Zer deadband
= (500.0 - 0.0) × 0.005
= 2.5 A

Based on this setting, all measured currents below 2.5 A for phase A are forced to zero.

In PWRMMXU, the measured current and the voltage signals have a separate zero-point clamping function that forces these signal values to zero when the signal value goes below the value of the *current zero Db* setting or *voltage zero Db* setting. This avoids erroneous measurement when either current or voltage signal is not present. The measured values for P, Q, S and cosφ are automatically forced to zero when either the voltage or current measurement is forced to zero.

Limit value supervision

The limit value supervision indicates whether the measured signal exceeds or goes below the set limits. The supervision has two different modes of operation:

- Overfunction, when the measured input value exceeds the High limit or the High-high limit preset values.
- Underfunction, when the measured input value goes below the Low limit or Low-low limit preset values.

Table 1007: Settings for the limit value supervision

Function	Settings for limit value supervision	
Three phase current measurement (CMMXU)	High limit	*A high limit PhA, A high limit PhB* and *A high limit PhC*
	Low limit	*A low limit PhA, A low limit PhB* and *A low limit PhC*
	High-high limit	*A Hi high Lim PhA, A Hi high Lim PhB* and *A Hi high Lim PhC*
	Low-low limit	*A low low Lim, PhA, A low low Lim PhB* and *A low low Lim PhC*
Three phase voltage measurement (VPHMMXU)	High limit	*V high limit PhA, V high limit PhB* and *V high limit PhC*
	Low limit	*V low limit PhA, V low limit PhB* and *V low limit PhC*
	High-high limit	*V Hi high Lim PhA, V Hi high Lim PhB* and *V Hi high Lim PhC*
	Low-low limit	*V low low Lim PhA, V low low Lim PhB* and *V low low Lim PhC*
Three phase-to-phase voltage measurement (VPPMMXU)	High limit	*V high limit PhAB, V high limit PhBC* and *V high limit PhCA*
	Low limit	*V low limit PhAB, V low limit PhBC* and *V low limit PhCA*
	High-high limit	*V Hi high Lim PhAB, V Hi high Lim PhBC* and *V Hi high Lim PhCA*
	Low-low limit	*V low low Lim PhAB, V low low Lim PhBC* and *V low low Lim PhCA*
Residual current measurement (RESCMMXU)	High limit	*A high Lim res*
	Low limit	*A low Lim res*
	High-high limit	*A Hi high Lim res*
	Low-low limit	*A low low Lim res*
Table continues on next page		

Function	Settings for limit value supervision	
Residual voltage measurement (RESVMMXU)	High limit	*V RMS high Lim res* and *V Mag high Lim res*
	Low limit	*V RMS low Lim res* and *V Mag low Lim res*
	High-high limit	*V RMS Hi Hi Lim res* and *V Mag Hi Hi Lim res*
	Low-low limit	*V RMS Lo low res* and *V Mag Lo low Lim res*
Phase sequence current measurement (CSMSQI)	High limit	*PS Seq A high limit* and *Ng Seq A high limit*
	Low limit	*PS Seq A low limit* and *Ng Seq A low limit*
	High-high limit	*PS Seq A Hi high Lim* and *NGgSeq A Hi high Lim*
	Low-low limit	*PS Seq A low low Lim* and *Ng Seq A low low Lim*
Phase sequence voltage measurement (VSMSQI)	High limit	*PS Seq V high limit* and *Ng Seq V high limit*
	Low limit	*PS Seq V low limit* and *Ng Seq V low limit*
	High-high limit	*PS Seq V Hi high Lim* and *Ng Seq V Hi high Lim*
	Low-low limit	*PS Seq V low low Lim* and *Ng Seq V low low Lim*
Three phase power measurement (PWRMMXU)	High limit	*Tot VA high limit, Tot W high limit, Tot VAr high limit, Av PF high limit* and *Hz high limit*
	Low limit	*Tot VA low limit, Tot W low limit, Tot VAr low limit* and *Hz low limit*
	High-high limit	*Tot VA high high Lim, Tot W high high Lim, Tot VAr high high Lim, Av PF high high Lim* and *Hz high high limit*
	Low-low limit	*Tot VA low low limit, Tot W low low limit, Tot VAr low low limit, Av PF low low limit* and *Hz low low limit*

Each analog output has one corresponding supervision level output (X_RANGE). The output signal is an integer in the range of zero to four (0: Normal, 1: High limit exceeded, 2: below Low limit, 3: High-high limit exceeded, and 4: below Low-low limit).

The logical value of the functional output signal changes as shown in the diagram.

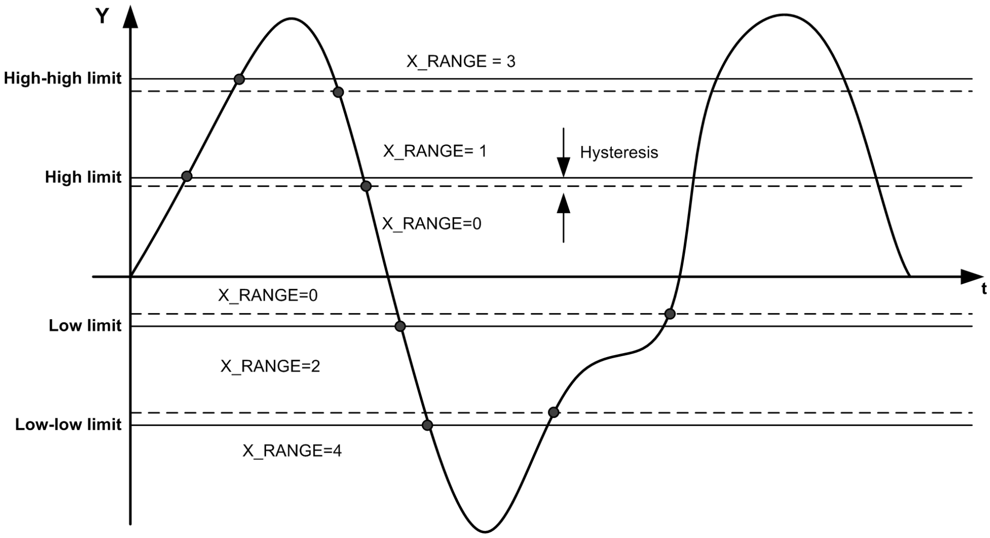


Figure 530: Presentation of the operating limits

The hysteresis determines the difference between the operating and the reset value at each operating point in a wide range for each measuring channel separately. The hysteresis is common for all operating values within one channel or measurement parameter.

Since the limit hysteresis settings are in percentage of the full range, defined by the maximum and minimum settings, the maximum, minimum and limit hysteresis setting values need to be carefully considered in accordance with the limit setting values, so that they do not lead to a too big hysteresis, which may result in an erroneous operating limit indication.

Table 1008: Settings for hysteresis-deciding operating limits

Function	Settings for hysteresis-deciding operating limits
Three phase current measurement (CMMXU)	*A limit Hys PhA, A limit Hys PhB* and *A limit Hys PhC*
Three phase voltage measurement (VPHMMXU)	*V limit Hys PhA, V limit Hys PhB* and *V limit Hys PhC*
Three phase-to-phase voltage measurement (VPPMMXU)	*V limit Hys PhAB, V limit Hys PhBC* and *V limit Hys PhCA*
Residual current measurement (RESCMMXU)	*A limit Hys res*
Residual voltage measurement (RESVMMXU)	*V RMS limit Hys res* and *V Mag limit Hys*
Table continues on next page	

Function	Settings for hysteresis-deciding operating limits
Phase sequence current measurement (CSMSQI)	*Ps Seq A limit Hys* and *Ng Seq A limit Hys*
Phase sequence voltage measurement (VSMSQI)	*Ps Seq V limit Hys* and *Ng Seq V limit Hys*
Three phase power measurement (PWRMMXU)	*Tot VA limit Hys, Tot W limit Hys, Tot VAr limit Hys , Av PF limit Hys* and *Hz limit hysteresis*

Actual value of the measured quantity

The actual value of the measured quantity is available locally and remotely. The measurement is continuous for each of the separately measured quantity. The reporting of the newer value depends on the selected reporting mode available. There are three basic reporting modes available:

- Cyclic reporting (Cyclic)
- Amplitude deadband reporting (Deadband)
- Integral deadband reporting (Int deadband)

Table 1009: Settings for the reporting mode

Functions	Settings for the reporting mode
Three phase current measurement (CMMXU)	*A Db type PhA, A Db type PhB* and *A Db type PhC*
Three phase voltage measurement (VPHMMXU)	*V Db type PhA, V Db type PhB* and *V Db type PhC*
Three phase-to-phase voltage measurement (VPPMMXU)	*V Db type PhAB, V Db type PhBC* and *V Db type PhCA*
Residual current measurement (RESCMMXU)	*A Db type res*
Residual voltage measurement (RESVMMXU)	*V RMS Db type res* and *V Mag Db type res*
Phase sequence current measurement (CSMSQI)	*Ps Seq A db type* and *Ng Seq A db type*
Phase sequence voltage measurement (VSMSQI)	*Ps Seq V db type* and *Ng Seq V db type*
Three phase power measurement (PWRMMXU)	*Tot VA deadband type, Tot W deadband type, Tot VAr Db type, Av PF deadband type* and *Hz deadband type*

Cyclic reporting

In cyclic reporting, the function gives a new value when the deadband time has elapsed.

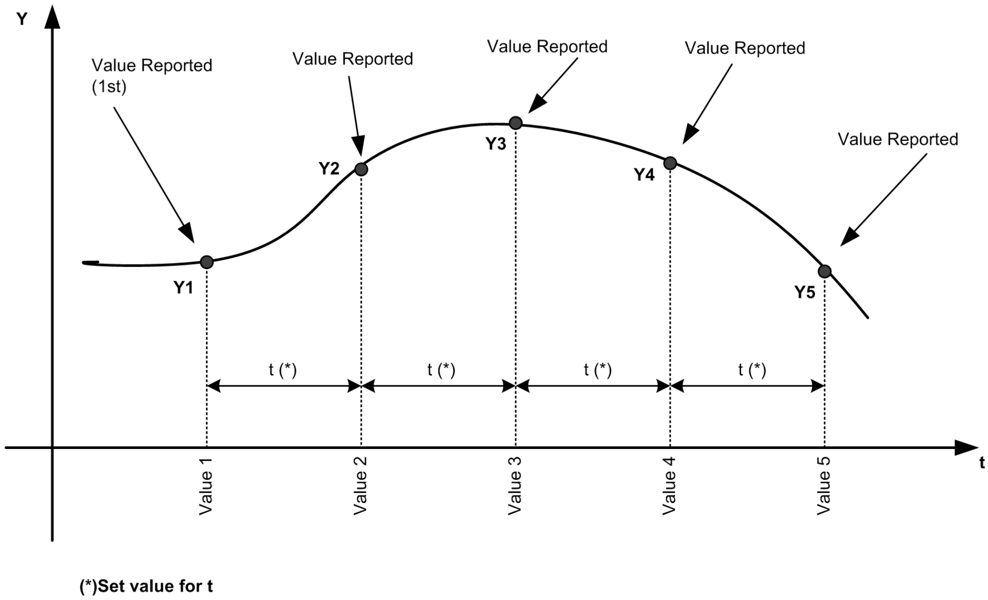


Figure 531: Cyclic reporting

Amplitude deadband reporting

In the amplitude deadband reporting mode, a new value is reported when the measured quantity changes more than the defined set limits (±ΔY).

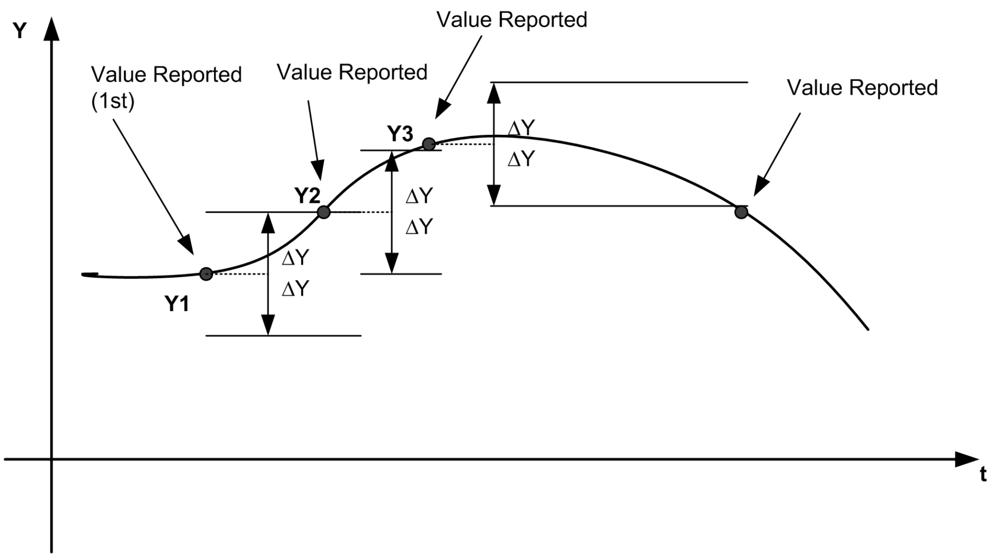


Figure 532: An example of amplitude deadband supervision reporting

This type of reporting limits the information flow to a minimum necessity.

Integral deadband reporting

In the integral reporting mode, the measured value is reported if the time integral of all changes exceeds the set limits.

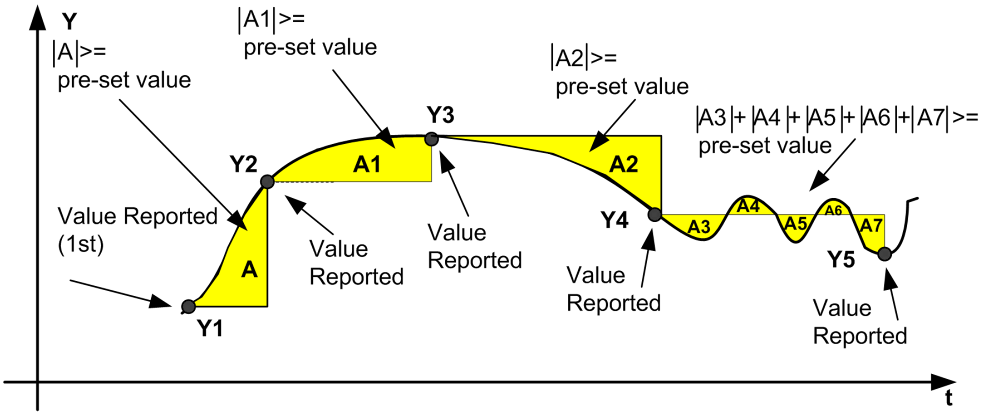


Figure 533: Integral deadband supervision reporting

The integral deadband supervision is particularly suitable for monitoring signals with small variations that can last for relatively long periods

Deadband is a common setting and its unit depends upon the "Type" of reporting mode selected:

- time (s) in case of cyclic reporting
- amplitude ±ΔY (% of range) in case of amplitude reporting
- time integral (%s) in case of time integral reporting.

The function takes into consideration whether the setting involved in the *X deadband* setting is for cyclic reporting, amplitude deadband or integral deadband depending on the reporting mode settings.

Table 1010: Settings for deadband

Functions	Settings for deadband
Three phase current measurement (CMMXU)	*A deadband PhA, A deadband PhB* and *A deadband PhC*
Three phase voltage measurement (VPHMMXU)	*V deadband PhA, V deadband PhB* and *V deadband PhC*
Three phase-to-phase voltage measurement (VPPMMXU)	*V deadband PhAB, V deadband PhBC* and *V deadband PhCA*
Residual current measurement (RESCMMXU)	*A deadband res*
Residual voltage measurement (RESVMMXU)	*V RMS deadband res* and *V Mag deadband res*

Table continues on next page

Functions	Settings for deadband
Phase sequence current measurement (CSMSQI)	*Ps Seq A deadband* and *Ng Seq A deadband*
Phase sequence voltage measurement (VSMSQI)	*Ps Seq V deadband* and *Ng Seq V deadband*
Three phase power measurement (PWRMMXU)	*Tot VA deadband, Tot W deadband, Tot VAr deadband, Av PF deadband* and *Hz deadband*

Measurement mode

The power measurement function is capable of calculating complex power quantities in nine different ways, depending on the availability of the transformer inputs connected to the IED. One of the ways can be selected with the *Measurement mode* setting.

Table 1011: Complex power calculation for different measurement mode

Measurement mode setting	Formula used for complex three-phase power calculation	Comment
PhsA, PhsB, PhsC	$\overline{S} = \overline{U}_A \times \overline{I_B}^* + \overline{U}_B \times \overline{I_B}^* + \overline{U}_C \times \overline{I_C}^*$	Used when three phase to earth voltages are available
Arone	$\overline{S} = (\overline{U}_{AB} \times \overline{I}_A^* - \overline{U}_{BC} \times \overline{I}_C^*)$	Used when two phase to phase voltages are available
Pos Seq	$\overline{S} = 3 \times \overline{U}_{PosSeq} \times \overline{I}_{PosSeq}^*$	Used only when the symmetrical three-phase power needs to be measured
PhsAB	$\overline{S} = \overline{U}_{AB} \times (\overline{I}_A^* - \overline{I}_B^*)$	Used only when the U_{AB} voltage is available
PhsBC	$\overline{S} = \overline{U}_{BC} \times (\overline{I}_B^* - \overline{I}_C^*)$	Used only when the U_{BC} voltage is available
PhsCA	$\overline{S} = \overline{U}_{CA} \times (\overline{I}_C^* - \overline{I}_A^*)$	Used only when the U_{CA} voltage is available
PhsA	$\overline{S} = 3 \times \overline{U}_A \times \overline{I}_A^*$	Used only when the U_{AN} voltage is available
PhsB	$\overline{S} = 3 \times \overline{U}_A \times \overline{I}_A^*$	Used only when the U_{BN} voltage is available
PhsC	$\overline{S} = 3 \times \overline{U}_A \times \overline{I}_A^*$	Used only when the U_{CN} voltage is available
* indicates that it is the complex conjugate		

In the first two measurement modes, the measurement function calculates the three-phase power. In other operating modes, it calculates the three-phase power under the assumption that the power system is fully symmetrical.

Once the complex apparent power is calculated, P, Q, S and Cosϕ are calculated as shown in the equations.

$$P = \mathrm{Re}(\overline{S})$$

(Equation 173)

$$Q = \mathrm{Im}(\overline{S})$$

(Equation 174)

$$S = \left|\overline{S}\right| = \sqrt{P^2 + Q^2}$$

(Equation 175)

$$Cos\phi = \frac{P}{S}$$

(Equation 176)

In addition to the power factor value, two binary output signals are provided. This provides the angular relationship between the current and voltage phasors. The `ILAG` output is set high when the current phasor is lagging the voltage phasor. Similarly, `ILEAD` is set high when the current phasor is leading the voltage phasor.

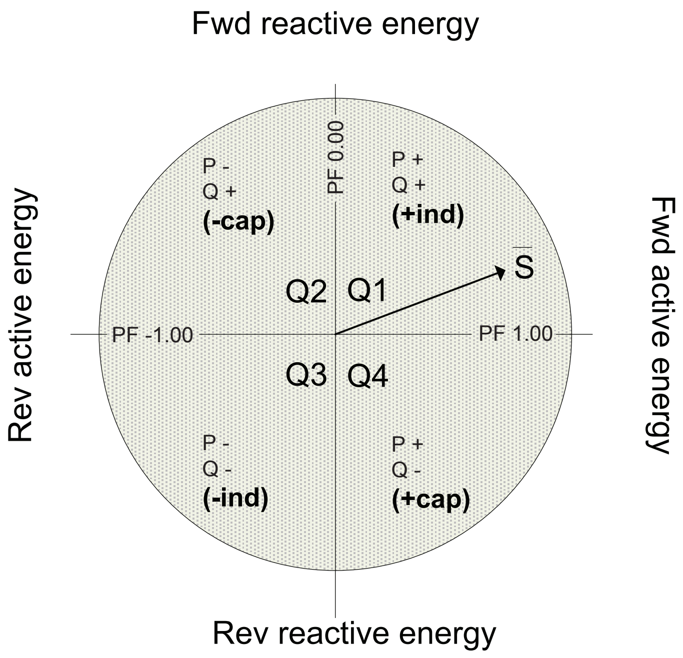


Figure 534: Complex power and power quadrants

Table 1012: Power quadrants

Quadrant	Current	P	Q	PF	Power
Q1	Lagging	+	+	0...+1.00	+ind
Q2	Lagging	–	+	0...-1.00	-cap
Q3	Leading	–	–	0...-1.00	-ind
Q4	Leading	+	-	0...+1.00	+cap

Low-pass filtering

To minimize the influence of the noise signal on the measurement, the recursive low-pass filtering of the P, Q, S and Cosφ measured values can be introduced. This makes the measurement response slower to the step changes in the measured quantity. The filtering is performed in accordance with the recursive formula:

$$X = k \times X_{old} + (1 - k) \times X_{calculated}$$

(Equation 177)

X	new measured value that needs to be represented as an output for example, P, Q, S or Cosφ
X_{old}	measured value of the previous execution cycle
$X_{calculated}$	new calculated value in the present execution cycle
k	set *relation constant*, which influences the filter properties

The default value for the *relation constant* k is zero. The new calculated value is given out without any filtering with this value k. When the value k is set above 0.00, filtering is enabled and the appropriate value k is determined separately for all applications.

8.1.3 Measurement function applications

The measurement functions are used for power system measurement, supervision and reporting to LHMI, a monitoring tool within PCM600 or to the station level, for example, via IEC 61850. The continuous monitoring of the measured values, for example active power, reactive power, currents, voltages, frequency and power factors, is vital for the efficient production, transmission and distribution of electrical energy. It provides a fast and easy overview of the present status of the power system to the system operator. Additionally, it can be used during the testing and the commissioning of protection and control functions to verify the proper operation and connection of instrument transformers, that is the CTs and VTs. The proper operation of the IED analog measurement chain can be verified during the normal service by a periodic comparison of the measured value from IED to the other independent meters.

When the zero signal is measured, the noise in the input signal can still produce small measurement values. The zero point clamping function can be used to ignore the noise in the input signal and hence, to prevent the noise getting displayed in the user display. Zero clamping is done for the measured analog signals and angle values.

The limit supervision indicates whether the measured signal has exceeded or gone below the set limits by activating the alarm or warning outputs of the function. These outputs can be used to configure the reporting function (events). The supervision function has four different limits:

- low alarm limit
- low warning limit
- high warning limit
- high alarm limit

The dead band supervision can be used to report the measured signal value to the station level when change in the measured value is above the set threshold limit or time integral of all the changes since, the last time value exceeding the threshold limit. The measured value can also be based on periodic reporting where the measured value is available for reporting as it is without performing any preprocesses.

The measuring functions CMMXU, VPHMMXU and VPPMMXU provide the physical quantities:

- I : magnitude of phase currents (CMMXU)
- I_{angle} : angle of phase currents (CMMXU)
- U: magnitude of phase and the phase-to-phase voltages (VPPMMXU, VPHMMXU)
- U_{angle} : angle of phase and phase-to-phase voltages (VPPMMXU, VPHMMXU)

The measuring functions RESCMMXU and RESVMMXU provide the residual quantities:

- I0 : magnitude of residual current (RESCMMXU)
- $I0_{angle}$: angle of residual current (RESCMMXU)
- U0 : magnitude of residual voltage (RESVMMXU)
- $U0_{angle}$: angle of the residual voltage (RESVMMXU)

The measuring functions CSMSQI and VSMSQI provides the sequence quantities:

- I1, I2 : magnitude of positive and negative sequence currents (CSMSQI)
- U1, U2 : magnitude of positive and negative sequence voltages (VSMSQI)

The measuring function PWRMMXU provides the power quantities:

- P, Q and S: three phase active, reactive and apparent power
- Cosφ : power factor
- f : power system frequency

8.1.4 Three-phase current CMMXU

8.1.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase current measurement	CMMXU	3I	3I

8.1.4.2 Function block

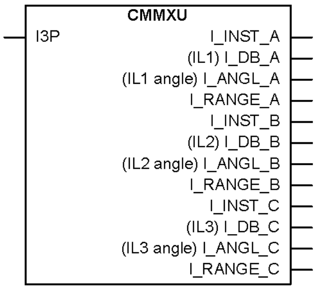


Figure 535: Function block

8.1.4.3 Signals

Table 1013: CMMXU Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs

Table 1014: CMMXU Output signals

Name	Type	Description
I_INST_A	REAL	Phase A amplitude, magnitude of instantaneous value
I_DB_A	REAL	Phase A amplitude, magnitude of reported value
I_ANGL_A	REAL	Phase A angle, instantaneous value
I_RANGE_A	INTEGER	Phase A amplitude range
I_INST_B	REAL	Phase B amplitude, magnitude of instantaneous value
I_DB_B	REAL	Phase B amplitude, magnitude of reported value
I_ANGL_B	REAL	Phase B angle, instantaneous value
I_RANGE_B	INTEGER	Phase B amplitude range
I_INST_C	REAL	Phase C amplitude, magnitude of instantaneous value
I_DB_C	REAL	Phase C amplitude, magnitude of reported value
I_ANGL_C	REAL	Phase C angle, instantaneous value
I_RANGE_C	INTEGER	Phase C amplitude range

8.1.4.4 Settings

Table 1015: CMMXU Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On / Off
A deadband PhA	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
A Hi high Lim PhA	0.0 - 100000.0	A	0.1	500.0	High High limit (physical value)
A high limit PhA	0.0 - 100000.0	A	0.1	400.0	High limit (physical value)
A low limit PhA	0.0 - 100000.0	A	0.1	0.0	Low limit (physical value)
A low low Lim PhA	0.0 - 100000.0	A	0.1	0.0	Low Low limit (physical value)
A minimum PhA	0.0 - 100000.0	A	0.1	0.0	Minimum value
A maximum PhA	0.0 - 100000.0	A	0.1	500.0	Maximum value
A Db type PhA	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
A deadband PhB	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
A Hi high Lim PhB	0.0 - 100000.0	A	0.1	500.0	High High limit (physical value)
A high limit PhB	0.0 - 100000.0	A	0.1	400.0	High limit (physical value)
A low limit PhB	0.0 - 100000.0	A	0.1	0.0	Low limit (physical value)
A low low Lim PhB	0.0 - 100000.0	A	0.1	0.0	Low Low limit (physical value)
A minimum PhB	0.0 - 100000.0	A	0.1	0.0	Minimum value
A maximum PhB	0.0 - 100000.0	A	0.1	500.0	Maximum value
A Db type PhB	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
A deadband PhC	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
A Hi high Lim PhC	0.0 - 100000.0	A	0.1	500.0	High High limit (physical value)
A high limit PhC	0.0 - 100000.0	A	0.1	400.0	High limit (physical value)
A low limit PhC	0.0 - 100000.0	A	0.1	0.0	Low limit (physical value)
A low low Lim PhC	0.0 - 100000.0	A	0.1	0.0	Low Low limit (physical value)
A minimum PhC	0.0 - 100000.0	A	0.1	0.0	Minimum value
A maximum PhC	0.0 - 100000.0	A	0.1	500.0	Maximum value
A Db type PhC	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type

Table 1016: CMMXU Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
A Zer deadband PhA	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
A limit Hys PhA	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits
A Zer deadband PhB	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
A limit Hys PhB	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits
A Zer deadband PhC	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
A limit Hys PhC	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits

8.1.4.5 Monitored data

Table 1017: CMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
I_INST_A	REAL	-	A	Phase A amplitude, magnitude of instantaneous value
I_DB_A	REAL	-	A	Phase A amplitude, magnitude of reported value
I_ANGL_A	REAL	-	deg	Phase A angle, instantaneous value
I_RANGE_A	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Phase A amplitude range
I_INST_B	REAL	-	A	Phase B amplitude, magnitude of instantaneous value
I_DB_B	REAL	-	A	Phase B amplitude, magnitude of reported value
I_ANGL_B	REAL	-	deg	Phase B angle, instantaneous value
I_RANGE_B	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Phase B amplitude range
I_INST_C	REAL	-	A	Phase C amplitude, magnitude of instantaneous value
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
I_DB_C	REAL	-	A	Phase C amplitude, magnitude of reported value
I_ANGL_C	REAL	-	deg	Phase C angle, instantaneous value
I_RANGE_C	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Phase C amplitude range

8.1.4.6 Technical data

Table 1018: CMMXU Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±0.5% or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.5 Three-phase voltage VPHMMXU

8.1.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase voltage measurement function	VPHMMXU	$3U_{pe}$	$3U_{pe}$

8.1.5.2 Function block

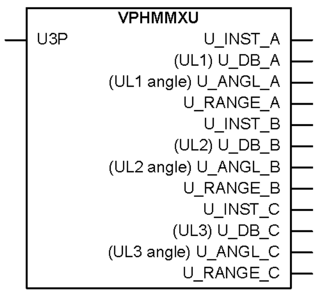


Figure 536: Function block

8.1.5.3 Signals

Table 1019: VPHMMXU Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs

Table 1020: VPHMMXU Output signals

Name	Type	Description
U_INST_A	REAL	Phase A amplitude, magnitude of instantaneous value
U_DB_A	REAL	Phase A amplitude, magnitude of reported value
U_ANGL_A	REAL	Phase A angle
U_RANGE_A	INTEGER	Phase A amplitude range
U_INST_B	REAL	Phase B amplitude, magnitude of instantaneous value
U_DB_B	REAL	Phase B amplitude, magnitude of reported value
U_ANGL_B	REAL	Phase B angle
U_RANGE_B	INTEGER	Phase B amplitude range
U_INST_C	REAL	Phase C amplitude, magnitude of instantaneous value
U_DB_C	REAL	Phase C amplitude, magnitude of reported value
U_ANGL_C	REAL	Phase C angle
U_RANGE_C	INTEGER	Phase C amplitude range

8.1.5.4 Settings

Table 1021: VPHMMXU Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On / Off
V deadband PhA	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
V Hi high Lim PhA	0 - 1000000	V	1	12990	High High limit (physical value)
V high limit PhA	0 - 1000000	V	1	12125	High limit (physical value)
V low limit PhA	0 - 1000000	V	1	0	Low limit (physical value)
V low low Lim PhA	0 - 1000000	V	1	0	Low Low limit (physical value)
V minimum PhA	0 - 1000000	V	1	0	Minimum value
V maximum PhA	0 - 1000000	V	1	15000	Maximum value
V Db type PhA	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
V deadband PhB	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
V Hi high Lim PhB	0 - 1000000	V	1	12990	High High limit (physical value)
V high limit PhB	0 - 1000000	V	1	12125	High limit (physical value)
V low limit PhB	0 - 1000000	V	1	0	Low limit (physical value)
V low low Lim PhB	0 - 1000000	V	1	0	Low Low limit (physical value)
V minimum PhB	0 - 1000000	V	1	0	Minimum value
V maximum PhB	0 - 1000000	V	1	15000	Maximum value
V Db type PhB	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
V deadband PhC	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
V Hi high Lim PhC	0 - 1000000	V	1	12990	High High limit (physical value)
V high limit PhC	0 - 1000000	V	1	12125	High limit (physical value)
V low limit PhC	0 - 1000000	V	1	0	Low limit (physical value)
V low low Lim PhC	0 - 1000000	V	1	0	Low Low limit (physical value)
V minimum PhC	0 - 1000000	V	1	0	Minimum value
V maximum PhC	0 - 1000000	V	1	15000	Maximum value
V Db type PhC	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type

Table 1022: VPHMMXU Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
V Zer deadband PhA	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
V limit Hys PhA	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits
V Zer deadband PhB	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
V limit Hys PhB	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits
V Zer deadband PhC	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
V limit Hys PhC	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits

8.1.5.5 Monitored data

Table 1023: VPHMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
U_INST_A	REAL	-	kV	Phase A amplitude, magnitude of instantaneous value
U_DB_A	REAL	-	kV	Phase A amplitude, magnitude of reported value
U_ANGL_A	REAL	-	deg	Phase A angle
U_RANGE_A	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Phase A amplitude range
U_INST_B	REAL	-	kV	Phase B amplitude, magnitude of instantaneous value
U_DB_B	REAL	-	kV	Phase B amplitude, magnitude of reported value
U_ANGL_B	REAL	-	deg	Phase B angle
U_RANGE_B	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Phase B amplitude range
U_INST_C	REAL	-	kV	Phase C amplitude, magnitude of instantaneous value
U_DB_C	REAL	-	kV	Phase C amplitude, magnitude of reported value
U_ANGL_C	REAL	-	deg	Phase C angle
U_RANGE_C	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Phase C amplitude range

8.1.5.6 Technical data

Table 1024: VPHMMXU Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±0.5% or ±0.002 × U_n (at voltages in the range of 0.01...1.15 × U_n)
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.6 Three-phase voltage VPPMMXU

8.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase voltage measurement function	VPPMMXU	$3U_{pp}$	$3U_{pp}$

8.1.6.2 Function block

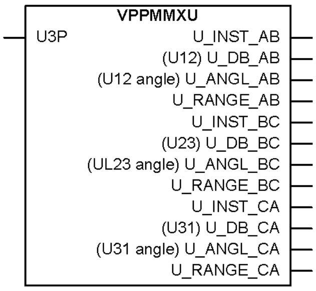


Figure 537: Function block

8.1.6.3 Signals

Table 1025: VPPMMXU Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs

Table 1026: VPPMMXU Output signals

Name	Type	Description
U_INST_AB	REAL	Phase A to B amplitude, magnitude of instantaneous value
U_DB_AB	REAL	Phase A to B amplitude, magnitude of reported value
U_ANGL_AB	REAL	Phase A to B angle
U_RANGE_AB	INTEGER	Phase A to B amplitude range
U_INST_BC	REAL	Phase B to C amplitude, magnitude of instantaneous value
U_DB_BC	REAL	Phase B to C amplitude, magnitude of reported value
U_ANGL_BC	REAL	Phase B to C angle
U_RANGE_BC	INTEGER	Phase B to C amplitude range
Table continues on next page		

Name	Type	Description
U_INST_CA	REAL	Phase C to A amplitude, magnitude of instantaneous value
U_DB_CA	REAL	Phase C to A amplitude, magnitude of reported value
U_ANGL_CA	REAL	Phase C to A angle
U_RANGE_CA	INTEGER	Phase C to A amplitude range

8.1.6.4 Settings

Table 1027: VPPMMXU Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On / Off
V deadband PhAB	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
V Hi high Lim PhAB	0 - 1000000	V	1	22500	High High limit (physical value)
V high limit PhAB	0 - 1000000	V	1	21000	High limit (physical value)
V low limit PhAB	0 - 1000000	V	1	0	Low limit (physical value)
V low low Lim PhAB	0 - 1000000	V	1	0	Low Low limit (physical value)
V minimum PhAB	0 - 1000000	V	1	0	Minimum value
V maximum PhAB	0 - 1000000	V	1	25000	Maximum value
V Db type PhAB	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
V deadband PhBC	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
V Hi high Lim PhBC	0 - 1000000	V	1	22500	High High limit (physical value)
V high limit PhBC	0 - 1000000	V	1	21000	High limit (physical value)
V low limit PhBC	0 - 1000000	V	1	0	Low limit (physical value)
V low low Lim PhBC	0 - 1000000	V	1	0	Low Low limit (physical value)
V minimum PhBC	0 - 1000000	V	1	0	Minimum value
V maximum PhBC	0 - 1000000	V	1	25000	Maximum value
V Db type PhBC	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
V deadband PhCA	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
V Hi high Lim PhCA	0 - 1000000	V	1	22500	High High limit (physical value)
V high limit PhCA	0 - 1000000	V	1	21000	High limit (physical value)
V low limit PhCA	0 - 1000000	V	1	0	Low limit (physical value)
V low low Lim PhCA	0 - 1000000	V	1	0	Low Low limit (physical value)

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
V minimum PhCA	0 - 1000000	V	1	0	Minimum value
V maximum PhCA	0 - 1000000	V	1	25000	Maximum value
V Db type PhCA	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type

Table 1028: VPPMMXU Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
V Zer deadband PhAB	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
V limit Hys PhAB	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits
V Zer deadband PhBC	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
V limit Hys PhBC	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits
V Zer deadband PhCA	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
V limit Hys PhCA	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits

8.1.6.5 Monitored data

Table 1029: VPPMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
U_INST_AB	REAL	-	kV	Phase A to B amplitude, magnitude of instantaneous value
U_DB_AB	REAL	-	kV	Phase A to B amplitude, magnitude of reported value
U_ANGL_AB	REAL	-	deg	Phase A to B angle
U_RANGE_AB	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Phase A to B amplitude range
U_INST_BC	REAL	-	kV	Phase B to C amplitude, magnitude of instantaneous value
U_DB_BC	REAL	-	kV	Phase B to C amplitude, magnitude of reported value
U_ANGL_BC	REAL	-	deg	Phase B to C angle
U_RANGE_BC	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Phase B to C amplitude range

Table continues on next page

Name	Type	Values (Range)	Unit	Description
U_INST_CA	REAL	-	kV	Phase C to A amplitude, magnitude of instantaneous value
U_DB_CA	REAL	-	kV	Phase C to A amplitude, magnitude of reported value
U_ANGL_CA	REAL	-	deg	Phase C to A angle
U_RANGE_CA	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Phase C to A amplitude range

8.1.6.6 Technical data

Table 1030: VPPMMXU Technical data

Characteristic	Value
Operation accuracy	At the frequency f = f_n
	±0.5% or ±0.002 × U_n (at voltages in the range of 0.01...1.15 × U_n)
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.7 Residual current RESCMMXU

8.1.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual current measurement	RESCMMXU	I0	I0

8.1.7.2 Function block

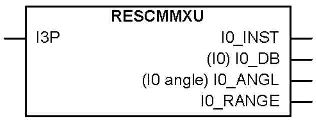


Figure 538: Function block

8.1.7.3 Signals

Table 1031: RESCMMXU Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs

Table 1032: RESCMMXU Output signals

Name	Type	Description
I0_INST	REAL	Residual current RMS, magnitude of instantaneous value
I0_DB	REAL	Residual current RMS, magnitude of reported value
I0_ANGL	REAL	Residual current angle
I0_RANGE	INTEGER	Residual current RMS range

8.1.7.4 Settings

Table 1033: RESCMMXU Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On / Off
A deadband res	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
A Hi high Lim res	0.0 - 100000.0	A	0.1	15.0	High High limit (physical value)
A high limit res	0.0 - 100000.0	A	0.1	5.0	High limit (physical value)
A low limit res	0.0 - 100000.0	A	0.1	0.0	Low limit (physical value)
A low low Lim res	0.0 - 100000.0	A	0.1	0.0	Low Low limit (physical value)
A minimum res	0.0 - 100000.0	A	0.1	0.0	Minimum value
A maximum res	0.0 - 100000.0	A	0.1	70.0	Maximum value
A Db type res	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type

Table 1034: RESCMMXU Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
A Zer deadband res	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
A limit Hys res	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits

8.1.7.5 Monitored data

Table 1035: RESCMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
I0_INST	REAL	-	A	Residual current RMS, magnitude of instantaneous value
I0_DB	REAL	-	A	Residual current RMS, magnitude of reported value
I0_ANGL	REAL	-	deg	Residual current angle
I0_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Residual current RMS range

8.1.7.6 Technical data

Table 1036: RESCMMXU Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±0.5% or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.8 Residual voltage RESVMMXU

8.1.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual voltage measurement	RESVMMXU	U0	U0

8.1.8.2 Function block

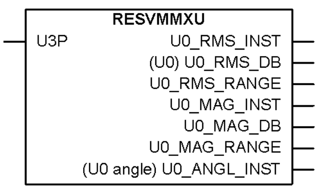


Figure 539: Function block

8.1.8.3 Signals

Table 1037: RESVMMXU Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs

Table 1038: RESVMMXU Output signals

Name	Type	Description
U0_RMS_INST	REAL	U0 RMS, magnitude of instantaneous value
U0_RMS_DB	REAL	U0 RMS, magnitude of reported value
U0_RMS_RANGE	INTEGER	U0 RMS range
U0_MAG_INST	REAL	U0 Amplitude, magnitude of instantaneous value
U0_MAG_DB	REAL	U0 Amplitude, magnitude of reported value
U0_MAG_RANGE	INTEGER	U0 Amplitude range
U0_ANGL_INST	REAL	U0 angle, instantaneous value

8.1.8.4 Settings

Table 1039: RESVMMXU Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On / Off
V RMS deadband res	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
V RMS Hi Hi Lim res	0 - 1000000	V	1	1154	High High limit (physical value)
V RMS high Lim res	0 - 1000000	V	1	577	High limit (physical value)
V RMS low limit res	0 - 1000000	V	1	0	Low limit (physical value)
V RMS Lo low Lim res	0 - 1000000	V	1	0	Low Low limit (physical value)
V RMS minimum res	0 - 1000000	V	1	0	Minimum value
V RMS maximum res	0 - 1000000	V	1	15000	Maximum value
V RMS Db type res	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
V Mag deadband res	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
V Mag Hi Hi Lim res	0 - 1000000	V	1	1154	High High limit (physical value)
V Mag high Lim res	0 - 1000000	V	1	577	High limit (physical value)
V Mag low limit res	0 - 1000000	V	1	0	Low limit (physical value)
V Mag Lo low Lim res	0 - 1000000	V	1	0	Low Low limit (physical value)

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
V Mag minimum res	0 - 1000000	V	1	0	Minimum value
V Mag maximum res	0 - 1000000	V	1	15000	Maximum value
V Mag Db type res	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type

Table 1040: RESVMMXU Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
V RMS zero db res	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
V RMS limit Hys res	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits
V Mag zero db res	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
V Mag limit Hys res	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits

8.1.8.5 Monitored data

Table 1041: RESVMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
U0_RMS_INST	REAL	-	kV	U0 RMS, magnitude of instantaneous value
U0_RMS_DB	REAL	-	kV	U0 RMS, magnitude of reported value
U0_RMS_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	U0 RMS range
U0_MAG_INST	REAL	-	kV	U0 Amplitude, magnitude of instantaneous value
U0_MAG_DB	REAL	-	kV	U0 Amplitude, magnitude of reported value
U0_MAG_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	U0 Amplitude range
U0_ANGL_INST	REAL	-	deg	U0 angle, instantaneous value

8.1.8.6 Technical data

Table 1042: RESVMMXU Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±0.5% or ±0.002 × U_n
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.9 Sequence current CSMSQI

8.1.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase sequence current	CSMSQI	I1, I2	I1, I2

8.1.9.2 Function block

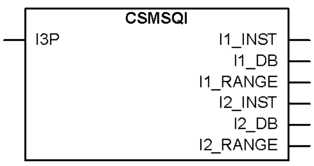


Figure 540: Function block

8.1.9.3 Signals

Table 1043: CSMSQI Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs

Table 1044: CSMSQI Output signals

Name	Type	Description
I1_INST	REAL	Positive sequence current amplitude, instantaneous value
I1_DB	REAL	Positive sequence current amplitude, reported value
I1_RANGE	INTEGER	Positive sequence current amplitude range
Table continues on next page		

Name	Type	Description
I2_INST	REAL	Negative sequence current amplitude, instantaneous value
I2_DB	REAL	Negative sequence current amplitude, reported value
I2_RANGE	INTEGER	Negative sequence current amplitude range

8.1.9.4 Settings

Table 1045: CSMSQI Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On / Off
Ps Seq A deadband	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
Ps Seq A Hi high Lim	0.0 - 100000.0	A	0.1	500.0	High High limit (physical value)
Ps Seq A high limit	0.0 - 100000.0	A	0.1	400.0	High limit (physical value)
Ps Seq A low limit	0.0 - 100000.0	A	0.1	0.0	Low limit (physical value)
Ps Seq A low low Lim	0.0 - 100000.0	A	0.1	0.0	Low Low limit (physical value)
Ps Seq current Min	0.0 - 100000.0	A	0.1	0.0	Minimum value
Ps Seq current Max	0.0 - 100000.0	A	0.1	500.0	Maximum value
Ps Seq A db type	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
Ng Seq A deadband	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
Ng Seq A Hi high Lim	0.0 - 100000.0	A	0.1	100.0	High High limit (physical value)
Ng Seq A high limit	0.0 - 100000.0	A	0.1	50.0	High limit (physical value)
Ng Seq A low limit	0.0 - 100000.0	A	0.1	0.0	Low limit (physical value)
Ng Seq A low low Lim	0.0 - 100000.0	A	0.1	0.0	Low Low limit (physical value)
Ng Seq current Min	0.0 - 100000.0	A	0.1	0.0	Minimum value
Ng Seq current Max	0.0 - 100000.0	A	0.1	500.0	Maximum value
Ng Seq A db type	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type

Table 1046: CSMSQI Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Ps Seq A zero Db	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
Ps Seq A limit Hys	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits
Ng Seq A zero Db	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
Ng Seq A limit Hys	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits

8.1.9.5 Monitored data

Table 1047: CSMSQI Monitored data

Name	Type	Values (Range)	Unit	Description
I1_INST	REAL	-	A	Positive sequence current amplitude, instantaneous value
I1_DB	REAL	-	A	Positive sequence current amplitude, reported value
I1_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Positive sequence current amplitude range
I1_ANGL_INST	REAL	-	deg	Positive sequence current angle, instantaneous value
I2_INST	REAL	-	A	Negative sequence current amplitude, instantaneous value
I2_DB	REAL	-	A	Negative sequence current amplitude, reported value
I2_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Negative sequence current amplitude range
I2_ANGL_INST	REAL	-	deg	Negative sequence current angle, instantaneous value

8.1.9.6 Technical data

Table 1048: CSMSQI Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.0% or ±0.002 × I_n at currents in the range of 0.01...4.00 × I_n
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

8.1.9.7 Technical revision history

Table 1049: CSMSQI technical revision history

Technical revision	Change
B	Mapped the unused data attributes for zero sequence to have their time quality fixed
C	Internal improvements

8.1.10 Sequence voltage VSMSQI

8.1.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase sequence voltage	VSMSQI	U1, U2	U1, U2

8.1.10.2 Function block

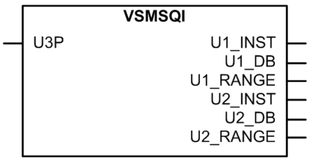


Figure 541: Function block

8.1.10.3 Signals

Table 1050: VSMSQI Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs

Table 1051: VSMSQI Output signals

Name	Type	Description
U1_INST	REAL	Positive sequence voltage amplitude, instantaneous value
U1_DB	REAL	Positive sequence voltage amplitude, reported value
U1 RANGE	INTEGER	Positive sequence voltage amplitude range
U2_INST	REAL	Negative sequence voltage amplitude, instantaneous value
U2_DB	REAL	Negative sequence voltage amplitude, reported value
U2_RANGE	INTEGER	Negative sequence voltage amplitude range

8.1.10.4 Settings

Table 1052: VSMSQI Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation On / Off
Ps Seq V deadband	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
Ps Seq V Hi high Lim	0 - 1000000	V	1	12990	High High limit (physical value)
Ps Seq V high limit	0 - 1000000	V	1	12125	High limit (physical value)
Ps Seq V low limit	0 - 1000000	V	1	0	Low limit (physical value)
Ps Seq V low low Lim	0 - 1000000	V	1	0	Low Low limit (physical value)
Ps Seq voltage Min	0 - 1000000	V	1	0	Minimum value
Ps Seq voltage Max	0 - 1000000	V	1	15000	Maximum value
Ps Seq V db type	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
Ng Seq V deadband	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
Ng Seq V Hi high Lim	0 - 1000000	V	1	1154	High High limit (physical value)
Ng Seq V High limit	0 - 1000000	V	1	577	High limit (physical value)
Ng Seq V low limit	0 - 1000000	V	1	0	Low limit (physical value)
Ng Seq V low low Lim	0 - 1000000	V	1	0	Low Low limit (physical value)
Ng Seq voltage Min	0 - 1000000	V	1	0	Minimum value
Ng Seq voltage Max	0 - 1000000	V	1	15000	Maximum value
Ng Seq V db type	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type

Table 1053: VSMSQI Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Ps Seq V zero Db	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
Ps Seq V limit Hys	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits
Ng Seq V zero Db	0 - 100000	m%	1	500	Zero point clamping in 0,001% of range
Ng Seq V limit Hys	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range and is common for all limits

8.1.10.5 Monitored data

Table 1054: VSMSQI Monitored data

Name	Type	Values (Range)	Unit	Description
U1_INST	REAL	-	kV	Positive sequence voltage amplitude, instantaneous value
U1_DB	REAL	-	kV	Positive sequence voltage amplitude, reported value
U1 RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Positive sequence voltage amplitude range
U1_ANGL_INST	REAL	-	deg	Positive sequence voltage angle, instantaneous value
U2_INST	REAL	-	kV	Negative sequence voltage amplitude, instantaneous value
U2_DB	REAL	-	kV	Negative sequence voltage amplitude, reported value
U2_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Negative sequence voltage amplitude range
U2_ANGL_INST	REAL	-	deg	Negative sequence voltage angle, instantaneous value

8.1.10.6 Technical data

Table 1055: VSMSQI Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.0% or ±0.002 × U_n At voltages in range of 0.01…1.15 × U_n
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

8.1.10.7 Technical revision history

Table 1056: VSMSQI technical revision history

Technical revision	Change
B	Mapped the unused data attributes for zero sequence to have their time quality fixed

8.1.11 Three-phase power PWRMMXU

8.1.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Power monitoring with P, Q, S, power factor, frequency	PWRMMXU	PQf	PQf

8.1.11.2 Function block

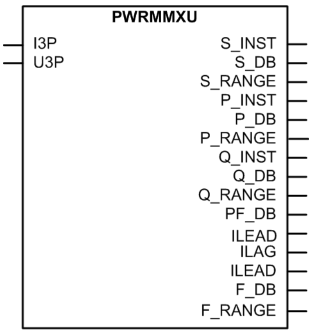


Figure 542: Function block

8.1.11.3 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

8.1.11.4 Signals

Table 1057: PWRMMXU Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Group Signal for current input
U3P	GROUP SIGNAL	-	Group Signal for voltage input

Table 1058: PWRMMXU Output signals

Name	Type	Description
S_INST	REAL	Apparent Power
S_DB	REAL	Apparent Power magnitude of deadband value
S_RANGE	INTEGER	Apparent Power range
P_INST	REAL	Active Power
P_DB	REAL	Active Power magnitude of deadband value
P_RANGE	INTEGER	Active Power range
Q_INST	REAL	Reactive Power
Q_DB	REAL	Reactive Power magnitude of deadband value
Q_RANGE	INTEGER	Reactive Power range
PF_DB	REAL	Power Factor magnitude of deadband value
PF_RANGE	INTEGER	Power Factor range
ILAG	BOOLEAN	Current is lagging voltage
ILEAD	BOOLEAN	Current is leading voltage
F_DB	REAL	System frequency magnitude of deadband value
F_RANGE	INTEGER	System frequency range

8.1.11.5 Settings

Table 1059: PWRMMXU Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Measurement mode	PhsA,PhsB,PhsC Arone Pos Seq PhsAB PhsBC PhsCA PhsA PhsB PhsC	-	-	PhsA,PhsB,PhsC	Selection of power calculation method
Tot VA deadband	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
Tot VA high high Lim	0 - 2000000	kVA	1	0	High High limit (physical value)
Tot VA high limit	0 - 2000000	kVA	1	0	High limit (physical value)
Tot VA low limit	0 - 2000000	kVA	1	0	Low limit (physical value)
Tot VA low low limit	0 - 2000000	kVA	1	0	Low Low limit (physical value)
Tot apparent Pwr Min	0 - 2000000	kVA	1	0	Minimum value
Tot apparent Pwr Max	0 - 2000000	kVA	1	2000000	Maximum value
Tot VA deadband type	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Tot W deadband	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
Tot W high high Lim	-2000000 - 2000000	kW	1	0	High High limit (physical value)
Tot W high limit	-2000000 - 2000000	kW	1	0	High limit (physical value)
Tot W low limit	-2000000 - 2000000	kW	1	0	Low limit (physical value)
Tot W low low limit	-2000000 - 2000000	kW	1	0	Low Low limit (physical value)
Total real Pwr Min	-2000000 - 2000000	kW	1	-2000000	Minimum value
Total real Pwr Max	-2000000 - 2000000	kW	1	2000000	Maximum value
Tot W deadband type	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
Tot VAr deadband	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
Tot VAr Hi high Lim	-2000000 - 2000000	kVar	1	0	High High limit (physical value)
Tot VAr high limit	-2000000 - 2000000	kVar	1	0	High limit (physical value)
Tot VAr low limit	-2000000 - 2000000	kVar	1	0	Low limit (physical value)
Tot VAr low low Lim	-2000000 - 2000000	kVar	1	0	Low Low limit (physical value)
Tot reactive Pwr Min	-2000000 - 2000000	kVar	1	-2000000	Minimum value
Tot reactive Pwr Max	-2000000 - 2000000	kVar	1	2000000	Maximum value
Tot VAr Db type	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
Av PF deadband	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
Av PF high high Lim	-1.000 - 1.000	-	0.001	1.000	High High limit (physical value)
Av PF high limit	-1.000 - 1.000	-	0.001	1.000	High limit (physical value)
Av PF low limit	-1.000 - 1.000	-	0.001	-1.000	Low limit (physical value)
Av PF low low limit	-1.000 - 1.000	-	0.001	-1.000	Low Low limit (physical value)
Average PF minimum	-1.000 - 0.000	-	0.001	-1.000	Minimum value
Average PF maximum	0.000 - 1.000	-	0.001	1.000	Maximum value
Av PF deadband type	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type
Hz deadband	1 - 300	Type	1	10	Cycl: Report interval (s), Db: In % of range, Int Db: In %s
Hz high high limit	15.000 - 75.000	Hz	0.001	60.000	High High limit (physical value)
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
Hz high limit	15.000 - 75.000	Hz	0.001	55.000	High limit (physical value)
Hz low limit	10.000 - 60.000	Hz	0.001	45.000	Low limit (physical value)
Hz low low limit	10.000 - 60.000	Hz	0.001	40.000	Low Low limit (physical value)
Frequency minimum	0.000 - 100.000	Hz	0.001	0.000	Minimum value
Frequency maximum	0.000 - 100.000	Hz	0.001	70.000	Maximum value
Hz deadband type	Cyclic Dead band Int deadband	-	-	Cyclic	Reporting type

Table 1060: PWRMMXU Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Relation constant	0.00 - 1.00	-	0.01	0.00	Low pass filter coefficient for power measurement
Voltage zero Db	0.01 - 1.00	pu	0.01	0.05	Zero point clamping
Current zero Db	0.01 - 1.00	pu	0.01	0.05	Zero point clamping
Tot VA zero deadband	0 - 100000	m%	1	0	Zero point clamping in 0,001% of range
Tot VA limit Hys	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range (common for all limits)
Tot W zero deadband	0 - 100000	m%	1	0	Zero point clamping in 0,001% of range
Tot W limit Hys	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range (common for all limits)
Tot VAr zero Db	0 - 100000	m%	1	0	Zero point clamping in 0,001% of range
Tot VAr limit Hys	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range (common for all limits)
Av PF zero deadband	0 - 100000	m%	1	0	Zero point clamping in 0,001% of range
Av PF limit Hys	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range (common for all limits)
Hz zero deadband	0 - 100000	m%	1	0	Zero point clamping in 0,001% of range
Hz limit hysteresis	0.000 - 100.000	%	0.001	5.000	Hysteresis value in % of range (common for all limits)

8.1.11.6 Monitored data

Table 1061: PWRMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
S_INST	REAL	-	MVA	Apparent Power
S_DB	REAL	-	MVA	Apparent Power magnitude of deadband value
S_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Apparent Power range
P_INST	REAL	-	MW	Active Power
P_DB	REAL	-	MW	Active Power magnitude of deadband value
P_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Active Power range
Q_INST	REAL	-	MVAr	Reactive Power
Q_DB	REAL	-	MVAr	Reactive Power magnitude of deadband value
Q_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Reactive Power range
PF_INST	REAL	-	-	Power Factor i.e. cosfi
PF_DB	REAL	-	-	Power Factor magnitude of deadband value
PF_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	Power Factor range
ILAG	BOOLEAN	0=FALSE 1=TRUE	-	Current is lagging voltage
ILEAD	BOOLEAN	0=FALSE 1=TRUE	-	Current is leading voltage
F_INST	REAL	-	Hz	System frequency
F_DB	REAL	-	Hz	System frequency magnitude of deadband value
F_RANGE	INTEGER	0=Normal 1=High 2=Low 3=High-High 4=Low-Low	-	System frequency range

8.1.11.7 Technical data

Table 1062: PWRMMXU Technical data

Characteristic	Value
Operation accuracy	At all three currents in range 0.10…1.20 × In_n At all three voltages in range 0.50…1.15 × U_n At the frequency f = f_n Active power and energy in range |PF| > 0.71 Reactive power and energy in range |PF| < 0.71
	±1.5% for power (S, P and Q) ±0.015 for power factor
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

8.2 Energy monitoring EPDMMTR

8.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Energy monitoring (including power demand)	EPDMMTR	E	E

8.2.2 Function block

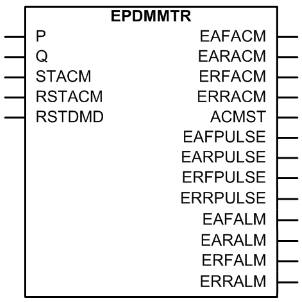


Figure 543: Function block

8.2.3 Functionality

The energy monitoring function EPDMMTR is used to calculate the active and reactive energy from the respective power inputs `P` and `Q`. The function also provides alarm outputs when the energy exceeds the set limit.

In addition, the function provides the service value of maximum power demand during the set interval time and the pulse outputs for the measured energy.

8.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the energy-monitoring function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

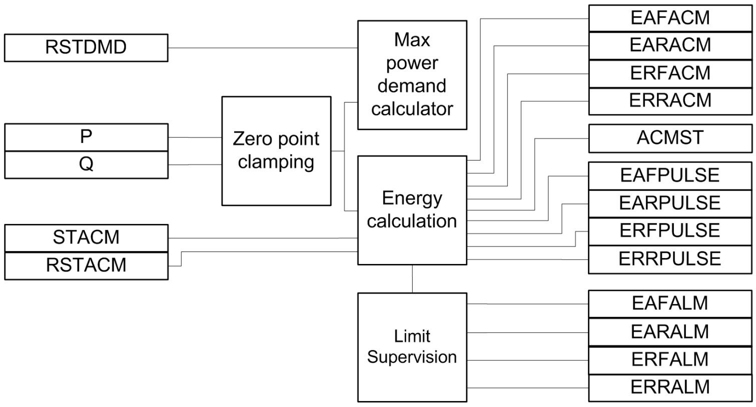


Figure 544: Functional module diagram

Zero-point clamping

Zero point clamping is used to ignore the possible noise in the input signals. The measured values below the zero point-clamping limits are forced to zero. *W zero deadband* and *VAr zero deadband* are the settings used to set the limit. *Enable zero deadband* can be set to “Yes” or “No” to enable or disable the function.

This module takes care of the directionality of the energy measured based on the set reference direction. The *Active energy Dir* and *Reactive energy Dir* settings can be used to set the reference directions for forward and reverse, active and reactive energy flows respectively. All the positive values, dependent on the set reference direction, are calculated and displayed in the forward outputs and the negative values in the reverse outputs. However, both forward and reverse output values are displayed as absolute values, that is, positive values. The active power, from supply to load, is shown in forward direction when *Active energy Dir* is set to “Forward”. The active power is shown in reverse direction when *Active energy Dir* is set to “Reverse”. The same applies to reactive energy calculation.

Energy calculation

This module calculates the linear average of the active and reactive energies over a set time interval *Demand period*, based on the measured powers. The interval can be set to “1”, “5”, “10”, “15”, “30”, “60” or “180” minutes. A new energy value is obtained once a minute, indicating the actual energy over the energy time interval preceding the update time. The energy values, based on sliding average and the final output value, are updated at the end of the time interval. For example, the energy value based on the setting interval of “180” minutes is displayed in the output for the first time after 180 minutes and the value is calculated from the interval $t_0 - t_{180}$. The next value is displayed at the moment t_{180+1} and it is based on average between $t_{0+1} - t_{180+1}$.

In the outputs, the energy values are calculated based on the set *Demand period*.

Energy = Average power calculated over the demand period × *Demand period*.

The accumulation of the energy values is based on the same principles as demand energy calculation. The accumulated values are always calculated from the one-minute values by summing, independent of the set *Demand period*. The accumulation feature can be enabled by setting *Enable accumulation* to “Yes” and it can be disabled by setting *Enable accumulation* to “No”. The binary input `STACM`, can also be used for starting the accumulation. `RSTACM` is used to reset the accumulation. The accumulated energy calculations can start from predefined offset values using the *Forward Wh Initial* and *Reverse Wh Initial* settings for the accumulated active energy values and *Forward VArh initial* and *Reverse VArh initial* settings for the accumulated reactive-energy values.

`EAFACM` and `EARACM` are the analog value outputs of the accumulated active-energy values in forward and reverse directions respectively. `ERFACM` and `ERRACM` are the analog value outputs of the accumulated reactive-energy values in forward and reverse directions respectively. These accumulated values are available in the monitored data view, so there is a possibility of saturation for these outputs. To handle this, the hidden parameter *Energy Acc Lim* setting is used. It is fixed to value 1 000 000 MWh. Whenever the accumulated energy crosses *Energy Acc Lim*, there is an increment on the energy counter value and the accumulated energy value becomes zero. `EAFCNT` and `EARCNT` are the counter values for accumulated active energy. `ERFCNT` and `ERVCNT` are the counter values for accumulated reactive energy. The `RSTACM` input is also used to reset the counter output values.

`ACMST` is the binary output indicating the start of the accumulation.

The pulse outputs, `EAFPULSE`, `EARPULSE`, `ERFPULSE` and `ERRPULSE`, are activated based on the calculated values of forward and reverse, active and reactive accumulated energy. The number of pulses depends on the energy quantity per pulse determined by the *Forward Wh Acc Pls*, *Reverse Wh Acc Pls*, *Forward VArh Acc Pls* and *Reverse VArh Acc Pls* settings. For instance, if the active accumulated forward-energy value is 1 MWh and *Forward Wh Acc Pls* is 100 KWh, 10 pulses of `EAFPULSE` is generated. The pulse-on-and-off time duration can be set using the *Pulse on time* and *Pulse off time* settings.

During the demand period, the BCR (binary counter reading) representations of the calculated energy are available as pulse counter outputs. The integer binary counter outputs `EAFDMD_BCR` and `EARDMD_BCR` represent the active energy in the forward and reverse directions respectively. The energy quantity per count is defined by the *Forward Wh Itrv Pls* and *Reverse Wh Itrv Pls* settings. For instance, if the active-forward-demand energy for the set interval is 100 kWh and *Forward*

Wh Itrv Pls is 10 kWh, the EAFDMD_BCR value is equal to 10. Similarly, the integer binary counter outputs ERFDMD_BCR and ERRDMD_BCR represent the reactive energy in the forward and reverse directions respectively. The energy quantity per count is defined by the *Forward VArh Itrv Pls* and *Reverse VArh Itrv Pls* settings.

The BCR representations of the accumulated energy are available as pulse counter outputs. The integer binary counter outputs EAFACM_BCR and EARACM_BCR represent the accumulated active energy in the forward and reverse directions respectively. The energy quantity per count is defined by the *Forward Wh Acc Pls* and *Reverse Wh Acc Pls* settings. For instance, if the accumulated forward-energy value is 500 kWh and *Forward Wh Acc Pls* is 10 kWh, the EAFACM_BCR value is equal to 50. Similarly, the integer binary counter outputs ERFACM_BCR and ERRACM_BCR represent the accumulated reactive energy in the forward and reverse directions respectively. The energy quantity per count is defined by the *Demand Varh Pls Qty* and *Supply Varh Pls Qty* settings.

Limit supervision

The limit supervision module supervises the energy values for each demand period for the limits defined by *Energy active limit* and *Energy reactive limit*. When the active energy values for the demand period exceeds *Energy active limit*, the binary alarm outputs EAFALM and EARALM are activated. When the reactive energy values for the demand period exceeds *Energy reactive limit*, the binary alarm outputs ERFALM and ERRALM are activated.

Maximum power demand calculator

The power demand is obtained by dividing the average energy in the interval with the set *Demand period*. The active power demand outputs PAFDMD and PARDMD in forward and reverse directions and the reactive power demand outputs PRFDMD and PRRDMD are available in the monitored data view.

The maximum demand value is initially zero. After the first *Demand period*, the calculated power demand is stored as the maximum power demand. Subsequently, whenever the calculated power demand exceeds the maximum power demand calculated earlier, the new values of maximum power demand are updated. The maximum power demand is reset with the RSTDMD binary input. The maximum demand values MAXPAFDMD, MAXPARDMD, MAXPRFDMD and MAXPRRDMD are available in the monitored data view.

8.2.5 Application

EPDMMTR measures and monitors the energy values from the connected power signals. The functionality includes zero point clamping, energy calculation, accumulation of the energy values and maximum power demand. The reference directions for positive and negative active and reactive energy flows can be set.

The function has a zero point clamping detection to ignore noise in the input signals. The zero point clamping detection function forces the input signal values under zero-value detection level to zero. The clamping limit can be set and the functionality can be enabled or disabled with the *Enable zero deadband* setting.

EPDMMTR calculates the linear average of the measured power signal over set time interval. The time interval can be set and it varies between one minute and three hours.

The alarm output signals indicate if the periodic accumulated energy value exceeds the limit set by the user during that energy interval. The maximum power demand for the set interval is calculated.

The accumulated values are calculated by summing the one-minute energy values. The calculation of the accumulated values are independent of the energy calculations based on the time interval which can be set. The accumulated values are displayed as power unit hours in the outputs. The accumulation can be started or reset with binary inputs. The accumulated energy is also available as pulse counter outputs.

8.2.6 Signals

Table 1063: EPDMMTR Input signals

Name	Type	Default	Description
P_INST	REAL	0	Measured active power
Q_INST	REAL	0	Measured reactive power
STACM	BOOLEAN	0	Start to accumulate energy values
RSTACM	BOOLEAN	0	Reset of accumulated energy reading
RSTDMD	BOOLEAN	0	Reset of maximum demand reading

Table 1064: EPDMMTR Output signals

Name	Type	Description
ACMST	BOOLEAN	Start of accumulating energy values.
EAFPULSE	BOOLEAN	Accumulated forward active energy pulse
EARPULSE	BOOLEAN	Accumulated reverse active energy pulse
ERFPULSE	BOOLEAN	Accumulated forward reactive energy pulse
ERRPULSE	BOOLEAN	Accumulated reverse reactive energy pulse
EAFAL	BOOLEAN	Alarm for active forward energy exceed limit in set interval
EARAL	BOOLEAN	Alarm for active reverse energy exceed limit in set interval
ERFAL	BOOLEAN	Alarm for reactive forward energy exceed limit in set interv
ERRAL	BOOLEAN	Alarm for reactive reverse energy exceed limit in set interv

Table continues on next page

Name	Type	Description
EAFACM	REAL	Accumulated forward active energy value in Ws
EARACM	REAL	Accumulated reverse active energy value in Ws
ERFACM	REAL	Accumulated forward reactive energy value in VArS
ERRACM	REAL	Accumulated reverse reactive energy value in VArS

8.2.7 Settings

Table 1065: EPDMMTR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
Forward Wh Acc Pls	1 - 10000	kWh	1	100	Pulse quantity for active forward accumulated energy value
Reverse Wh Acc Pls	1 - 10000	kWh	1	100	Pulse quantity for active reverse accumulated energy value
Forward VArh Acc Pls	1 - 10000	kVarh	1	100	Pulse quantity for reactive forward accumulated energy value
Reverse VArh Acc Pls	1 - 10000	kVarh	1	100	Pulse quantity for reactive reverse accumulated energy value
Forward Wh Itrv Pls	1 - 10000	kWh	1	100	Pulse quantity for active forward energy of set interval
Reverse Wh Itrv Pls	1 - 10000	kWh	1	100	Pulse quantity for active reverse energy of set interval
Forward VArh ItrvPls	1 - 10000	kVarh	1	100	Pulse quantity for reactive forward energy of set interval
Reverse VArh ItrvPls	1 - 10000	kVarh	1	100	Pulse quantity for reactive reverse energy of set interval
Demand period	1 Minute 5 Minutes 10 Minutes 15 Minutes 30 Minutes 60 Minutes 180 Minutes	-	-	1 Minute	Time interval for energy calculation
Pulse on time	0.000 - 60.000	s	0.001	1.000	Energy accumulated pulse ON time in secs
Pulse off time	0.000 - 60.000	s	0.001	0.500	Energy accumulated pulse OFF time in secs
Enable accumulation	No Yes	-	-	No	Activate the accumulation of energy values

Table 1066: EPDMMTR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Active energy Dir	Forward Reverse	-	-	Forward	Direction of active energy flow Forward/ Reverse
Reactive energy Dir	Forward Reverse	-	-	Forward	Direction of reactive energy flow Forward/Reverse
Energy active limit	1 - 10000000	kWh	1	1000000	Active energy limit
Energy reactive lim	1 - 10000000	kVarh	1	1000	Reactive energy limit
W zero deadband	0.001 - 10000.000	kW	0.001	10.000	Zero point clamping level at active Power
VAr zero deadband	0.001 - 10000.000	kVar	0.001	10.000	Zero point clamping level at reactive Power
Forward Wh initial	0 - 10000000	kWh	1	0	Preset Initial value for forward active energy
Reverse Wh initial	0 - 10000000	kWh	1	0	Preset Initial value for reverse active energy
Forward VArh initial	0 - 10000000	kVarh	1	0	Preset Initial value for forward reactive energy
Reverse VArh initial	0 - 10000000	kVarh	1	0	Preset Initial value for reverse reactive energy
Enable zero deadband	No Yes	-	-	Yes	Enable of zero point clamping detection function

8.2.8 Measured values

Table 1067: EPDMMTR Measured values

Name	Type	Default	Description
P_INST	REAL	0	Measured active power
Q_INST	REAL	0	Measured reactive power
STACM	BOOLEAN	0	Start to accumulate energy values
RSTACM	BOOLEAN	0	Reset of accumulated energy reading
RSTDMD	BOOLEAN	0	Reset of maximum demand reading

8.2.9 Monitored data

Table 1068: EPDMMTR Monitored data

Name	Type	Values (Range)	Unit	Description
ACMST	BOOLEAN	0=FALSE 1=TRUE	-	Start of accumulating energy values.
EAFAL	BOOLEAN	0=FALSE 1=TRUE	-	Alarm for active forward energy exceed limit in set interval
EARAL	BOOLEAN	0=FALSE 1=TRUE	-	Alarm for active reverse energy exceed limit in set interval

Table continues on next page

Name	Type	Values (Range)	Unit	Description
ERFAL	BOOLEAN	0=FALSE 1=TRUE	-	Alarm for reactive forward energy exceed limit in set interv
ERRAL	BOOLEAN	0=FALSE 1=TRUE	-	Alarm for reactive reverse energy exceed limit in set interv
EAFDMD_BCR	INTEGER	-	-	Last forward active energy value for set interval (BCR)
EARDMD_BCR	INTEGER	-	-	Last reverse active energy value for set interval (BCR)
ERFDMD_BCR	INTEGER	-	-	Last forward reactive energy value for set interval (BCR)
ERRDMD_BCR	INTEGER	-	-	Last reverse reactive energy value for set interval (BCR)
EAFACM_BCR	INTEGER	-	-	Accumulated forward active energy value (BCR)
EARACM_BCR	INTEGER	-	-	Accumulated reverse active energy value (BCR)
ERFACM_BCR	INTEGER	-	-	Accumulated forward reactive energy value (BCR)
ERVACM_BCR	INTEGER	-	-	Accumulated reverse reactive energy value (BCR)
EAFCNT	INTEGER	-	-	Counter for accumulated forward active energy exceed limit
EARCNT	INTEGER	-	-	Counter for accumulated reverse active energy exceed limit
ERFCNT	INTEGER	-	-	Counter for accumulated forward reactive energy exceed limit
ERRCNT	INTEGER	-	-	Counter for accumulated reverse reactive energy exceed limit
EAFACM	REAL	-	MWh	Accumulated forward active energy value in Ws
EARACM	REAL	-	MWh	Accumulated reverse active energy value in Ws
ERFACM	REAL	-	MVArh	Accumulated forward reactive energy value in VArS

Table continues on next page

Name	Type	Values (Range)	Unit	Description
ERRACM	REAL	-	MVArh	Accumulated reverse reactive energy value in VArS
PAFDMD	REAL	-	MW	Last forward active power demand value for set interval
PARDMD	REAL	-	MW	Last reverse active power demand value for set interval
PRFDMD	REAL	-	MVAr	Last forward reactive power demand value for set interval
PRRDMD	REAL	-	MVAr	Last reverse reactive power demand value for set interval
MAXPAFDMD	REAL	-	MW	Maximum forward active power demand value for set interval
MAXPARDMD	REAL	-	MW	Maximum reverse active power demand value for set interval
MAXPRFDMD	REAL	-	MVAr	Maximum forward reactive power demand value for set interval
MAXPRRDMD	REAL	-	MVAr	Maximum reverse reactive power demand value for set interval

8.2.10 Technical data

Table 1069: EPDMMTR Technical data

Characteristic	Value
Operation accuracy	At all three currents in range 0.10…1.20 × I_{n} At all three voltages in range 0.50…1.15 × U_n At the frequency f = f_n Active power and energy in range |PF| > 0.71 Reactive power and energy in range |PF| < 0.71
	±1.5% for energy
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

8.2.11 Technical revision history

Table 1070: EPDMMTR technical revision history

Technical revision	Change
B	Internal improvements

Section 9 Power quality measurement functions

9.1 Voltage unbalance VSQVUB

9.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage unbalance power quality function	VSQVUB	PQMUBU	PQMUBV

9.1.2 Function block

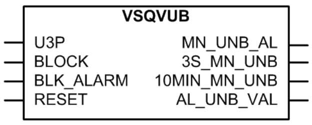


Figure 545: Function block

9.1.3 Functionality

The voltage unbalance power quality function VSQVUB monitors voltage unbalance conditions in power transmission and distribution networks. It can be applied to identify a network and load unbalance that cause sustained voltage unbalance. VSQVUB is also used to monitor the commitment of the power supply utility of providing a high-quality, that is, a balanced voltage supply on a continuous basis.

VSQVUB uses five different methods for calculating voltage unbalance. The methods are the negative-sequence voltage magnitude, zero-sequence voltage magnitude, ratio of the negative-sequence voltage magnitude to the positive-sequence voltage magnitude, ratio of the zero-sequence voltage magnitude to the positive-sequence voltage magnitude or ratio of maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of the phase voltage magnitude.

VSQVUB includes an alarm and a blocking functionality. It is possible to block a set of function outputs or the function itself, if desired.

9.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the voltage unbalance power quality function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

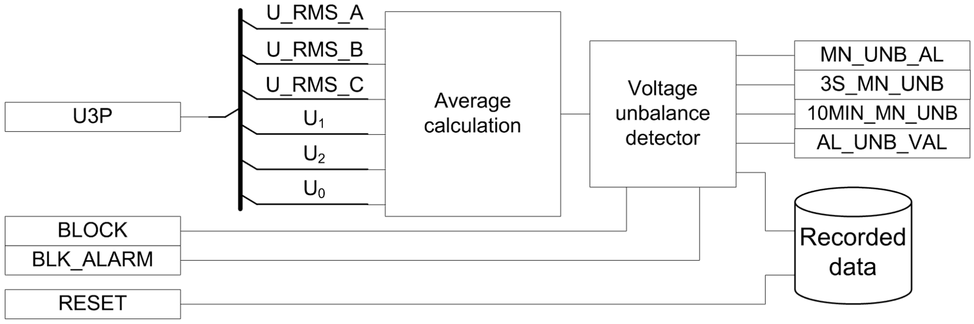


Figure 546: Functional module diagram. Group signal I3P and U3P are used for feeding the necessary analog signals to the function.

Average calculation

VSQVUB calculates two sets of measured voltage unbalance values, a three-second and a ten-minute non-sliding average value. The three-second average value is used for continuous monitoring.

The module uses five different methods for the average calculation. The required method can be selected using the *Unb detection method* parameter.

When the "Negative sequence" mode is selected with *Unb detection method*, the voltage unbalance is calculated based on the negative-sequence voltage magnitude. Similarly, when the "Zero sequence" mode is selected, the voltage unbalance is calculated based on the zero-sequence voltage magnitude. When the "Neg to Pos Seq" mode is selected, the voltage unbalance is calculated based on the ratio of the negative-sequence voltage magnitude to the positive-sequence magnitude. When the "Zero to Pos Seq" mode is selected, the voltage unbalance is calculated based on the ratio of the zero-sequence voltage magnitude to the positive-sequence magnitude. When the "Ph vectors Comp" mode is selected, the ratio of the maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of the phase voltage magnitude is used for voltage unbalance calculation.

The calculated three-second value and the ten-minute value are available through the outputs `3S_MN_UNB` and `10MIN_MN_UNB`.

Voltage unbalance detector

The three-second average value is continuously calculated and compared to the set value *Unbalance start val*. If the voltage unbalance exceeds this limit, the

MN_UNB_AL output is activated. A maximum value calculation based on the values of the three-second sliding average is started when MN_UNB_AL is active. The highest unbalance value AL_UNB_VAL and the time of occurrence AL_UNB_DATE are available in the monitored data view.

The BLK_ALARM input is used to block the alarm output MN_UNB_VAL. In this case, the other outputs are updated normally. However, the activation of the BLOCK input blocks the alarm output MN_UNB_VAL and also the internal recorders. All the other outputs are updated normally.

Recorded data

The information required for a later fault analysis is stored when the recorded data module is triggered. This happens when a voltage unbalance is detected by the voltage unbalance detector module.

Three sets of recorded data are available in total. The sets are saved in data banks 1-3. The data bank 1 holds the most recent recorded data. Older data are moved to the subsequent banks (1→2 and 2→3) when a voltage unbalance is detected. When all three banks have data and a new unbalance is detected, the most recent data set is placed into bank 1 and the data in bank 3 are overwritten by the data from bank 2.

The recorded data can be reset with the RESET binary input signal or by navigating to the HMI reset (**Main menu / Clear / Clear recorded data / VSQVUBx**).

When a voltage unbalance is detected in the system, the function responds with the MN_UNB_AL alarm signal. During the alarm situation, the function stores the maximum magnitude and the time of occurrence. The recorded data are stored when MN_UNB_AL is deactivated.

Parameter name	Description
n Recording time	Time of recording data
n AL_UNB_VAL	Maximum 3 sec voltage unbalance

9.1.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

9.1.6 Application

Ideally, in a three-phase or multiphase power system, the frequency and voltage magnitude of all the phases are equal and the phase displacement between any two consecutive phases is also equal. This is called a balanced source. Apart from the balanced source, usually the power system network and loads are also balanced, implying that the network impedance and load impedance in each phase are equal. In some cases, the condition of a balance network and load are not met completely, which leads to a current and voltage unbalance in the system. Providing unbalanced supply voltage to some of the loads causes a detrimental effect on their operation. For example, a small magnitude of a negative-sequence voltage applied to an induction motor results in a significant heating of the motor.

A balanced supply, balanced network and balanced load lead to a better power quality. When one of these conditions is disturbed, the power quality is deteriorated. VSQVUB monitors such voltage unbalance conditions in power transmission and distribution networks. VSQVUB calculates two sets of measured values, a three-second and a ten-minute non-sliding average value. The three-second average value is used for continuous monitoring while the ten-minute average value is used for percentile calculation for a longer period of time. It can be applied to identify the network and load unbalance that may cause sustained voltage unbalance. A single-phase or phase-to-phase fault in the network or load side can create voltage unbalance but, as faults are usually isolated in a short period of time, the voltage unbalance is not a sustained one. Therefore, the voltage unbalance may not be covered by VSQVUB.

The function uses five different methods for calculating voltage unbalance. The methods are:

- Negative-sequence voltage magnitude
- Zero-sequence voltage magnitude
- Ratio of negative-sequence to positive-sequence voltage magnitude
- Ratio of zero-sequence to positive-sequence voltage magnitude
- Ratio of maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of phase voltage magnitude.

Usually, the ratio of the negative-sequence voltage magnitude to the positive-sequence voltage magnitude is selected for monitoring the voltage unbalance. However, other methods may also be used if required.

9.1.7 Signals

Table 1071: VSQVUB Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block all outputs except measured values
BLK_ALARM	BOOLEAN	0	Block alarm outputs
RESET	BOOLEAN	0	Resets the registered values of the data banks

Table 1072: VSQVUB Output signals

Name	Type	Description
MN_UNB_AL	BOOLEAN	Alarm active when 3 sec voltage unbalance exceeds the limit
3S_MN_UNB	REAL	Sliding 3 second mean value of voltage unbalance
10MIN_MN_UNB	REAL	Sliding 10 minutes mean value of voltage unbalance
AL_UNB_VAL	REAL	Maximum 3 sec sliding mean voltage unbalance measured

9.1.8 Settings

Table 1073: VSQVUB Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation mode Off / On
Unb detection method	Negative Seq Zero sequence Neg to Pos Seq Zero to Pos Seq Ph vectors Comp	-	-	Neg to Pos Seq	Set the operation mode for voltage unbalance calculation.

Table 1074: VSQVUB Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector phase / phase to phase
Unbalance start Val	1 - 100	%	1	1	Voltage unbalance start value

9.1.9 Measured values

Table 1075: VSQVUB Measured values

Name	Type	Default	Description
U_RMS_A	REAL	0.0	Voltage amptitude (RMS) phase A
U_RMS_B	REAL	0.0	Voltage amptitude (RMS) phase B
U_RMS_C	REAL	0.0	Voltage amptitude (RMS) phase C
U_AMPL_RES	REAL	0.0	Residual voltage amplitude
U1_AMPL	REAL	0.0	Positive sequence voltage amplitude
U2_AMPL	REAL	0.0	Negative sequence voltage amplitude
BLOCK	BOOLEAN	0	Block all outputs except measured values
BLK_ALARM	BOOLEAN	0	Block alarm outputs
RESET	BOOLEAN	0	Resets the registered values of the data banks

9.1.10 Monitored data

Table 1076: VSQVUB Monitored data

Name	Type	Values (Range)	Unit	Description
MN_UNB_AL	BOOLEAN	0=FALSE 1=TRUE	-	Alarm active when 3 sec voltage unbalance exceeds the limit
3S_MN_UNB	REAL	-	%	Sliding 3 second mean value of voltage unbalance
10MIN_MN_UNB	REAL	-	%	Sliding 10 minutes mean value of voltage unbalance
AL_UNB_VAL	REAL	-	%	Maximum 3 sec sliding mean voltage unbalance measured
AL_UNB_DATE	INTEGER	-	-	Time of max 3 sec sliding mean voltage unbalance occurrence
1 Recording time	INTEGER	-	-	Time of recording data in record data bank1
1 AL_UNB_VAL	REAL	-	%	Record data of bank1 for maximum 3 sec voltage unbalance
1 AL_UNB_DATE	INTEGER	-	-	Time of occurrence of the unbalance of time stamp bank1
2 Recording time	INTEGER	-	-	Time of recording data in record data bank2
2 AL_UNB_VAL	REAL	-	%	Record data of bank2 for maximum 3 sec voltage unbalance

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 AL_UNB_DATE	INTEGER	-	-	Time of occurrence of the unbalance of time stamp bank2
3 Recording time	INTEGER	-	-	Time of recording data in record data bank3
3 AL_UNB_VAL	REAL	-	%	Record data of bank3 for maximum 3 sec voltage unbalance
3 AL_UNB_DATE	INTEGER	-	-	Time of occurrence of the unbalance of time stamp bank3

9.2 Current harmonics CMHAI

9.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current harmonics	CMHAI	PQM3I	PQM3I

9.2.2 Function block

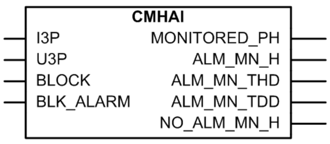


Figure 547: Function block

9.2.3 Functionality

The current harmonics monitoring function CMHAI is a sample-based function designed for monitoring the waveform distortion in distribution and transmission networks.

CMHAI is used for monitoring the individual current harmonic components (up to 20^{th}), total harmonic distortion (THD) and total demand distortion (TDD). The function monitors the selected phase or the phase with the highest THD or TDD. CMHAI provides three-second mean RMS values of the harmonic components, THD and TDD.

The function also includes an alarm functionality. Each harmonic and the THD or TDD RMS values are monitored; exceeding the selected limit raises an alarm. When CMHAI enters an alarm state (a harmonic RMS limit is exceeded), it also tracks the maximum THD or TDD value. After the alarm state is exited, the function provides THD or TDD and RMS values for each harmonic component.

The function contains a blocking functionality. It is possible to block a set of function outputs or the function itself.

9.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the current waveform distortion measurement can be described with a module diagram. All modules in the diagram are explained in the next sections.

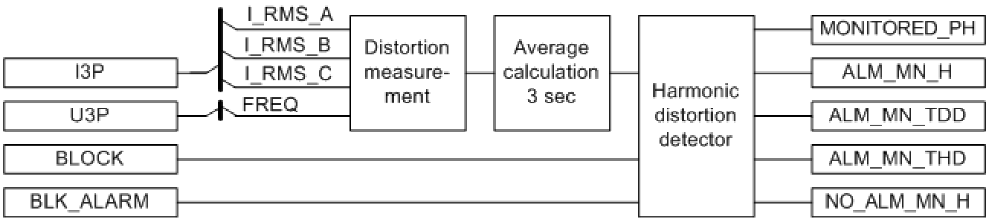


Figure 548: Functional module diagram

9.2.4.1 Distortion measurement

Distortion measurement is a sample-based module which measures the quasi-stationary (slowly varying) harmonics up to 20th. The distortion measurement does not include rapidly changing harmonics, interharmonics or other spurious components. The harmonics are calculated when the amplitude of fundamental current is above *Low limit* setting. The distortion measurement module calculates THD or TDD depending on the *Distortion factor* setting.

$$THD = \frac{\sqrt{\sum_{k=2}^{L} I_k^2}}{I_1}$$

(Equation 178)

I_k	RMS value of current harmonic component 2…L (L=20)
I_1	RMS value of current fundamental component

$$TDD = \frac{\sqrt{\sum_{k=2}^{L} I_k^2}}{I_N}$$

(Equation 179)

I_N RMS value of current fundamental component

9.2.4.2 Average calculation 3 seconds

This module calculates the three-phase three-second average THD or TDD and each individual 1...20 harmonic value, which are used for continuous monitoring. The output values 3SMNH(1…20)_A, 3SMNTHD_A, 3SMNTDD_A, 3SMNH(1…20)_B, 3SMNTHD_B, 3SMNTDD_B, 3SMNH(1…20)_C, 3SMNTHD_C and 3SMNTDD_C are available in monitored data view.

9.2.4.3 Harmonic distortion detector

The *Measuring mode* setting defines which phase is being monitored. “Phase A”, “Phase B” and “Phase C” are available for selecting phases. The "Worst case" monitoring mode is used for the phase with the highest measured THD or TDD value. This means that the actual monitored phase can change continuously. The `MONITORED_PH` output indicates the actual phase.

The three-second average THD or TDD and each individual 2...20 harmonic value are continuously calculated and compared to the set value *THD limit value*, *TDD limit value* and 2...20 *H limit Val*. If the value exceeds limit, the `ALM_MN_H`, `ALM_MN_THD` and `ALM_MN_TDD` outputs are activated.

The `NO_ALM_MN_H` output indicates the number of harmonics components that exceeds the limit value.

Tracking of maximum values based on the three-second averages is started when at least one of the outputs `ALM_MN_H`, `ALM_MN_THD` or `ALM_MN_TDD` is active. The `MAXH`(1…20), `MAXTHD` and `MAXTDD` outputs indicate the maximum harmonic values occurred during the previous alarm state. These outputs are available in the monitored data view.

The `MAXHDATE` output indicates the date and time at which the last maximum harmonic distortion (THD / TDD) was measured.

The `BLK_ALARM` input is used to block all the alarm outputs (`ALM_MN_H`, `ALM_MN_THD` and `ALM_MN_TDD`). In this case, all the other outputs are updated normally. Activation of the `BLOCK` input blocks all the alarm outputs and the outputs indicating the maximum value.

The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the current signal slightly varies above or below the *limit value* setting.

9.2.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

9.2.6 Application

The power quality in standards is defined through the characteristics of the supply voltage. Transients, short- and long-duration voltage variations, unbalance and waveform distortion are the key characteristics describing the power quality. The power quality is, however, a customer-driven issue. It can be said that any power problem concerning the voltage or current that results in the failure or misoperation of the customer equipment is a power quality problem.

Harmonic distortion in a power system is caused by nonlinear devices. Electronic power converter loads constitute the most important class of nonlinear loads in a power system. Switch-mode power supplies in a number of single-phase electronic equipment (personal computers, printers, copiers and so on) have very high third-harmonic content in the current. The three-phase electronic power converters (dc/ac drives) do not generate third-harmonic currents, but they can be a significant source of harmonics.

The harmonic voltage distortion in a power system depends on the current distortion produced by the nonlinear loads and on the impedance characteristics visible to each load. The most sensitive equipment to voltage harmonics is the data processing and communication equipment. However, these devices are considerable current harmonic sources. These devices are susceptible to the misoperation caused by a harmonic distortion. For example, in computers and medical instruments considerably low harmonic levels can result in malfunctions that can have serious consequences. In a rotating machinery, the major effect of harmonic voltages and currents is increased heating due to iron and copper losses at the harmonic frequencies.

The power quality monitoring is an essential service that utilities can provide for the industries and key customers. A monitoring system provides information about the system disturbances and their possible causes. The monitoring system can also detect problem conditions throughout the system before they can cause customer complaints, equipment malfunctions and even equipment damage or failure. Power quality problems are not limited to the utility side of the system. In fact, the majority of power quality problems are localized within the customer facilities. Thus, the power quality monitoring is not only an effective customer service strategy, but also a way to protect a utility's reputation for a quality power and service.

xMHAI provides a convenient method for monitoring power quality by means of a voltage or current waveform distortion. The function monitors the voltage or current harmonics in the power transmission and distribution networks.

9.2.7 Signals

Table 1077: CMHAI Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block of function
BLK_ALARM	BOOLEAN	0	Block alarm outputs

Table 1078: CMHAI Output signals

Name	Type	Description
MONITORED_PH	INTEGER	Indicates the actual phase monitored 1=Ph A, 2=Ph B, 3=Ph C
ALM_MN_H	BOOLEAN	Alarm signal when harmonic RMS value is greater than limit
ALM_MN_THD	BOOLEAN	Alarm signal when THD value is greater than limit
ALM_MN_TDD	BOOLEAN	Alarm signal when TDD value is greater than limit
NO_ALM_MN_H	INTEGER	Highest harmonic that exceeded its alarm limit

9.2.8 Settings

Table 1079: CMHAI Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
Measuring mode	Phase A Phase B Phase C Worst case	-	-	Worst case	Specifies the monitored phase
Low limit	1.0 - 50.0	%	0.1	1.0	Minimum amplitude limit for fundamental component

Table 1080: CMHAI Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
2nd H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 2nd harmonic component
3rd H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 3rd harmonic component
4th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 4th harmonic component
5th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 5th harmonic component
6th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 6th harmonic component
7th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 7th harmonic component
8th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 8th harmonic component
9th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 9th harmonic component
10th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 10th harmonic component
11th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 11th harmonic component
12th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 12th harmonic component
13th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 13th harmonic component
14th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 14th harmonic component
15th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 15th harmonic component
16th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 16th harmonic component
17th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 17th harmonic component
18th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 18th harmonic component
19th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 19th harmonic component
20th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 20th harmonic component
THD limit value	1.0 - 100.0	%	0.1	50.0	Limit for THD
TDD limit value	1.0 - 100.0	%	0.1	50.0	Limit for TDD
Distortion factor	THD TDD	-	-	THD	Defines the distortion factor used in limit supervision
Relative hysteresis	0 - 5	%	1	2	Relative hysteresis for limit supervision of mean values

9.2.9 Measured values

Table 1081: CMHAI Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_ALARM	BOOLEAN	0	Block alarm outputs

9.2.10 Monitored Data

Table 1082: CMHAI Monitored data

Name	Type	Values (Range)	Unit	Description
3SMNH1_A	REAL	-	%	Non-sliding 3s mean RMS value of 1st harmonic for phase A
3SMNH2_A	REAL	-	%	Non-sliding 3s mean RMS value of 2nd harmonic for phase A
3SMNH3_A	REAL	-	%	Non-sliding 3s mean RMS value of 3rd harmonic for phase A
3SMNH4_A	REAL	-	%	Non-sliding 3s mean RMS value of 4th harmonic for phase A
3SMNH5_A	REAL	-	%	Non-sliding 3s mean RMS value of 5th harmonic for phase A
3SMNH6_A	REAL	-	%	Non-sliding 3s mean RMS value of 6th harmonic for phase A
3SMNH7_A	REAL	-	%	Non-sliding 3s mean RMS value of 7th harmonic for phase A
3SMNH8_A	REAL	-	%	Non-sliding 3s mean RMS value of 8th harmonic for phase A
3SMNH9_A	REAL	-	%	Non-sliding 3s mean RMS value of 9th harmonic for phase A
3SMNH10_A	REAL	-	%	Non-sliding 3s mean RMS value of 10th harmonic for phase A
3SMNH11_A	REAL	-	%	Non-sliding 3s mean RMS value of 11th harmonic for phase A
3SMNH12_A	REAL	-	%	Non-sliding 3s mean RMS value of 12th harmonic for phase A
3SMNH13_A	REAL	-	%	Non-sliding 3s mean RMS value of 13th harmonic for phase A

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH14_A	REAL	-	%	Non-sliding 3s mean RMS value of 14th harmonic for phase A
3SMNH15_A	REAL	-	%	Non-sliding 3s mean RMS value of 15th harmonic for phase A
3SMNH16_A	REAL	-	%	Non-sliding 3s mean RMS value of 16th harmonic for phase A
3SMNH17_A	REAL	-	%	Non-sliding 3s mean RMS value of 17th harmonic for phase A
3SMNH18_A	REAL	-	%	Non-sliding 3s mean RMS value of 18th harmonic for phase A
3SMNH19_A	REAL	-	%	Non-sliding 3s mean RMS value of 19th harmonic for phase A
3SMNH20_A	REAL	-	%	Non-sliding 3s mean RMS value of 20th harmonic for phase A
3SMNTHD_A	REAL	-	%	Non-sliding 3s mean value of THD for phase A
3SMNTDD_A	REAL	-	%	Non-sliding 3s mean value of TDD for phase A
3SMNH1_B	REAL	-	%	Non-sliding 3s mean RMS value of 1st harmonic for phase B
3SMNH2_B	REAL	-	%	Non-sliding 3s mean RMS value of 2nd harmonic for phase B
3SMNH3_B	REAL	-	%	Non-sliding 3s mean RMS value of 3rd harmonic for phase B
3SMNH4_B	REAL	-	%	Non-sliding 3s mean RMS value of 4th harmonic for phase B
3SMNH5_B	REAL	-	%	Non-sliding 3s mean RMS value of 5th harmonic for phase B
3SMNH6_B	REAL	-	%	Non-sliding 3s mean RMS value of 6th harmonic for phase B
3SMNH7_B	REAL	-	%	Non-sliding 3s mean RMS value of 7th harmonic for phase B
3SMNH8_B	REAL	-	%	Non-sliding 3s mean RMS value of 8th harmonic for phase B

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH9_B	REAL	-	%	Non-sliding 3s mean RMS value of 9th harmonic for phase B
3SMNH10_B	REAL	-	%	Non-sliding 3s mean RMS value of 10th harmonic for phase B
3SMNH11_B	REAL	-	%	Non-sliding 3s mean RMS value of 11th harmonic for phase B
3SMNH12_B	REAL	-	%	Non-sliding 3s mean RMS value of 12th harmonic for phase B
3SMNH13_B	REAL	-	%	Non-sliding 3s mean RMS value of 13th harmonic for phase B
3SMNH14_B	REAL	-	%	Non-sliding 3s mean RMS value of 14th harmonic for phase B
3SMNH15_B	REAL	-	%	Non-sliding 3s mean RMS value of 15th harmonic for phase B
3SMNH16_B	REAL	-	%	Non-sliding 3s mean RMS value of 16th harmonic for phase B
3SMNH17_B	REAL	-	%	Non-sliding 3s mean RMS value of 17th harmonic for phase B
3SMNH18_B	REAL	-	%	Non-sliding 3s mean RMS value of 18th harmonic for phase B
3SMNH19_B	REAL	-	%	Non-sliding 3s mean RMS value of 19th harmonic for phase B
3SMNH20_B	REAL	-	%	Non-sliding 3s mean RMS value of 20th harmonic for phase B
3SMNTHD_B	REAL	-	%	Non-sliding 3s mean value of THD for phase B
3SMNTDD_B	REAL	-	%	Non-sliding 3s mean value of TDD for phase B
3SMNH1_C	REAL	-	%	Non-sliding 3s mean RMS value of 1st harmonic for phase C
3SMNH2_C	REAL	-	%	Non-sliding 3s mean RMS value of 2nd harmonic for phase C
3SMNH3_C	REAL	-	%	Non-sliding 3s mean RMS value of 3rd harmonic for phase C

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH4_C	REAL	-	%	Non-sliding 3s mean RMS value of 4th harmonic for phase C
3SMNH5_C	REAL	-	%	Non-sliding 3s mean RMS value of 5th harmonic for phase C
3SMNH6_C	REAL	-	%	Non-sliding 3s mean RMS value of 6th harmonic for phase C
3SMNH7_C	REAL	-	%	Non-sliding 3s mean RMS value of 7th harmonic for phase C
3SMNH8_C	REAL	-	%	Non-sliding 3s mean RMS value of 8th harmonic for phase C
3SMNH9_C	REAL	-	%	Non-sliding 3s mean RMS value of 9th harmonic for phase C
3SMNH10_C	REAL	-	%	Non-sliding 3s mean RMS value of 10th harmonic for phase C
3SMNH11_C	REAL	-	%	Non-sliding 3s mean RMS value of 11th harmonic for phase C
3SMNH12_C	REAL	-	%	Non-sliding 3s mean RMS value of 12th harmonic for phase C
3SMNH13_C	REAL	-	%	Non-sliding 3s mean RMS value of 13th harmonic for phase C
3SMNH14_C	REAL	-	%	Non-sliding 3s mean RMS value of 14th harmonic for phase C
3SMNH15_C	REAL	-	%	Non-sliding 3s mean RMS value of 15th harmonic for phase C
3SMNH16_C	REAL	-	%	Non-sliding 3s mean RMS value of 16th harmonic for phase C
3SMNH17_C	REAL	-	%	Non-sliding 3s mean RMS value of 17th harmonic for phase C
3SMNH18_C	REAL	-	%	Non-sliding 3s mean RMS value of 18th harmonic for phase C
3SMNH19_C	REAL	-	%	Non-sliding 3s mean RMS value of 19th harmonic for phase C
3SMNH20_C	REAL	-	%	Non-sliding 3s mean RMS value of 20th harmonic for phase C

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNTHD_C	REAL	-	%	Non-sliding 3s mean value of THD for phase C
3SMNTDD_C	REAL	-	%	Non-sliding 3s mean value of TDD for phase C
MAXH1	REAL	-	%	Max 1st harmonic updated after exiting alarm state
MAXH2	REAL	-	%	Max 2nd harmonic updated after exiting alarm state
MAXH3	REAL	-	%	Max 3rd harmonic updated after exiting alarm state
MAXH4	REAL	-	%	Max 4th harmonic updated after exiting alarm state
MAXH5	REAL	-	%	Max 5th harmonic updated after exiting alarm state
MAXH6	REAL	-	%	Max 6th harmonic updated after exiting alarm state
MAXH7	REAL	-	%	Max 7th harmonic updated after exiting alarm state
MAXH8	REAL	-	%	Max 8th harmonic updated after exiting alarm state
MAXH9	REAL	-	%	Max 9th harmonic updated after exiting alarm state
MAXH10	REAL	-	%	Max 10th harmonic updated after exiting alarm state
MAXH11	REAL	-	%	Max 11th harmonic updated after exiting alarm state
MAXH12	REAL	-	%	Max 12th harmonic updated after exiting alarm state
MAXH13	REAL	-	%	Max 13th harmonic updated after exiting alarm state
MAXH14	REAL	-	%	Max 14th harmonic updated after exiting alarm state
MAXH15	REAL	-	%	Max 15th harmonic updated after exiting alarm state

Table continues on next page

Name	Type	Values (Range)	Unit	Description
MAXH16	REAL	-	%	Max 16th harmonic updated after exiting alarm state
MAXH17	REAL	-	%	Max 17th harmonic updated after exiting alarm state
MAXH18	REAL	-	%	Max 18th harmonic updated after exiting alarm state
MAXH19	REAL	-	%	Max 19th harmonic updated after exiting alarm state
MAXH20	REAL	-	%	Max 20th harmonic updated after exiting alarm state
MAXTHD	REAL	-	%	Max THD updated after exiting alarm state
MAXTDD	REAL	-	%	Max TDD updated after exiting alarm state
MAXHDATE	INTEGER	-	-	Date and time when maximum harmonic occurred
MONITORED_PH	INTEGER	1=Phase A 2=Phase B 3=Phase C	-	Indicates the actual phase monitored 1=Ph A, 2=Ph B, 3=Ph C
ALM_MN_H	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when harmonic RMS value is greater than limit
ALM_MN_THD	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when THD value is greater than limit
ALM_MN_TDD	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when TDD value is greater than limit
NO_ALM_MN_H	INTEGER	-	-	Highest harmonic that exceeded its alarm limit

9.3 Voltage harmonics VPPMHAI and VPHMHAI

9.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage harmonics (phase-to-phase)	VPPMHAI	PQM3Upp	PQM3Vpp
Voltage harmonics (phase-to-earth)	VPHMHAI	PQM3Upe	PQM3Vpg

9.3.2 Function block

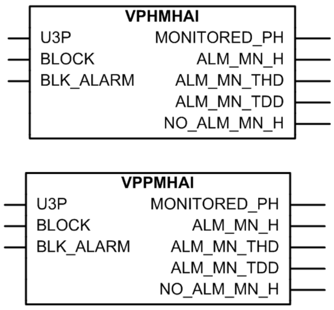


Figure 549: Function block

9.3.3 Functionality

The voltage harmonics monitoring function VPxMHAI is a sample-based function designed for monitoring the waveform distortion in distribution and transmission networks.

VPxMHAI is used for monitoring the individual voltage harmonic components (up to 20^{th}), total harmonic distortion (THD) and total demand distortion (TDD). The function monitors the selected phase or the phase with the highest THD or TDD. VPxMHAI provides three-second mean RMS values of the harmonic components, THD and TDD.

The function also includes an alarm functionality. Each harmonic and THD or TDD RMS values are monitored; exceeding the selected limit raises an alarm. When VPxMHAI enters an alarm state (a harmonic RMS limit is exceeded), it also tracks the maximum THD or TDD value. After the alarm state is exited, the function provides THD or TDD and RMS values for each harmonic component.

The function contains a blocking functionality. It is possible to block a set of function outputs or the function itself.

9.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the voltage waveform distortion measurement function can be described with a module diagram. All modules in the diagrams are explained in the next sections.

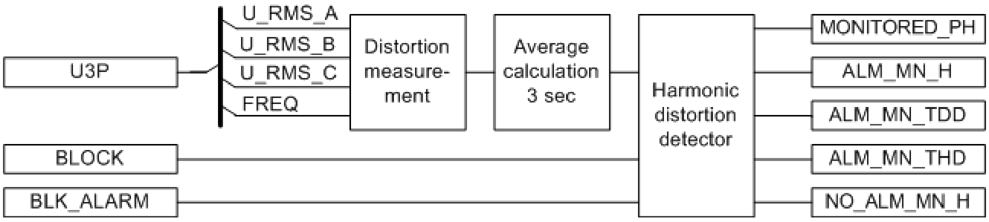


Figure 550: VPHMHAI functional module diagram

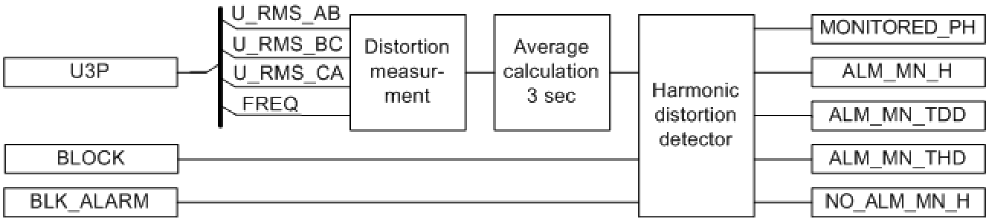


Figure 551: VPPMHAI functional module diagram

9.3.4.1 Distortion measurement

Distortion measurement is a sample-based module which measures the quasi-stationary (slowly varying) harmonics up to 20^{th}. The distortion measurement does not include rapidly changing harmonics, interharmonics or other spurious components. The harmonics are calculated when the amplitude of fundamental voltage is above the *Low limit* setting. The distortion measurement module calculates THD or TDD depending on the *Distortion factor* setting.

$$THD = \frac{\sqrt{\sum_{k=2}^{L} U_k^2}}{U_1}$$

(Equation 180)

U_k RMS value of voltage harmonic component 2…L (L = 20)

U_1 RMS value of voltage fundamental component

$$TDD = \frac{\sqrt{\sum_{k=2}^{L} U_k^2}}{U_N}$$

(Equation 181)

U_N RMS value of voltage fundamental component

9.3.4.2 Average calculation 3 seconds

This module calculates the three-phase three-second average THD or TDD and each individual 1...20 harmonic value which are used for continuous monitoring. For VPHMHAI, the output values 3SMNH(1…20)_A, 3SMNTHD_A, 3SMNTDD_A, 3SMNH(1…20)_B, 3SMNTHD_B, 3SMNTDD_B, 3SMNH(1…20)_C, 3SMNTHD_C and 3SMNTDD_C are available in the monitored data view. Similarly for VPPMHAI, the output values 3SMNH(1…20)_AB, 3SMNTHD_AB, 3SMNTDD_AB, 3SMNH(1…20)_BC, 3SMNTHD_BC, 3SMNTDD_BC, 3SMNH(1…20)_CA, 3SMNTHD_CA and 3SMNTDD_CA are available in the monitored data view.

9.3.4.3 Harmonic distortion detector

The *Measuring mode* setting defines which phase is being monitored. “Phase A”, “Phase B” and “Phase C” for VPHMHAI and "Phase AB", “Phase BC” and “Phase CA” for VPPMHAI are the options available for selecting the phases. The "Worst case" monitoring mode is used for the phase with the highest measured THD or TDD value. This means that the actual phase monitored can change continuously. The MONITORED_PH output indicates the actual phase.

The three-second average THD or TDD and each individual 2...20 harmonic value is continuously calculated and compared to the set value *THD limit value*, *TDD limit value* and 2...20 *H limit Val*. If a value exceeds the limit, the ALM_MN_H, ALM_MN_THD and ALM_MN_TDD outputs are activated respectively.

The NO_ALM_MN_H output indicates the number of harmonics components that exceeds the respective limit value.

The tracking of maximum values based on the three second averages starts when at least one of the outputs ALM_MN_H, ALM_MN_THD or ALM_MN_TDD is active. The MAXH(1...20), MAXTHD and MAXTDD outputs indicate the maximum harmonic values occurred during the previous alarm state. These outputs are available in the monitored data view.

The MAXHDATE output indicates the date and time at which the last maximum harmonic distortion (THD / TDD) was measured.

The BLK_ALARM input is used to block all the alarm outputs (ALM_MN_H, ALM_MN_THD and ALM_MN_TDD). In this case, all the other outputs are updated normally. Activation of the BLOCK input blocks all the alarm outputs and the output indicating the maximum values.

The *Relative hysteresis* setting is used for preventing an unnecessary oscillations if the voltage signal varies above or below the *limit value* setting.

9.3.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

9.3.6 Application

The power quality in standards is defined through the characteristics of the supply voltage. Transients, short and long duration voltage variations, unbalance and waveform distortion are the key characteristics describing power quality. The power quality is however a customer-driven issue. It can be said that any power problem concerning the voltage or current that results in the failure or misoperation of the customer equipment is a power quality problem.

Harmonic distortion in a power system is caused by nonlinear devices. Electronic power converter loads constitute the most important class of the nonlinear loads in a power system. A number of single-phase electronic equipments (personal computers, printers, copiers and so on) in the switch mode power supplies, have a high third-harmonic content in the current. The three-phase electronic power converters (dc/ac drives) do not generate the third-harmonic currents, but they can be a significant source of harmonics.

The harmonic voltage distortion in a power system depends on the current distortion produced by the nonlinear loads and on the impedance characteristics visible to each load. The most sensitive equipment to voltage harmonics is the data processing and communication equipment, However, these devices are considerable current harmonic sources. These devices are susceptible to the misoperation caused by a harmonic distortion. For example, in computers and medical instruments considerably low harmonic levels can result in malfunctions that can have serious consequences. In a rotating machinery, the major effect of harmonic voltages and currents is an increased heating due to iron and copper losses at the harmonic frequencies.

The power quality monitoring is an essential service utility that can be provided for the industries and key customers. Monitoring system provides the information about the system disturbances and their possible causes. The monitoring system can also detect problem conditions throughout the system before they can cause customer complaints, equipment malfunctions, and even equipment damage or failure. Power quality problems are not limited to the utility side of the system. In fact, the majority of power quality problems are localized within the customer facilities. Thus, the power quality monitoring is not only an effective customer service strategy, but also a way to protect the quality of the utility reputation for a quality power and service.

xMHAI provides a convenient method for monitoring the power quality by means of a voltage or current waveform distortion. The function monitors the voltage or current harmonics in the power transmission and distribution networks. xMHAI produces statistical data about the harmonic distortion which is comparable to the standard definitions of good quality power. In addition, the function provides a short term, three seconds average and maximum values for the THD and individual harmonics.

9.3.7 Signals

Table 1083: VPHMHAI Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block of function
BLK_ALARM	BOOLEAN	0	Block alarm outputs

Table 1084: VPPMHAI Input signals

Name	Type	Default	Description
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block of function
BLK_ALARM	BOOLEAN	0	Block alarm outputs

Table 1085: VPHMHAI Output signals

Name	Type	Description
MONITORED_PH	INTEGER	Indicates the actual phase monitored 1=Ph A, 2=Ph B, 3=Ph C
ALM_MN_H	BOOLEAN	Alarm signal when harmonic RMS value is greater than limit
ALM_MN_THD	BOOLEAN	Alarm signal when THD value is greater than limit
ALM_MN_TDD	BOOLEAN	Alarm signal when TDD value is greater than limit
NO_ALM_MN_H	INTEGER	Highest harmonic that exceeded its alarm limit

Table 1086: VPPMHAI Output signals

Name	Type	Description
MONITORED_PH	INTEGER	Indicates the actual phase monitored 1=Ph A, 2=Ph B, 3=Ph C
ALM_MN_H	BOOLEAN	Alarm signal when harmonic RMS value is greater than limit
ALM_MN_THD	BOOLEAN	Alarm signal when THD value is greater than limit
ALM_MN_TDD	BOOLEAN	Alarm signal when TDD value is greater than limit
NO_ALM_MN_H	INTEGER	Highest harmonic that exceeded its alarm limit

9.3.8 Settings

Table 1087: VPHMHAI Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
Measuring mode	Phase A Phase B Phase C Worst case	-	-	Worst case	Specifies the monitored phase
Low limit	1.0 - 50.0	%	0.1	1.0	Minimum amplitude limit for fundamental component

Table 1088: VPHMHAI Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
2nd H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 2nd harmonic component
3rd H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 3rd harmonic component
4th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 4th harmonic component
5th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 5th harmonic component
6th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 6th harmonic component
7th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 7th harmonic component
8th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 8th harmonic component
9th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 9th harmonic component
10th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 10th harmonic component
11th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 11th harmonic component
12th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 12th harmonic component
13th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 13th harmonic component
14th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 14th harmonic component
15th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 15th harmonic component
16th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 16th harmonic component
Table continues on next page					

Name	Values (Range)	Unit	Step	Default	Description
17th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 17th harmonic component
18th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 18th harmonic component
19th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 19th harmonic component
20th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 20th harmonic component
THD limit value	1.0 - 100.0	%	0.1	50.0	Limit for THD
TDD limit value	1.0 - 100.0	%	0.1	50.0	Limit for TDD
Distortion factor	THD TDD	-	-	THD	Defines the distortion factor used in limit supervision
Relative hysteresis	0 - 5	%	1	2	Relative hysteresis for limit supervision of mean values

Table 1089: VPPMHAI Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off/On
Measuring mode	Phase AB Phase BC Phase CA Worst case	-	-	Worst case	Specifies the monitored phase
Low limit	1.0 - 50.0	%	0.1	1.0	Minimum amplitude limit for fundamental component

Table 1090: VPPMHAI Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
2nd H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 2nd harmonic component
3rd H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 3rd harmonic component
4th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 4th harmonic component
5th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 5th harmonic component
6th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 6th harmonic component
7th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 7th harmonic component
8th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 8th harmonic component

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
9th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 9th harmonic component
10th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 10th harmonic component
11th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 11th harmonic component
12th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 12th harmonic component
13th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 13th harmonic component
14th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 14th harmonic component
15th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 15th harmonic component
16th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 16th harmonic component
17th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 17th harmonic component
18th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 18th harmonic component
19th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 19th harmonic component
20th H limit Val	1.0 - 100.0	%IB	0.1	50.0	Limit for RMS value of 20th harmonic component
THD limit value	1.0 - 100.0	%	0.1	50.0	Limit for THD
TDD limit value	1.0 - 100.0	%	0.1	50.0	Limit for TDD
Distortion factor	THD TDD	-	-	THD	Defines the distortion factor used in limit supervision
Relative hysteresis	0 - 5	%	1	2	Relative hysteresis for limit supervision of mean values

9.3.9 Measured values

Table 1091: VPHMHAI Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_ALARM	BOOLEAN	0	Block alarm outputs

Table 1092: VPPMHAI Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_ALARM	BOOLEAN	0	Block alarm outputs

9.3.10 Monitored Data

Table 1093: VPHMHAI Monitored data

Name	Type	Values (Range)	Unit	Description
3SMNH1_A	REAL	-	%	Non-sliding 3s mean RMS value of 1st harmonic for phase A
3SMNH2_A	REAL	-	%	Non-sliding 3s mean RMS value of 2nd harmonic for phase A
3SMNH3_A	REAL	-	%	Non-sliding 3s mean RMS value of 3rd harmonic for phase A
3SMNH4_A	REAL	-	%	Non-sliding 3s mean RMS value of 4th harmonic for phase A
3SMNH5_A	REAL	-	%	Non-sliding 3s mean RMS value of 5th harmonic for phase A
3SMNH6_A	REAL	-	%	Non-sliding 3s mean RMS value of 6th harmonic for phase A
3SMNH7_A	REAL	-	%	Non-sliding 3s mean RMS value of 7th harmonic for phase A
3SMNH8_A	REAL	-	%	Non-sliding 3s mean RMS value of 8th harmonic for phase A
3SMNH9_A	REAL	-	%	Non-sliding 3s mean RMS value of 9th harmonic for phase A
3SMNH10_A	REAL	-	%	Non-sliding 3s mean RMS value of 10th harmonic for phase A
3SMNH11_A	REAL	-	%	Non-sliding 3s mean RMS value of 11th harmonic for phase A
3SMNH12_A	REAL	-	%	Non-sliding 3s mean RMS value of 12th harmonic for phase A
3SMNH13_A	REAL	-	%	Non-sliding 3s mean RMS value of 13th harmonic for phase A
3SMNH14_A	REAL	-	%	Non-sliding 3s mean RMS value of 14th harmonic for phase A
3SMNH15_A	REAL	-	%	Non-sliding 3s mean RMS value of 15th harmonic for phase A
3SMNH16_A	REAL	-	%	Non-sliding 3s mean RMS value of 16th harmonic for phase A

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH17_A	REAL	-	%	Non-sliding 3s mean RMS value of 17th harmonic for phase A
3SMNH18_A	REAL	-	%	Non-sliding 3s mean RMS value of 18th harmonic for phase A
3SMNH19_A	REAL	-	%	Non-sliding 3s mean RMS value of 19th harmonic for phase A
3SMNH20_A	REAL	-	%	Non-sliding 3s mean RMS value of 20th harmonic for phase A
3SMNTHD_A	REAL	-	%	Non-sliding 3s mean value of THD for phase A
3SMNTDD_A	REAL	-	%	Non-sliding 3s mean value of TDD for phase A
3SMNH1_B	REAL	-	%	Non-sliding 3s mean RMS value of 1st harmonic for phase B
3SMNH2_B	REAL	-	%	Non-sliding 3s mean RMS value of 2nd harmonic for phase B
3SMNH3_B	REAL	-	%	Non-sliding 3s mean RMS value of 3rd harmonic for phase B
3SMNH4_B	REAL	-	%	Non-sliding 3s mean RMS value of 4th harmonic for phase B
3SMNH5_B	REAL	-	%	Non-sliding 3s mean RMS value of 5th harmonic for phase B
3SMNH6_B	REAL	-	%	Non-sliding 3s mean RMS value of 6th harmonic for phase B
3SMNH7_B	REAL	-	%	Non-sliding 3s mean RMS value of 7th harmonic for phase B
3SMNH8_B	REAL	-	%	Non-sliding 3s mean RMS value of 8th harmonic for phase B
3SMNH9_B	REAL	-	%	Non-sliding 3s mean RMS value of 9th harmonic for phase B
3SMNH10_B	REAL	-	%	Non-sliding 3s mean RMS value of 10th harmonic for phase B
3SMNH11_B	REAL	-	%	Non-sliding 3s mean RMS value of 11th harmonic for phase B

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH12_B	REAL	-	%	Non-sliding 3s mean RMS value of 12th harmonic for phase B
3SMNH13_B	REAL	-	%	Non-sliding 3s mean RMS value of 13th harmonic for phase B
3SMNH14_B	REAL	-	%	Non-sliding 3s mean RMS value of 14th harmonic for phase B
3SMNH15_B	REAL	-	%	Non-sliding 3s mean RMS value of 15th harmonic for phase B
3SMNH16_B	REAL	-	%	Non-sliding 3s mean RMS value of 16th harmonic for phase B
3SMNH17_B	REAL	-	%	Non-sliding 3s mean RMS value of 17th harmonic for phase B
3SMNH18_B	REAL	-	%	Non-sliding 3s mean RMS value of 18th harmonic for phase B
3SMNH19_B	REAL	-	%	Non-sliding 3s mean RMS value of 19th harmonic for phase B
3SMNH20_B	REAL	-	%	Non-sliding 3s mean RMS value of 20th harmonic for phase B
3SMNTHD_B	REAL	-	%	Non-sliding 3s mean value of THD for phase B
3SMNTDD_B	REAL	-	%	Non-sliding 3s mean value of TDD for phase B
3SMNH1_C	REAL	-	%	Non-sliding 3s mean RMS value of 1st harmonic for phase C
3SMNH2_C	REAL	-	%	Non-sliding 3s mean RMS value of 2nd harmonic for phase C
3SMNH3_C	REAL	-	%	Non-sliding 3s mean RMS value of 3rd harmonic for phase C
3SMNH4_C	REAL	-	%	Non-sliding 3s mean RMS value of 4th harmonic for phase C
3SMNH5_C	REAL	-	%	Non-sliding 3s mean RMS value of 5th harmonic for phase C
3SMNH6_C	REAL	-	%	Non-sliding 3s mean RMS value of 6th harmonic for phase C

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH7_C	REAL	-	%	Non-sliding 3s mean RMS value of 7th harmonic for phase C
3SMNH8_C	REAL	-	%	Non-sliding 3s mean RMS value of 8th harmonic for phase C
3SMNH9_C	REAL	-	%	Non-sliding 3s mean RMS value of 9th harmonic for phase C
3SMNH10_C	REAL	-	%	Non-sliding 3s mean RMS value of 10th harmonic for phase C
3SMNH11_C	REAL	-	%	Non-sliding 3s mean RMS value of 11th harmonic for phase C
3SMNH12_C	REAL	-	%	Non-sliding 3s mean RMS value of 12th harmonic for phase C
3SMNH13_C	REAL	-	%	Non-sliding 3s mean RMS value of 13th harmonic for phase C
3SMNH14_C	REAL	-	%	Non-sliding 3s mean RMS value of 14th harmonic for phase C
3SMNH15_C	REAL	-	%	Non-sliding 3s mean RMS value of 15th harmonic for phase C
3SMNH16_C	REAL	-	%	Non-sliding 3s mean RMS value of 16th harmonic for phase C
3SMNH17_C	REAL	-	%	Non-sliding 3s mean RMS value of 17th harmonic for phase C
3SMNH18_C	REAL	-	%	Non-sliding 3s mean RMS value of 18th harmonic for phase C
3SMNH19_C	REAL	-	%	Non-sliding 3s mean RMS value of 19th harmonic for phase C
3SMNH20_C	REAL	-	%	Non-sliding 3s mean RMS value of 20th harmonic for phase C
3SMNTHD_C	REAL	-	%	Non-sliding 3s mean value of THD for phase C
3SMNTDD_C	REAL	-	%	Non-sliding 3s mean value of TDD for phase C
MAXH1	REAL	-	%	Max 1st harmonic updated after exiting alarm state

Table continues on next page

Name	Type	Values (Range)	Unit	Description
MAXH2	REAL	-	%	Max 2nd harmonic updated after exiting alarm state
MAXH3	REAL	-	%	Max 3rd harmonic updated after exiting alarm state
MAXH4	REAL	-	%	Max 4th harmonic updated after exiting alarm state
MAXH5	REAL	-	%	Max 5th harmonic updated after exiting alarm state
MAXH6	REAL	-	%	Max 6th harmonic updated after exiting alarm state
MAXH7	REAL	-	%	Max 7th harmonic updated after exiting alarm state
MAXH8	REAL	-	%	Max 8th harmonic updated after exiting alarm state
MAXH9	REAL	-	%	Max 9th harmonic updated after exiting alarm state
MAXH10	REAL	-	%	Max 10th harmonic updated after exiting alarm state
MAXH11	REAL	-	%	Max 11th harmonic updated after exiting alarm state
MAXH12	REAL	-	%	Max 12th harmonic updated after exiting alarm state
MAXH13	REAL	-	%	Max 13th harmonic updated after exiting alarm state
MAXH14	REAL	-	%	Max 14th harmonic updated after exiting alarm state
MAXH15	REAL	-	%	Max 15th harmonic updated after exiting alarm state
MAXH16	REAL	-	%	Max 16th harmonic updated after exiting alarm state
MAXH17	REAL	-	%	Max 17th harmonic updated after exiting alarm state
MAXH18	REAL	-	%	Max 18th harmonic updated after exiting alarm state

Table continues on next page

Name	Type	Values (Range)	Unit	Description
MAXH19	REAL	-	%	Max 19th harmonic updated after exiting alarm state
MAXH20	REAL	-	%	Max 20th harmonic updated after exiting alarm state
MAXTHD	REAL	-	%	Max THD updated after exiting alarm state
MAXTDD	REAL	-	%	Max TDD updated after exiting alarm state
MAXHDATE	INTEGER	-	-	Date and time when maximum harmonic occurred
MONITORED_PH	INTEGER	1=Phase A 2=Phase B 3=Phase C	-	Indicates the actual phase monitored 1=Ph A, 2=Ph B, 3=Ph C
ALM_MN_H	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when harmonic RMS value is greater than limit
ALM_MN_THD	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when THD value is greater than limit
ALM_MN_TDD	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when TDD value is greater than limit
NO_ALM_MN_H	INTEGER	-	-	Highest harmonic that exceeded its alarm limit

Table 1094: VPPMHAI Monitored data

Name	Type	Values (Range)	Unit	Description
3SMNH1_AB	REAL	-	%	Non-sliding 3s mean RMS value of 1st harmonic for phase AB
3SMNH2_AB	REAL	-	%	Non-sliding 3s mean RMS value of 2nd harmonic for phase AB
3SMNH3_AB	REAL	-	%	Non-sliding 3s mean RMS value of 3rd harmonic for phase AB
3SMNH4_AB	REAL	-	%	Non-sliding 3s mean RMS value of 4th harmonic for phase AB
3SMNH5_AB	REAL	-	%	Non-sliding 3s mean RMS value of 5th harmonic for phase AB
3SMNH6_AB	REAL	-	%	Non-sliding 3s mean RMS value of 6th harmonic for phase AB
3SMNH7_AB	REAL	-	%	Non-sliding 3s mean RMS value of 7th harmonic for phase AB

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH8_AB	REAL	-	%	Non-sliding 3s mean RMS value of 8th harmonic for phase AB
3SMNH9_AB	REAL	-	%	Non-sliding 3s mean RMS value of 9th harmonic for phase AB
3SMNH10_AB	REAL	-	%	Non-sliding 3s mean RMS value of 10th harmonic for phase AB
3SMNH11_AB	REAL	-	%	Non-sliding 3s mean RMS value of 11th harmonic for phase AB
3SMNH12_AB	REAL	-	%	Non-sliding 3s mean RMS value of 12th harmonic for phase AB
3SMNH13_AB	REAL	-	%	Non-sliding 3s mean RMS value of 13th harmonic for phase AB
3SMNH14_AB	REAL	-	%	Non-sliding 3s mean RMS value of 14th harmonic for phase AB
3SMNH15_AB	REAL	-	%	Non-sliding 3s mean RMS value of 15th harmonic for phase AB
3SMNH16_AB	REAL	-	%	Non-sliding 3s mean RMS value of 16th harmonic for phase AB
3SMNH17_AB	REAL	-	%	Non-sliding 3s mean RMS value of 17th harmonic for phase AB
3SMNH18_AB	REAL	-	%	Non-sliding 3s mean RMS value of 18th harmonic for phase AB
3SMNH19_AB	REAL	-	%	Non-sliding 3s mean RMS value of 19th harmonic for phase AB
3SMNH20_AB	REAL	-	%	Non-sliding 3s mean RMS value of 20th harmonic for phase AB
3SMNTHD_AB	REAL	-	%	Non-sliding 3s mean value of THD for phase AB
3SMNTDD_AB	REAL	-	%	Non-sliding 3s mean value of TDD for phase AB
3SMNH1_BC	REAL	-	%	Non-sliding 3s mean RMS value of 1st harmonic for phase BC
3SMNH2_BC	REAL	-	%	Non-sliding 3s mean RMS value of 2nd harmonic for phase BC

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH3_BC	REAL	-	%	Non-sliding 3s mean RMS value of 3rd harmonic for phase BC
3SMNH4_BC	REAL	-	%	Non-sliding 3s mean RMS value of 4th harmonic for phase BC
3SMNH5_BC	REAL	-	%	Non-sliding 3s mean RMS value of 5th harmonic for phase BC
3SMNH6_BC	REAL	-	%	Non-sliding 3s mean RMS value of 6th harmonic for phase BC
3SMNH7_BC	REAL	-	%	Non-sliding 3s mean RMS value of 7th harmonic for phase BC
3SMNH8_BC	REAL	-	%	Non-sliding 3s mean RMS value of 8th harmonic for phase BC
3SMNH9_BC	REAL	-	%	Non-sliding 3s mean RMS value of 9th harmonic for phase BC
3SMNH10_BC	REAL	-	%	Non-sliding 3s mean RMS value of 10th harmonic for phase BC
3SMNH11_BC	REAL	-	%	Non-sliding 3s mean RMS value of 11th harmonic for phase BC
3SMNH12_BC	REAL	-	%	Non-sliding 3s mean RMS value of 12th harmonic for phase BC
3SMNH13_BC	REAL	-	%	Non-sliding 3s mean RMS value of 13th harmonic for phase BC
3SMNH14_BC	REAL	-	%	Non-sliding 3s mean RMS value of 14th harmonic for phase BC
3SMNH15_BC	REAL	-	%	Non-sliding 3s mean RMS value of 15th harmonic for phase BC
3SMNH16_BC	REAL	-	%	Non-sliding 3s mean RMS value of 16th harmonic for phase BC
3SMNH17_BC	REAL	-	%	Non-sliding 3s mean RMS value of 17th harmonic for phase BC
3SMNH18_BC	REAL	-	%	Non-sliding 3s mean RMS value of 18th harmonic for phase BC
3SMNH19_BC	REAL	-	%	Non-sliding 3s mean RMS value of 19th harmonic for phase BC

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH20_BC	REAL	-	%	Non-sliding 3s mean RMS value of 20th harmonic for phase BC
3SMNTHD_BC	REAL	-	%	Non-sliding 3s mean value of THD for phase BC
3SMNTDD_BC	REAL	-	%	Non-sliding 3s mean value of TDD for phase BC
3SMNH1_CA	REAL	-	%	Non-sliding 3s mean RMS value of 1st harmonic for phase CA
3SMNH2_CA	REAL	-	%	Non-sliding 3s mean RMS value of 2nd harmonic for phase CA
3SMNH3_CA	REAL	-	%	Non-sliding 3s mean RMS value of 3rd harmonic for phase CA
3SMNH4_CA	REAL	-	%	Non-sliding 3s mean RMS value of 4th harmonic for phase CA
3SMNH5_CA	REAL	-	%	Non-sliding 3s mean RMS value of 5th harmonic for phase CA
3SMNH6_CA	REAL	-	%	Non-sliding 3s mean RMS value of 6th harmonic for phase CA
3SMNH7_CA	REAL	-	%	Non-sliding 3s mean RMS value of 7th harmonic for phase CA
3SMNH8_CA	REAL	-	%	Non-sliding 3s mean RMS value of 8th harmonic for phase CA
3SMNH9_CA	REAL	-	%	Non-sliding 3s mean RMS value of 9th harmonic for phase CA
3SMNH10_CA	REAL	-	%	Non-sliding 3s mean RMS value of 10th harmonic for phase CA
3SMNH11_CA	REAL	-	%	Non-sliding 3s mean RMS value of 11th harmonic for phase CA
3SMNH12_CA	REAL	-	%	Non-sliding 3s mean RMS value of 12th harmonic for phase CA
3SMNH13_CA	REAL	-	%	Non-sliding 3s mean RMS value of 13th harmonic for phase CA
3SMNH14_CA	REAL	-	%	Non-sliding 3s mean RMS value of 14th harmonic for phase CA

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3SMNH15_CA	REAL	-	%	Non-sliding 3s mean RMS value of 15th harmonic for phase CA
3SMNH16_CA	REAL	-	%	Non-sliding 3s mean RMS value of 16th harmonic for phase CA
3SMNH17_CA	REAL	-	%	Non-sliding 3s mean RMS value of 17th harmonic for phase CA
3SMNH18_CA	REAL	-	%	Non-sliding 3s mean RMS value of 18th harmonic for phase CA
3SMNH19_CA	REAL	-	%	Non-sliding 3s mean RMS value of 19th harmonic for phase CA
3SMNH20_CA	REAL	-	%	Non-sliding 3s mean RMS value of 20th harmonic for phase CA
3SMNTHD_CA	REAL	-	%	Non-sliding 3s mean value of THD for phase CA
3SMNTDD_CA	REAL	-	%	Non-sliding 3s mean value of TDD for phase CA
MAXH1	REAL	-	%	Max 1st harmonic updated after exiting alarm state
MAXH2	REAL	-	%	Max 2nd harmonic updated after exiting alarm state
MAXH3	REAL	-	%	Max 3rd harmonic updated after exiting alarm state
MAXH4	REAL	-	%	Max 4th harmonic updated after exiting alarm state
MAXH5	REAL	-	%	Max 5th harmonic updated after exiting alarm state
MAXH6	REAL	-	%	Max 6th harmonic updated after exiting alarm state
MAXH7	REAL	-	%	Max 7th harmonic updated after exiting alarm state
MAXH8	REAL	-	%	Max 8th harmonic updated after exiting alarm state
MAXH9	REAL	-	%	Max 9th harmonic updated after exiting alarm state

Table continues on next page

Name	Type	Values (Range)	Unit	Description
MAXH10	REAL	-	%	Max 10th harmonic updated after exiting alarm state
MAXH11	REAL	-	%	Max 11th harmonic updated after exiting alarm state
MAXH12	REAL	-	%	Max 12th harmonic updated after exiting alarm state
MAXH13	REAL	-	%	Max 13th harmonic updated after exiting alarm state
MAXH14	REAL	-	%	Max 14th harmonic updated after exiting alarm state
MAXH15	REAL	-	%	Max 15th harmonic updated after exiting alarm state
MAXH16	REAL	-	%	Max 16th harmonic updated after exiting alarm state
MAXH17	REAL	-	%	Max 17th harmonic updated after exiting alarm state
MAXH18	REAL	-	%	Max 18th harmonic updated after exiting alarm state
MAXH19	REAL	-	%	Max 19th harmonic updated after exiting alarm state
MAXH20	REAL	-	%	Max 20th harmonic updated after exiting alarm state
MAXTHD	REAL	-	%	Max THD updated after exiting alarm state
MAXTDD	REAL	-	%	Max TDD updated after exiting alarm state
MAXHDATE	INTEGER	-	-	Date and time when maximum harmonic occurred
MONITORED_PH	INTEGER	1=Phase AB 2=Phase BC 3=Phase CA	-	Indicates the actual phase monitored 1=Ph A, 2=Ph B, 3=Ph C
ALM_MN_H	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when harmonic RMS value is greater than limit
ALM_MN_THD	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when THD value is greater than limit
ALM_MN_TDD	BOOLEAN	0=FALSE 1=TRUE	-	Alarm signal when TDD value is greater than limit
NO_ALM_MN_H	INTEGER	-	-	Highest harmonic that exceeded its alarm limit

9.4 Voltage variation PHQVVR

9.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage variation	PHQVVR	PQMU	PQMV

9.4.2 Function block

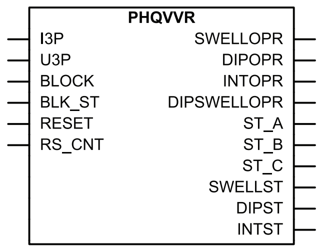


Figure 552: Function block

9.4.3 Functionality

The voltage variation measurement function PHQVVR is used for measuring the short-duration voltage variations in distribution networks.

Power quality in the voltage waveform is evaluated by measuring voltage swells, dips and interruptions. PHQVVR includes single-phase and three-phase voltage variation modes.

Typically, short-duration voltage variations are defined to last more than half of the nominal frequency period and less than one minute. The maximum magnitude (in the case of a voltage swell) or depth (in the case of a voltage dip or interruption) and the duration of the variation can be obtained by measuring the RMS value of the voltage for each phase. International standard 61000-4-30 defines the function to be implemented using the RMS value of the voltage.

PHQVVR contains a blocking functionality. It is possible to block a set of function outputs or the function itself, if desired.

9.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

When the setting is set to "Off", the counter outputs are stored in the nonvolatile memory and SWELLCNT, DIPCNT and INTCNT are reset.

The operation of the voltage variation detection function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

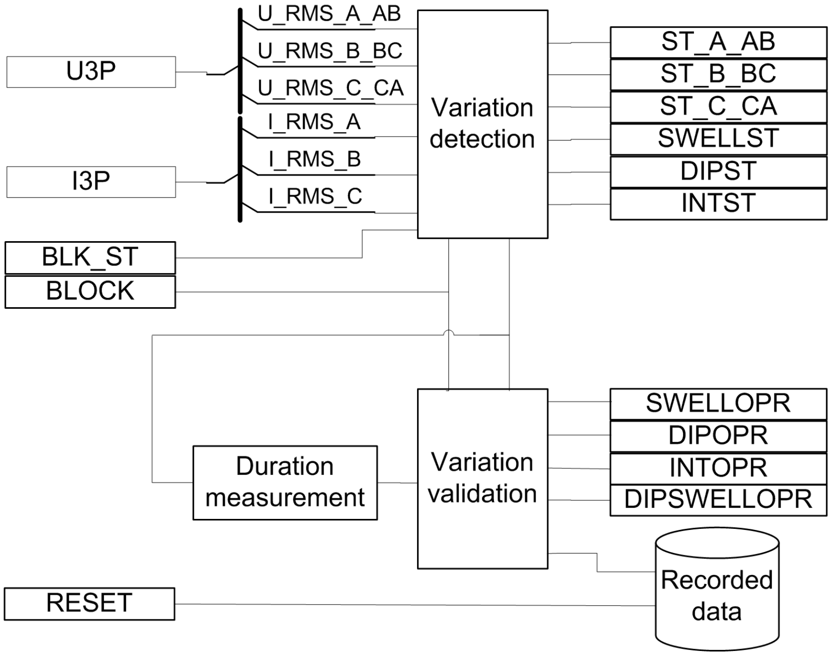


Figure 553: Functional module diagram. Group signal I3P and U3P are used for feeding the necessary analog signals to the function.

9.4.4.1 Variation detection

Variation detection compares the measured voltage to the limit settings. The input parameter *Voltage selection* is used to select whether phase-to-earth or phase-to-phase voltages are used for power quality monitoring. When there is a permanent undervoltage or overvoltage, the *Reference voltage* setting can be set to this voltage level to avoid the undesired voltage dip or swell indications. This is accomplished by converting the variation limits with the *Reference voltage* setting in the variation detection module. In other words, when there is a voltage different from the nominal voltage, the *Reference voltage* setting is set to that voltage.

The voltage detection module monitors continuously the voltage waveform for detecting voltage swells, dips and interruptions. When the measured RMS value drops below *Voltage dip set* and simultaneously stays above the value of *Voltage Int set*, the DIPST output is activated. If the voltage drops below the value of *Voltage Int set*, the INTST output is activated. When the measured RMS value rises above the value of *Voltage swell set*, the SWELLST output is activated.

The detection principle for voltage interruption is a special case. The INTST output is activated when the voltage levels of all monitored phases (defined with the *Phase supervision* setting) drop below the *Voltage Int* setting.

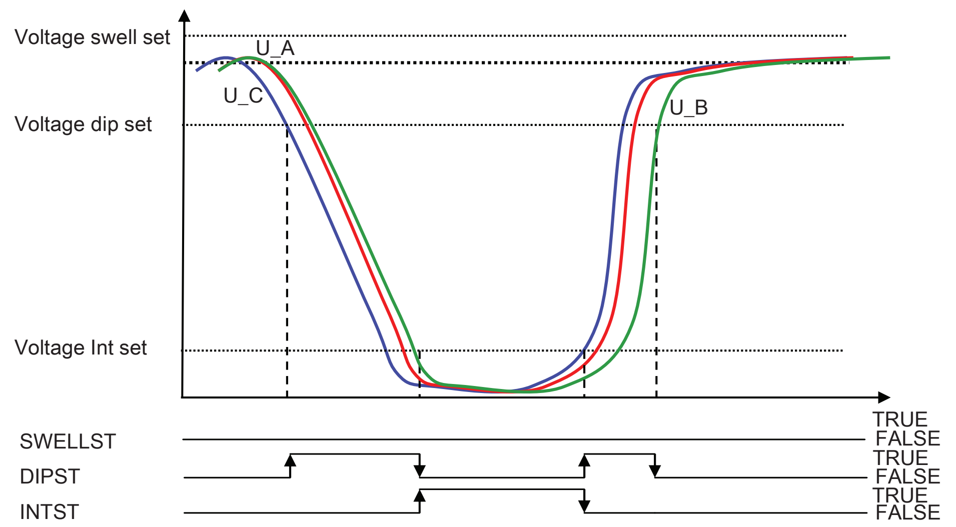


Figure 554: Detection of three-phase voltage interruption

Variation detection measures the voltage variation magnitude on each phase separately. This per-phase measurement enables the detection of, for example, single-phase earth faults. The ST_A_AB, ST_B_BC and ST_C_CA outputs are used to indicate on which phase voltage variation is detected. The *Phase supervision* parameter defines which voltage phase or phases are monitored. If a voltage phase is selected to be monitored, the function assumes it to be connected to a voltage measurement channel. In other words, if an unconnected phase is monitored, the function falsely detects voltage interruption on that particular phase.

The maximum magnitude and depth are defined as a percentage value calculated from the difference between the referenced and the measured voltage. For example, a 70 percent depth means that the minimum magnitude of a voltage dip variation is 70 percent of the reference voltage amplitude).

The BLK_ST input is used to block all the start outputs (ST_A_AB, ST_B_BC, ST_C_CA, SWELLST, DIPST and INTST). In this case, all other outputs (registers, operate outputs and counters) are updated normally. The activation of the BLOCK input blocks all the outputs, including the start outputs.

9.4.4.2 Duration measurement

The duration of each voltage phase corresponds to the period during which the measured RMS values remain above or below the corresponding limit.

The duration measurement module measures the voltage variation duration of each voltage channel separately and also the total variation duration. This means that the voltage variation may start on one phase and terminate on another phase. The total variation duration is as shown in Figure 555. The measured value of the total variation duration is used in the variation validation module for variation validation.

The duration of each voltage phase corresponds to the period during which the measured TRMS values remain above (swell) or below (dip, interruption) the corresponding limit.

Besides the three limit settings for the variation types dip and swell, there is also a specific duration setting for each limit setting. For interruption, there is only one limit setting common for the three duration settings. The maximum duration setting is common for all variation types.

The duration measurement module measures the voltage variation duration of each phase voltage separately when the *Phase mode* setting is "Single Phase". The phase variation durations are independent. However, when the *Phase mode* setting is "Three Phase", voltage variation may start only when all the monitored phases are active. An example of variation duration when *Phase mode* is "Single Phase" can be seen in Figure 555. The voltage variation in the example is detected as an interruption for the phase B and a dip for the phase A, and also the variation durations are interpreted as independent `U_B` and `U_A` durations. In case of single-phase interruption, the `DIPST` output is active when either `ST_A` or `ST_B` is active. The measured variation durations are the times measured between the activation of the `ST_A` or `ST_B` outputs and deactivation of the `ST_A` or `ST_B` outputs. When the *Phase mode* setting is "Three Phase", the example case does not result in any activation.

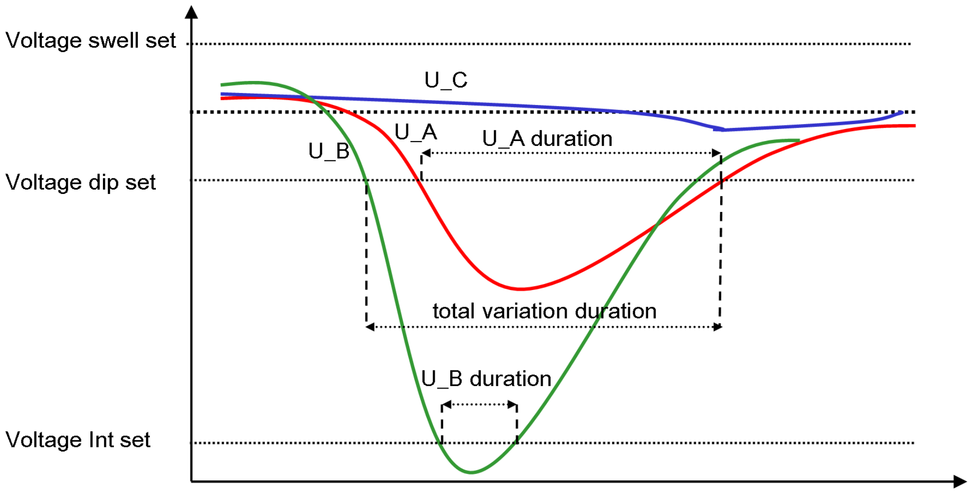


Figure 555: Duration measurements of single-phase interruption regarded as a voltage dip

9.4.4.3 Variation validation

The validation criterion for a valid voltage variation is that the measured total variation duration should be between the set value of the minimum and maximum duration (the *V Var Dur point 1* and *V Var Dur point 2* settings). In case of a three-phase interruption as shown in Figure 554, the measured total variation duration is the time measured between the first activation of the DIPST output and the last deactivation of the DIPST output.

A valid voltage variation is indicated with the SWELLOPR, DIPOPR, INTOPR or DIPSWELLOPR outputs. These outputs indicate also the type of the detected variation. The functionality of these outputs is shown in Figure 556 for start and operation outputs for concurrent dip and swell. After a new valid variation is detected, the measurement data of that variation are provided and the recorded data are updated accordingly.

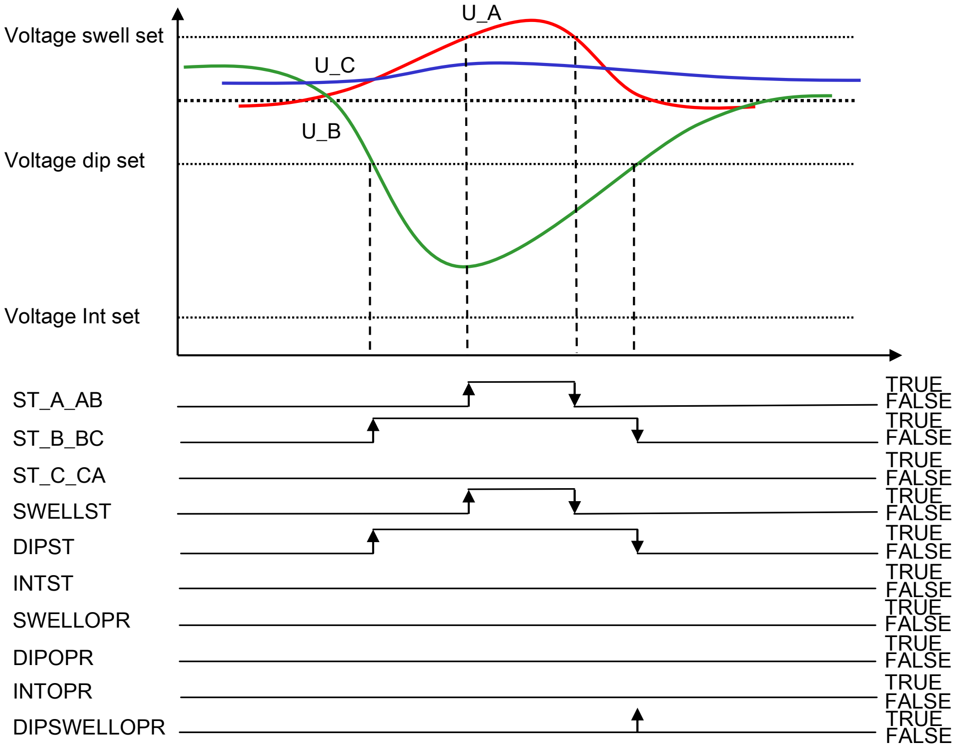


Figure 556: Start and operation outputs in case of concurrent dip and swell. The start outputs ST_A_AB, ST_B_BC, ST_C_CA, SWELLST. DIPST and INTST are activated by the variation detection module.

Each time a voltage variation is validated, the variation counter SWELLCNT, DIPCNT or INTCNT is increased by one according to the variation type. In case of a concurrent voltage dip and voltage swell, both SWELLCNT and DIPCNT are increased by one. These counters are available in the monitored data view on the

LHMI or through tools via communications. All variation counters can be reset with the binary input signal RS_CNT.

The SWELLOPR, DIPOPR, INTOPR and DIPSWELLOPR outputs stay activated for only 10 ms.

When the measured total variation duration is longer than the maximum duration *V Var Dur point 2*, the corresponding outputs are set to FALSE. Furthermore, the function block is disabled for as long as the variation remains active in order to prevent unnecessary indications.

The variation validation module contains a blocking functionality. The BLOCK input is used to block all the outputs of the function. However, the internal state of the function remains unchanged.

9.4.5 Recorded data

The information required for a later fault analysis is stored when the recorded data module is triggered. This happens when a valid voltage variation is detected.

Three sets of recorded data are available in total. The data are saved in data banks 1-3. The data bank 1 holds always the most recent recorded data. Older ones are moved into the subsequent banks (1→2 and 2→3) when a valid voltage variation is detected. When all three banks have data and a new variation is detected, the most recent data are placed into the bank 1 and the data in bank 3 become overwritten by the data from bank 2.

The recorded data can be reset with the RESET binary input signal or by navigating to the HMI reset (**Main menu / Clear / Clear recorded data / PHQVVRx**).

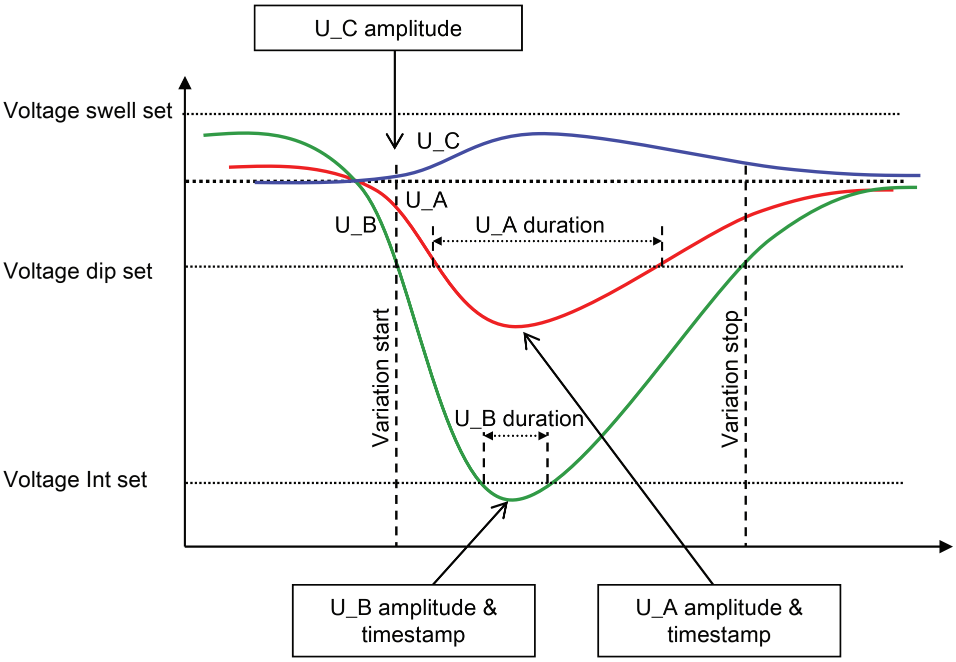


Figure 557: Valid recorded voltage dip

When the voltage variation starts, the function stores the phase current magnitudes preceding the activation moment. Also the initial voltage magnitudes are stored at the same moment. If the variation is, for example, a two-phase voltage dip, the voltage magnitude of the non-active phase is stored from this same moment. The function tracks each variation-active voltage phase, and the minimum or maximum magnitude, corresponding to the overvoltage or undervoltage, is stored. The time instant at which the minimum or maximum magnitude is measured is also stored for each voltage phase that is variation active. The recorded data are stored when variation stops.

Table 1095: PHQVVR recorded data

Parameter name	Description
Variation type	Variation type
Recording time	Fault time stamp
n Varn Str Tm PhA	Phase A variation start time
n Varn Str Tm PhB	Phase B variation start time
n Varn Str Tm PhC	Phase C variation start time
n Varn time PhA	Phase A voltage magnitude measuring time
n Varn time PhB	Phase B voltage magnitude measuring time
n Varn time PhC	Phase C voltage magnitude measuring time
n Varn A PhA	Phase A current magnitude
n Varn A PhB	Phase B current magnitude

Table continues on next page

Parameter name	Description
n Varn A PhC	Phase C current magnitude
n Varn V PhA	Phase A voltage magnitude
n Varn V PhB	Phase B voltage magnitude
n Varn V PhC	Phase C voltage magnitude
n Varn Dur PhA	Phase A variation duration
n Varn Dur PhB	Phase B variation duration
n Varn Dur PhC	Phase C variation duration

Table 1096: Enumeration values for the PHQVVR recorded data parameters

Parameter name	Enum name	Value
Variation type	No variation	"0"
Variation type	Swell	"1"
Variation type	Dip	"2"
Variation type	Interruption	"3"
Variation type	Dip and swell	"4"

9.4.6 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

9.4.7 Application

Voltage variations are the most typical power quality variations on the public electric network. Typically, short-duration voltage variations are defined to last more than half of the nominal frequency period and less than one minute (European Standard EN 50160 and IEEE Std 1159-1995).

These short-duration voltage variations are almost always caused by a fault condition. Depending on where the fault is located, it can cause either a temporary voltage rise (swell) or voltage drop (dip). A special case of voltage variation is the complete loss of voltage (interruption).

PHQVVR is used for measuring short-duration voltage variations in distribution networks. The power quality is evaluated in the voltage waveform by measuring the voltage swells, dips and interruptions.

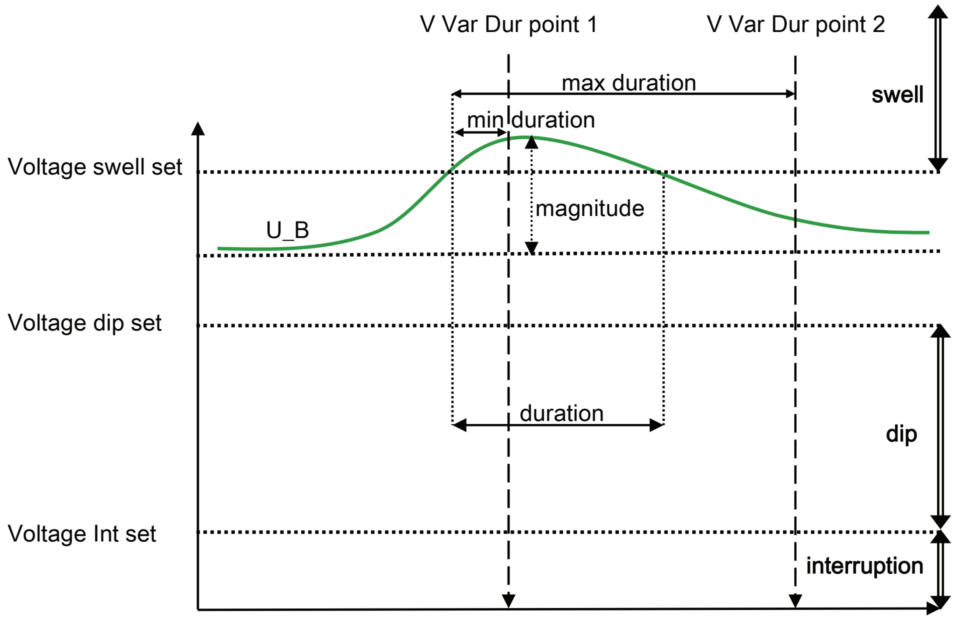


Figure 558: Duration and voltage magnitude limits for swell, dip and interruption measurement

Voltage dips disturb the sensitive equipment such as computers connected to the power system and may result in the failure of the equipment. Voltage dips are typically caused by faults occurring in the power distribution system. Typical reasons for the faults are lightning strikes and tree contacts. In addition to fault situations, the switching of heavy loads and starting of large motors also cause dips.

Voltage swells cause extra stress for the network components and the devices connected to the power system. Voltage swells are typically caused by the earth faults that occur in the power distribution system.

Voltage interruptions are typically associated with the switchgear operation related to the occurrence and termination of short circuits. The operation of a circuit breaker disconnects a part of the system from the source of energy. In the case of overhead networks, automatic reclosing sequences are often applied to the circuit breakers that interrupt fault currents. All these actions result in a sudden reduction of voltages on all voltage phases.

Due to the nature of voltage variations, the power quality standards do not specify any acceptance limits. There are only indicative values for, for example, voltage dips in the European standard EN 50160. However, the power quality standards like the international standard IEC 61000-4-30 specify that the voltage variation event is characterized by its duration and magnitude.

Voltage variation measurement can be done to the phase-to-earth and phase-to-phase voltages. The power quality standards do not specify whether the measurement should be done to phase or phase-to-phase voltages. However, in some cases it is preferable to use phase-to-earth voltages for measurement.

9.4.8 Signals

Table 1097: PHQVVR Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
BLOCK	BOOLEAN	0	Block all outputs
BLK_ST	BOOLEAN	0	Block start outputs
RESET	BOOLEAN	0	Input signal for resetting registers
RS_CNT	BOOLEAN	0	Input signal for resetting counters

Table 1098: PHQVVR Output signals

Name	Type	Description
SWELLOPR	BOOLEAN	Voltage swell detected
DIPOPR	BOOLEAN	Voltage dip detected
INTOPR	BOOLEAN	Voltage interruption detected
DIPSWELLOPR	BOOLEAN	Concurrent voltage dip and voltage swell detected
ST_A	BOOLEAN	Voltage variation present on phase A
ST_B	BOOLEAN	Voltage variation present on phase B
ST_C	BOOLEAN	Voltage variation present on phase C
SWELLST	BOOLEAN	Voltage swell active
DIPST	BOOLEAN	Voltage dip active
INTST	BOOLEAN	Voltage interruption active

9.4.9 Settings

Table 1099: PHQVVR Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Voltage swell set	100.0 - 200.0	%	0.1	110.0	Swell limit in % of declared voltage
Voltage dip set	0.0 - 100.0	%	0.1	90.0	Dip limit in % of declared voltage
Voltage Int set	0.0 - 100.0	%	0.1	1.0	Interruption limit in % of declared voltage
V Var Dur point 1	0.008 - 60.000	s	0.001	0.010	Minimum voltage variation duration
V Var Dur point 2	0.008 - 60.000	s	0.001	60.000	Maximum voltage variation duration

Table 1100: PHQVVR Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Phase supervision	A or AB B or BC A&B or AB&BC C or CA A&C or AB&CA B&C or BC&CA All	-	-	All	Monitored voltage phase

Table 1101: PHQVVR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On

Table 1102: PHQVVR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Voltage selection	phase-to-earth phase-to-phase	-	-	phase-to-earth	Parameter to select phase or phase-to-phase voltages
Reference voltage	80.0 - 120.0	%	0.1	100.0	Reference voltage in %

9.4.10 Measured values

Table 1103: PHQVVR Measured values

Name	Type	Default	Description
I_RMS_A	REAL	0	Current amplitude (RMS) phase A
I_RMS_B	REAL	0	Current amplitude (RMS) phase B
I_RMS_C	REAL	0	Current amplitude (RMS) phase C
U_RMS_A	REAL	0	Voltage amplitude (RMS) phase A
U_RMS_B	REAL	0	Voltage amplitude (RMS) phase B
U_RMS_C	REAL	0	Voltage amplitude (RMS) phase C
U_RMS_AB	REAL	0	Voltage amplitude (RMS) phase AB
U_RMS_BC	REAL	0	Voltage amplitude (RMS) phase BC
U_RMS_CA	REAL	0	Voltage amplitude (RMS) phase CA
BLOCK	BOOLEAN	0	Block all outputs
BLK_ST	BOOLEAN	0	Block start outputs
RESET	BOOLEAN	0	Input signal for resetting registers
RS_CNT	BOOLEAN	0	Input signal for resetting counters

9.4.11 Monitored data

Table 1104: PHQVVR Monitored data

Name	Type	Values (Range)	Unit	Description
SWELLOPR	BOOLEAN	0=FALSE 1=TRUE	-	Voltage swell detected
DIPOPR	BOOLEAN	0=FALSE 1=TRUE	-	Voltage dip detected
INTOPR	BOOLEAN	0=FALSE 1=TRUE	-	Voltage interruption detected
DIPSWELLOPR	BOOLEAN	0=FALSE 1=TRUE	-	Concurrent voltage dip and voltage swell detected
ST_A	BOOLEAN	0=FALSE 1=TRUE	-	Voltage variation present on phase A
ST_B	BOOLEAN	0=FALSE 1=TRUE	-	Voltage variation present on phase B
ST_C	BOOLEAN	0=FALSE 1=TRUE	-	Voltage variation present on phase C
SWELLST	BOOLEAN	0=FALSE 1=TRUE	-	Voltage swell active
DIPST	BOOLEAN	0=FALSE 1=TRUE	-	Voltage dip active
INTST	BOOLEAN	0=FALSE 1=TRUE	-	Voltage interruption active
SWELLCNT	INTEGER	-	-	Counter for detected voltage swells
DIPCNT	INTEGER	-	-	Counter for detected voltage dips
INTCNT	INTEGER	-	-	Counter for detected voltage interruptions
1 Variation type	INTEGER	0=No variation 1=Swell 3=Interruption 2=Dip 4=Dip and swell	-	Record data of bank 1 for variation type
1 Recording time	INTEGER	-	-	Record data of bank 1 for fault time stamp
1 Varn Str Tm PhA	INTEGER	-	-	Record data of bank 1 for phase A variation start time
1 Varn Str Tm PhB	INTEGER	-	-	Record data of bank 1 for phase B variation start time
1 Varn Str Tm PhC	INTEGER	-	-	Record data of bank 1 for phase C variation start time
1 Varn time PhA	INTEGER	-	-	Record data of bank 1 for phase A voltage magnitude meas time

Table continues on next page

Name	Type	Values (Range)	Unit	Description
1 Varn time PhB	INTEGER	-	-	Record data of bank 1 for phase B voltage magnitude meas time
1 Varn time PhC	INTEGER	-	-	Record data of bank 1 for phase C voltage magnitude meas time
1 Varn A PhA	REAL	-	%	Record data of bank 1 for phase A current magnitude
1 Varn A PhB	REAL	-	%	Record data of bank 1 for phase B current magnitude
1 Varn A PhC	REAL	-	%	Record data of bank 1 for phase C current magnitude
1 Varn V PhA	REAL	-	%	Record data of bank 1 for phase A voltage magnitude
1 Varn V PhB	REAL	-	%	Record data of bank 1 for phase B voltage magnitude
1 Varn V PhC	REAL	-	%	Record data of bank 1 for phase C voltage magnitude
1 Varn Dur PhA	REAL	-	ms	Record data of bank 1 for phase A variation duration
1 Varn Dur PhB	REAL	-	ms	Record data of bank 1 for phase B variation duration
1 Varn Dur PhC	REAL	-	ms	Record data of bank 1 for phase C variation duration
2 Variation type	INTEGER	0=No variation 1=Swell 3=Interruption 2=Dip 4=Dip and swell	-	Record data of bank 2 for variation type
2 Recording time	INTEGER	-	-	Record data of bank 2 for fault time stamp
2 Varn Str Tm PhA	INTEGER	-	-	Record data of bank 2 for phase A variation start time
2 Varn Str Tm PhB	INTEGER	-	-	Record data of bank 2 for phase B variation start time
2 Varn Str Tm PhC	INTEGER	-	-	Record data of bank 2 for phase C variation start time
2 Varn time PhA	INTEGER	-	-	Record data of bank 2 for phase A voltage magnitude meas time

Table continues on next page

Name	Type	Values (Range)	Unit	Description
2 Varn time PhB	INTEGER	-	-	Record data of bank 2 for phase B voltage magnitude meas time
2 Varn time PhC	INTEGER	-	-	Record data of bank 2 for phase C voltage magnitude meas time
2 Varn A PhA	REAL	-	%	Record data of bank 2 for phase A current magnitude
2 Varn A PhB	REAL	-	%	Record data of bank 2 for phase B current magnitude
2 Varn A PhC	REAL	-	%	Record data of bank 2 for phase C current magnitude
2 Varn V PhA	REAL	-	%	Record data of bank 2 for phase A voltage magnitude
2 Varn V PhB	REAL	-	%	Record data of bank 2 for phase B voltage magnitude
2 Varn V PhC	REAL	-	%	Record data of bank 2 for phase C voltage magnitude
2 Varn Dur PhA	REAL	-	ms	Record data of bank 2 for phase A variation duration
2 Varn Dur PhB	REAL	-	ms	Record data of bank 2 for phase B variation duration
2 Varn Dur PhC	REAL	-	ms	Record data of bank 2 for phase C variation duration
3 Variation type	INTEGER	0=No variation 1=Swell 3=Interruption 2=Dip 4=Dip and swell	-	Record data of bank 3 for variation type
3 Recording time	INTEGER	-	-	Record data of bank 3 for fault time stamp
3 Varn Str Tm PhA	INTEGER	-	-	Record data of bank 3 for phase A variation start time
3 Varn Str Tm PhB	INTEGER	-	-	Record data of bank 3 for phase B variation start time
3 Varn Str Tm PhC	INTEGER	-	-	Record data of bank 3 for phase C variation start time
3 Varn time PhA	INTEGER	-	-	Record data of bank 3 for phase A voltage magnitude meas time

Table continues on next page

Name	Type	Values (Range)	Unit	Description
3 Varn time PhB	INTEGER	-	-	Record data of bank 3 for phase B voltage magnitude meas time
3 Varn time PhC	INTEGER	-	-	Record data of bank 3 for phase C voltage magnitude meas time
3 Varn A PhA	REAL	-	%	Record data of bank 3 for phase A current magnitude
3 Varn A PhB	REAL	-	%	Record data of bank 3 for phase B current magnitude
3 Varn A PhC	REAL	-	%	Record data of bank 3 for phase C current magnitude
3 Varn V PhA	REAL	-	%	Record data of bank 3 for phase A voltage magnitude
3 Varn V PhB	REAL	-	%	Record data of bank 3 for phase B voltage magnitude
3 Varn V PhC	REAL	-	%	Record data of bank 3 for phase C voltage magnitude
3 Varn Dur PhA	REAL	-	ms	Record data of bank 3 for phase A variation duration
3 Varn Dur PhB	REAL	-	ms	Record data of bank 3 for phase B variation duration
3 Varn Dur PhC	REAL	-	ms	Record data of bank 3 for phase C variation duration

9.4.12 Technical data

Table 1105: PHQVVR Technical data

Characteristic	Value
Operation accuracy	±1.5% of the set value or ±0.2% of reference voltage
Reset ratio	Typically 0.96 (Swell), 1.04 (Dip, Interruption)

Section 10 Control functions

10.1 Apparatus control

10.1.1 Introduction

The apparatus control is a combination of functions which continuously supervise and control the circuit breakers, disconnectors and earthing switches within a bay. The permission to operate an apparatus is given after the evaluation of other functions' conditions such as interlocking, synchrocheck, operator place selection and the external or internal blockings.

10.1.2 Application

The apparatus control is a combination of functions which continuously supervise and control the circuit breakers, disconnectors and earthing switches within a bay. The permission to operate an apparatus is given after the evaluation of other functions' conditions, such as interlocking, synchrocheck, operator place selection and external or internal blockings.

The commands to an apparatus can be initiated from the Control Center (CC), the station HMI or the local HMI on the IED front.

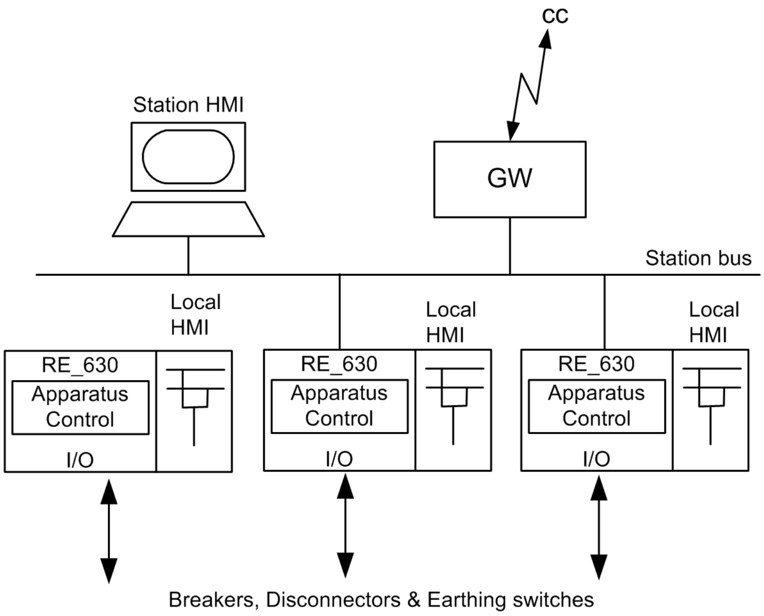


Figure 559: Apparatus control function

The features in the apparatus control function are:

- Operation of primary apparatuses
- Select-Execute principle to give a high reliability
- Selection and reservation function to prevent simultaneous operation
- Selection and supervision of operator place
- Command supervision
- Block/deblock of operation
- Block/deblock of the updating of position indications
- Substitution of position indications
- Overriding of interlocking functions
- Overriding of synchrocheck
- Operation counter

The apparatus control is realized with a number of function blocks designated:

- LocalRemote switch function (LOCREM)
- Bay control function (QCCBAY)
- Switch controller function (GNRLCSWI)
- Circuit breaker function (DAXCBR)
- Circuit switch function (DAXSWI)
- Interlocking interface (SCILO)

The last three functions are logical nodes according to IEC 61850. The signal flow between these function blocks is as shown in Figure 560. The application description for these functions can be found below. SCILO is the logical node for interlocking.

The control operation can be performed from the LHMI. If the administrator has defined users with the User Manager Tool (UTM), the local/remote switch is under authority control. If not, the default, that is, the factory user, is the SuperUser, who can perform control operations from the LHMI without LogOn. The default position of the local/remote switch is on remote.

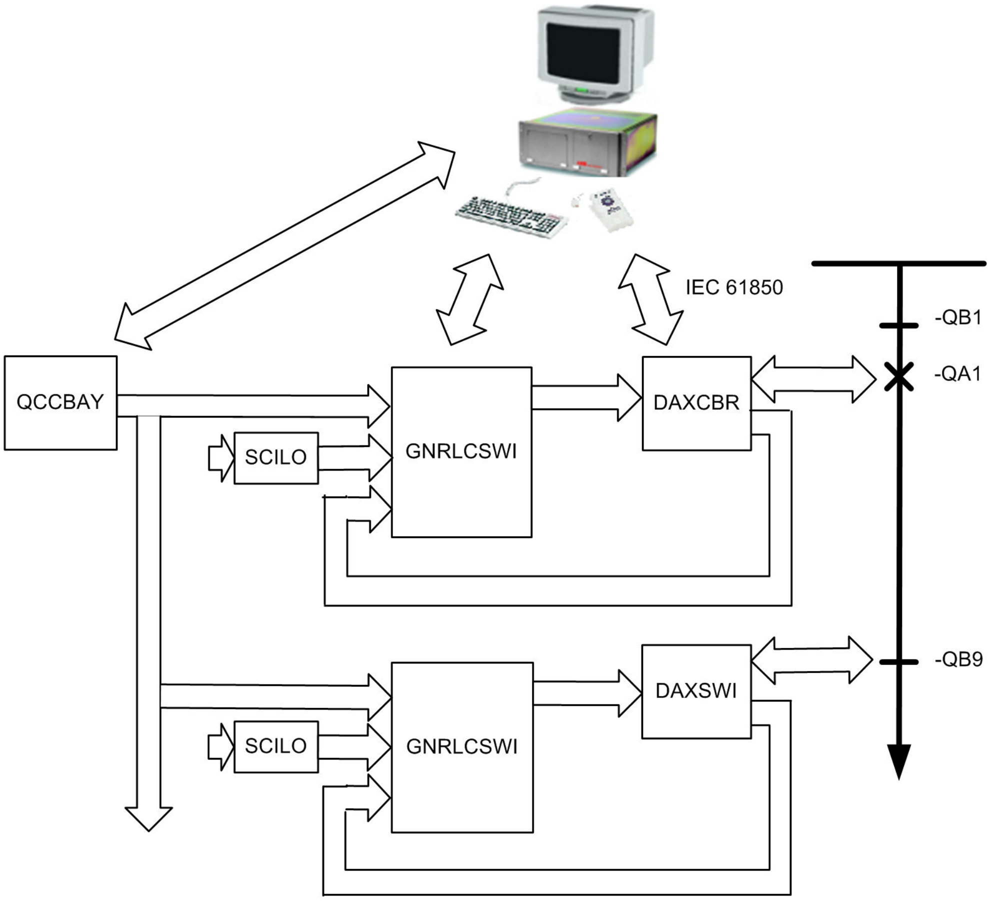


Figure 560: Signal flow between the apparatus control function blocks

10.1.3 Interaction between modules

A typical bay with apparatus control function consists of a combination of logical nodes or functions.

- The switch controller function GNRLCSWI initializes all the operations for one apparatus and performs the actual switching and also more or less the interface to the drive of one apparatus. GNRLCSWI includes the position handling as well as the control of the position.
- The circuit breaker function DAXCBR is the process interface to the circuit breaker for the apparatus control function.
- The circuit switch function DAXSWI is the process interface to the disconnector or the earthing switch for the apparatus control function.
- The bay control function QCCBAY fulfils the bay-level functions for the apparatuses, such as operator place selection and blockings for a complete bay.
- The overcurrent protection function PHxPTOC trips the breaker in case of overcurrent with the tripping logic function TRPPTRC.

- The autoreclosing function DARREC consists of the facilities to automatically close a tripped breaker with respect to a number of configurable conditions.
- The logical node SCILO provides the information to GNRLCSWI if SCILO is permitted to operate due to the switchyard topology. The interlocking conditions are evaluated with a separate logic and connected to SCILO.
- The synchronism-check function SYNCRSYN calculates the voltage phasor difference from both sides of an open breaker and compares it to predefined switching conditions (synchrocheck). Also the case that one side is dead (energizing-check) is included.

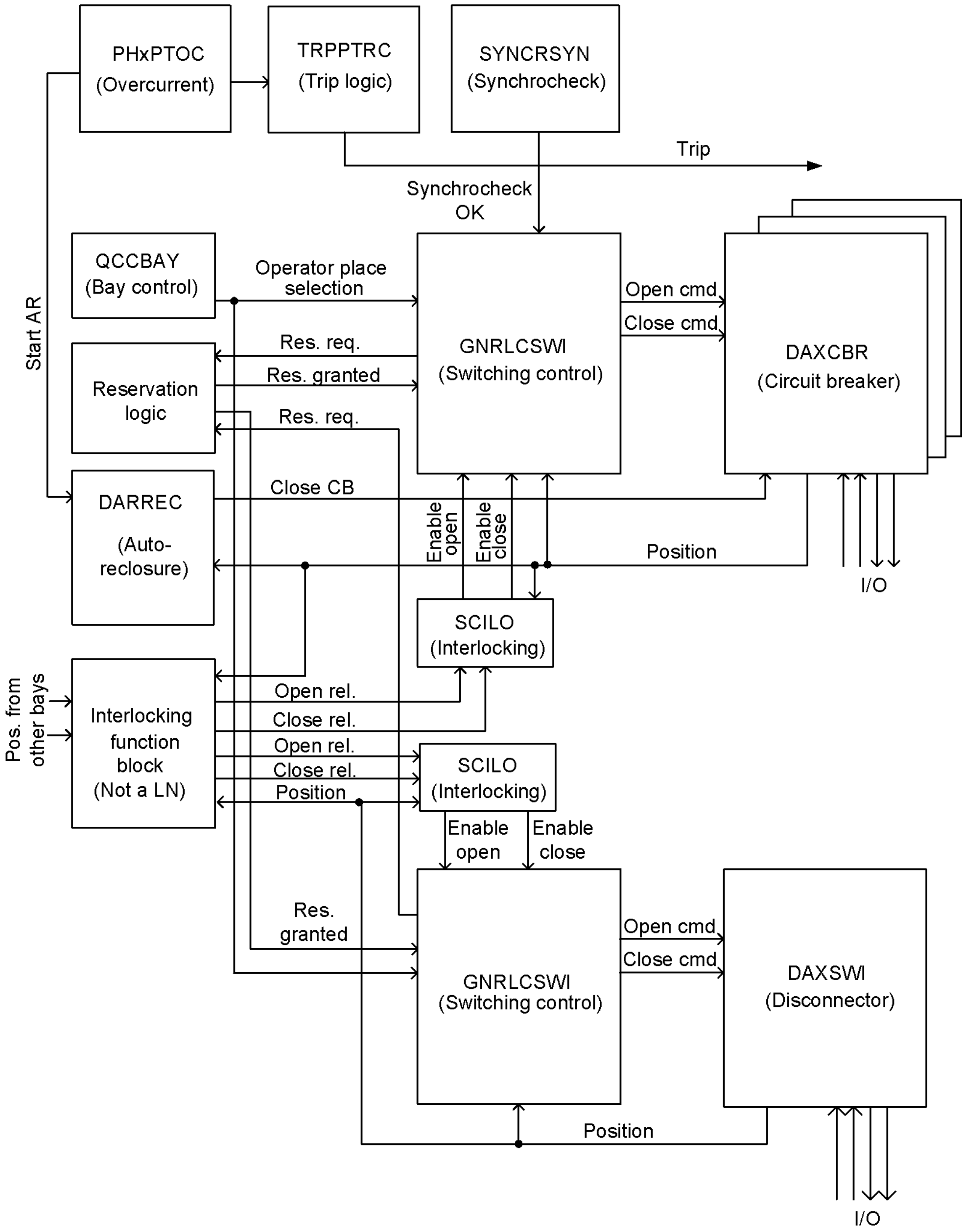


Figure 561: Example overview of the interactions between functions in a typical bay

10.1.4 Operation principle

A bay handles, for example, a power line, transformer, reactor or a capacitor bank. The different primary apparatuses within the bay are controlled with the apparatus control function directly by the operator or indirectly by the automatic sequences.

A primary apparatus can be allocated to many functions within the substation automation system. Therefore, the object-oriented approach with a function module that handles the interaction and status of each process object ensures consistency in the process information used by higher-level control functions.

The primary apparatuses such as breakers, disconnectors and earthing switch are controlled and supervised by the switch controller function GNRLCSWI. The number and type of signals connected to a breaker, disconnector and earthing switch are almost the same. The function module used to handle all three types of apparatuses is also same.

The module is connected to the physical process in the switchyard through an interface module with a number of digital inputs and outputs. The circuit breaker function DAXCBR acts as an interface module for circuit breaker, and the earthing switch function DAXSWI acts as an interface module for disconnectors and earthing switch. There are four types of function blocks available to cover most of the control and supervision within the bay. These function blocks are interconnected to form a control function reflecting the switchyard configuration. The total number of these functions to be used depends on the number of apparatuses to be controlled.

The function block *LocalRemote* used to handle the local/remote switch also belongs to the control function.

10.1.5 Local/remote switch LOCREM

10.1.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Local/Remote switch control function	LOCREM	R/L	R/L

10.1.5.2 Function block

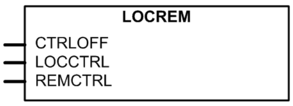


Figure 562: Function block

10.1.5.3 Functionality

The signals from an external local/remote switch are applied with the local remote switch function LOCREM to the bay control function QCCBAY. The value of the *Control mode* setting is set to select if the switch signals are coming from the local HMI or from an external local/remote switch connected with the binary inputs.

10.1.5.4 Operation principle

The local/remote switch interface function LOCREM handles the signals coming from the local/remote switch. The `CTRLOFF`, `LOCCTRL` and `REMCTRL` inputs of LOCREM are connected to the binary inputs if an external switch is used. When the switch available on local HMI is used, LOCREM is not used.

The local-remote switching is done under strict password control. This is activated by defining an administrator and user with their passwords. The default password is “administrator”. The selected position local-remote or local and remote is indicated by the LED is displayed on Local-Remote indicator available on the front panel.

10.1.5.5 Application

LOCREM handles the signals coming from the local/remote switch. The `CTRLOFF`, `LOCCTRL` and `REMCTRL` inputs of LOCREM are connected to the binary inputs if an external switch is used. When a switch available on local HMI is used, it is not necessary to use the LOCREM function.

The local-remote switching is under strict password control. This is activated by defining an administrator and user with their passwords. The default password is “administrator”. The selected position local-remote or local and remote is indicated by the LED displayed on local-remote indicator available on front panel.

10.1.5.6 Signals

Table 1106: LOCREM Input signals

Name	Type	Default	Description
CTRLOFF	BOOLEAN	0	Disable control
LOCCTRL	BOOLEAN	0	Local in control
REMCTRL	BOOLEAN	0	Remote in control

10.1.5.7 Settings

Table 1107: LOCREM Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Control mode	Internal LR-switch External LR-switch	-	-	Internal LR-switch	Control mode for internal/external LR-switch

10.1.5.8 Measured values

Table 1108: LOCREM Measured values

Name	Type	Default	Description
CTRLOFF	BOOLEAN	0	Disable control
LOCCTRL	BOOLEAN	0	Local in control
REMCTRL	BOOLEAN	0	Remote in control

10.1.6 Bay control QCCBAY

10.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Bay control function	QCCBAY	CBAY	CBAY

10.1.6.2 Function block

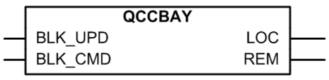


Figure 563: Function block

10.1.6.3 Functionality

The bay control function QCCBAY is used to handle the selection of the operator place per bay. QCCBAY also provides the blocking functions distributed to different apparatuses within the bay. The functionality of QCCBAY is not defined in the IEC 61850 standard, which means that QCCBAY is a vendor specific logical node. QCCBAY sends information about the Permitted Source To Operate and blocking conditions to other functions within the bay, for example, switch control functions, voltage control functions and measurement functions.

10.1.6.4 Operation principle

Local panel switch

The local panel switch defines the operator place selection. The switch connected to this function have three positions: "remote", "local" and "off". The positions are defined so that "remote" means that the operation is allowed from a station/remote level and local from the IED level. The local/remote switch is located on the front panel of the IED, which means that the position of the switch and its validity information are connected internally, not with the input/output boards. When the switch is mounted separately on the IED, the signals are connected to the function with the input/output boards.

When the local panel switch is in the "Off" position, all commands from the remote and local level are ignored.

To adapt the signals from an external local/remote switch, the local remote switch function LOCREM is needed.

Permitted Source To Operate PSTO

The actual state of the operator place is presented with the value of the LR_POS output signal. The LR_POS output value is evaluated from the local/remote switch position. When the external panel switch is in the "Off" position, the LR_POS output value is set to 0. In this case, it is not possible to control anything. The permitted source to operate information is internally delivered to the functions that depend on it (GNRLCSWI, LSHDPFRQ, OLATCC, VSGGIO and SLGGIO).

Blockings

The blockings state the position indications and commands that are intend to provide the possibility for the user to make common blockings for the functions configured within a complete bay.

The blocking facilities provided by the bay control function are:

- Blocking of position indications: The activation of the BLK_UPD input blocks all the inputs related to apparatus positions for all configured functions within the bay.
- Blocking of commands: The activation of the BLK_CMD input blocks all the commands for all configured functions within the bay.

10.1.6.5 Application

QCCBAY is used to handle the selection of the operator place per bay. QCCBAY gives permission to operate from two types of locations either from remote, for example, control center or station HMI or from local, for example, the local HMI on the IED. The Local/Remote switch position can also be set to Off, which means no operator place selected, resulting into a no operation from local or remote.

The bay control function QCCBAY also provides blocking functions that can be distributed to different apparatuses within the bay. There are two different blocking alternatives:

- Blocking of update of positions
- Blocking of commands

10.1.6.6 Signals

Table 1109: QCCBAY Input signals

Name	Type	Default	Description
BLK_UPD	BOOLEAN	0	Steady signal to block the position updates
BLK_CMD	BOOLEAN	0	Steady signal to block the command

Table 1110: QCCBAY Output signals

Name	Type	Description
LOC	BOOLEAN	Local operation allowed
REM	BOOLEAN	Remote operation allowed

10.1.6.7 Measured values

Table 1111: QCCBAY Measured values

Name	Type	Default	Description
BLK_UPD	BOOLEAN	0	Steady signal to block the position updates
BLK_CMD	BOOLEAN	0	Steady signal to block the command
LR_OFF	BOOLEAN	0	External Local/Remote switch is in Off position
LR_LOC	BOOLEAN	0	External Local/Remote switch is in Local position
LR_REM	BOOLEAN	0	External Local/Remote switch is in Remote position
LR_VALID	BOOLEAN	0	Data representing the L/R switch position is valid

10.1.6.8 Monitored data

Table 1112: QCCBAY Monitored data

Name	Type	Values (Range)	Unit	Description
LR_POS	INTEGER	0=Off 1=Local 2=Remote 3=Faulty	-	Position of the Local/ Remote switch
UPD_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Update of position is blocked
CMD_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Function is blocked for commands
LOC	BOOLEAN	0=FALSE 1=TRUE	-	Local operation allowed
REM	BOOLEAN	0=FALSE 1=TRUE	-	Remote operation allowed

10.1.7 Switch control GNRLCSWI

10.1.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Switch controller function	GNRLCSWI	I<-> O CB/DC	I<-> O CB/DC

10.1.7.2 Function block

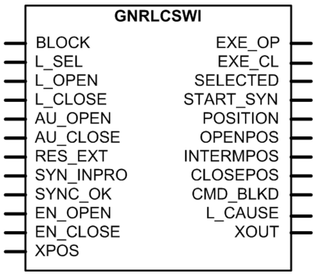


Figure 564: Function block

10.1.7.3 Functionality

The switch controller function GNRLCSWI initializes and supervises all the functions to properly select and operate switching primary apparatuses. GNRLCSWI provides with verification checks for the select-execute sequence, that is, the function checks the conditions before each step of operation. The functions involved for these condition verifications are interlocking, reservation, blockings and synchrocheck.

10.1.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

Command handling

The two types of command models that can be used are "direct with enhanced security" and "Select-Before-Operate (SBO)" with enhanced security command models. The value of the *Control Model* setting defines the command model to be used. When the *Control model* setting is set as "direct with enhanced security", no selection is required. If *Control model* is set to "SBO with enhanced security", a selection is required before execution.

In this function, only a command with enhanced security is supported regarding position changes. The enhanced security means the command sequence is supervised in three steps: the selection, command evaluation and the supervision of position. Each step ends with a pulsed signal to indicate that the respective step in the command sequence is finished. If an error occurs in one of the steps in the command sequence, the sequence is terminated and the error is mapped into the enumerated variable "cause" attribute belonging to the pulsed response signal for the IEC 61850 communication. The L_CAUSE output signal is read and used from the function block, for example, in commissioning.

There is no relation between the command direction and the actual position. For example, if the switch is in closed position, it is possible to execute a closing command.

The evaluation of the position is done before an executing command. If the value of *Pos dependent* setting is set to "Not perm 00/11" and the apparatus position is in the intermediate or bad state, no executing command is sent. If the parameter is "Always permit", the execution command is sent regardless of the position value.

The blocking principles are:

- Blocking only commands is possible in several ways
  - With the bay control function QCCBAY: The command blocking can be issued either with the BLK_UPD input or through the IEC 61850 DO (Data Object) BlkCmd input in QCCBAY.
  - With the IEC 61850 DO BlkCmd in GNRLCSWI.
- The BLOCK input signal is used to block the function from DO (Data Object) Behavior (IEC 61850). If *DO Beh* is set to "blocked", the function is active but no outputs or reports are generated. The control commands are rejected and the functional and configuration data is visible. The *DO Beh* can be set to "blocked" with *DO Mod* of the LN GNRLCSWI or with *DO Mod* of LLN0 of the logical device (LD) where GNRLCSWI resides.

The different block conditions affect only the operation of this function, no blocking signals are forwarded to the other functions. The blocking outputs are stored in a non-volatile memory.

Interaction with synchrocheck and synchronizing functions

GNRLCSWI works in conjunction with the synchrocheck and synchronizing function SYNCRSYN. It is assumed that the synchrocheck function operates continuously and activates the SYNC_OK when all synchronizing conditions are satisfied to the switch controller GNRLCSWI. The result from the synchrocheck function is evaluated during the closing execution. If the synchrocheck is overridden, the evaluation of the synchrocheck state is omitted. Upon a positive confirmation from the synchrocheck function, the switch controller sends the closing signal EXE_CL to the switch function DAXCBR.

When there is no positive confirmation from the synchrocheck function, the switch controller sends a start signal `START_SYN` to the synchronizing function. The function sends a closing command to the switch function when the synchronizing conditions are fulfilled. If no synchronizing function is included, the timer for the supervision of the synchronizing-in-progress signal is set to 0, which means the synchronizing function is in the "Off" state. The switch controller sets the attribute "blocked-by-synchrocheck" in the cause signal.

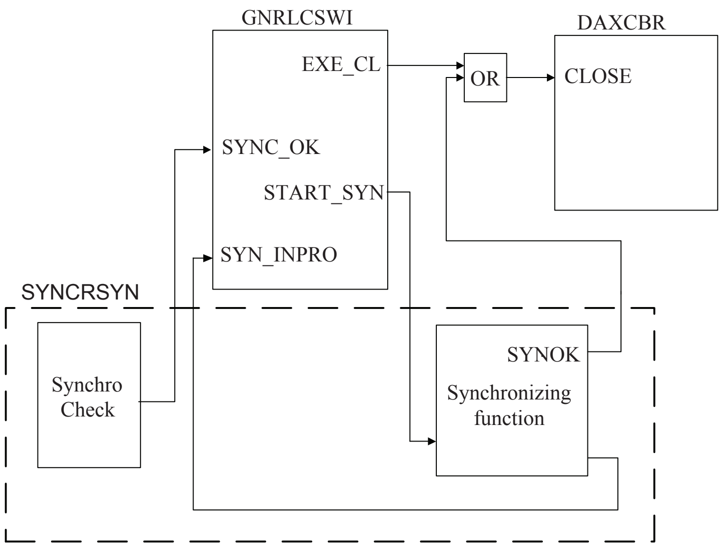


Figure 565: Interaction between GNRLCSWI, synchrocheck, synchronizing function and DAXCBR

Time diagrams

GNRLCSWI uses timers to evaluate different time supervision conditions.

The timer setting *Select command time* supervises the time between the select and the execute command signals, that is, the time operator has for performing the command execution after selecting the object of operation.

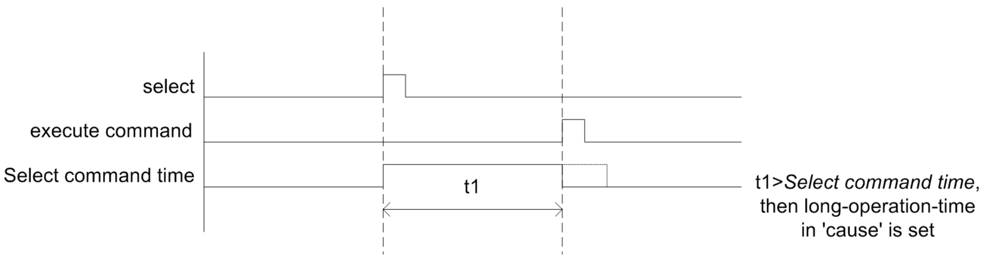


Figure 566: Select command time

The timer setting *Cmd response time* supervises the time between the execute command and command termination.

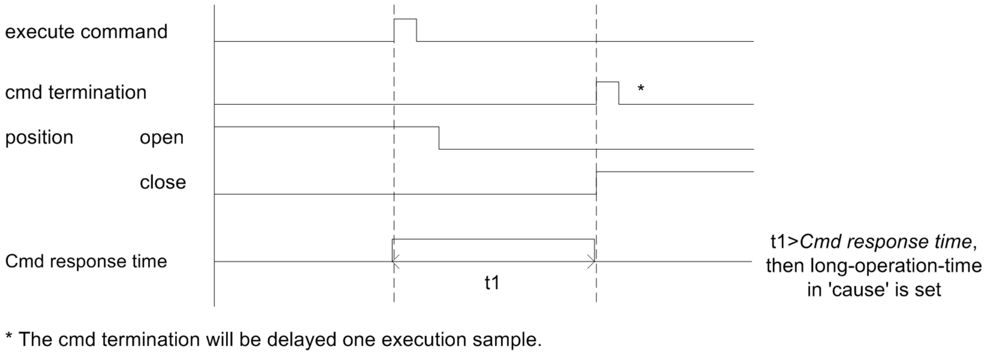


Figure 567: Cmd response time

The value of the *Synchrocheck time* setting defines the maximum allowed time between the execute command and the value of the SYNC_OK input to become true. The SYNC_OK input is available from synchrocheck function. If the SYNC_OK input is TRUE at the time of receipt of execute command signal, the value of the timer setting *Synchrocheck time* does not start. If SYNC_OK fails to activate within the value of the *Synchrocheck time* setting, the START_SY output is activated, which in turn starts the synchronizing module of SYNCRSYN. When all the synchronizing conditions are fulfilled, SYNCRSYN provides a closing command. The SYN_INPRO input indicates that the checks for synchronizing conditions are in process. The SYN_INPRO input for GNRLCSWI is connected directly from the SYN_INPRO output of SYNCRSYN function. If SYN_INPRO fails to activate within *Synchronizing time* after the receipt of START_SY, the L_CAUSE output is set to 11 indicating “blocked-by-synchrocheck”.

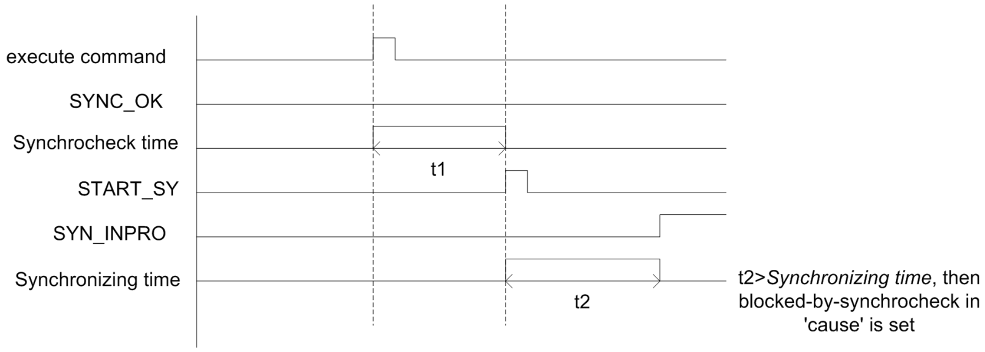


Figure 568: Synchrocheck time and Synchronizing time

Opening and Closing Command

The output command for opening or closing EXE_OP and EXE_CL can be activated in various ways. The activation of L_SEL and then L_OPEN results in the EXE_OP output being set to high. Similarly, the activation of L_SEL and then L_CLOSE results in EXE_CL to activate. Also, the EXE_OP and EXE_CL outputs can be activated by the activation of the automatic opening and closing command AU_OPEN and AU_CLOSE respectively. In case of an interlocking logic being used, the output from SCILO, EN_OPEN and EN_CLOSE can be connected directly to the EN_OPEN and EN_CLOSE inputs of GNRLCSWI.

Error handling

Depending on the error that occurs during the command sequence, the error signal is set with a value whose order of priority is described in the table listing the "cause" values. The values are available over the IEC 61850. The L_CAUSE output on the function block indicates the latest value of error during the command.

Table 1113: Values for the cause signal in priority order

"cause" value	Description
0	no-error
8	blocked-by-mode
22	wrong-CTL-mode
4	invalid-position
10	blocked-by-interlocking
-23	blocked-for-command
11	blocked-by-synchrocheck
14	1-of-n-control
-30	long-operation-time
-35	not-expected-final-position
-31	switch-not-start-moving
-32	persistent-intermediate-state

The L_CAUSE output indicates only the cause why operation of the controlled object failed. It does not indicate communication attempts towards it.

10.1.7.5 Application

GNRLCSWI is used for controlling the circuit breakers, disconnectors and earthing switches.

The control of the circuit breakers is implemented with the cooperation of GNRLCSWI and the circuit breaker DAXCBR. The circuit breaker represents the lowest level power switching device with short-circuit breaking capability.

The control of all other switching devices is implemented with cooperation of GNRLCSWI and the switch DAXSWI. The switch represents lowest level power switching devices without the short-circuit breaking capability, for example, the disconnectors, air-break switches and earthing switches.

GNRLCSWI initializes and supervises all the functions to properly select and operate primary switching devices .

The user of GNRLCSWI is primarily an operator, working either locally or remotely. GNRLCSWI is not dependent on the type of switching device DAXCBR or DAXSWI. It represents the content of the switch controller (CSWI) logical node according to IEC 61850 with mandatory functionality.

After the selection of an apparatus and before the execution, GNRLCSWI performs the checks and actions such as:

- A request that initiates to reserve other bays to prevent simultaneous operation.
- Actual position inputs for interlocking information are read and evaluated if the operation is permitted.
- The synchrocheck/synchronizing conditions are read and checked, and performs operation upon positive response.
- The blocking conditions are evaluated.
- The position indications are evaluated according to given command and its requested direction (open or closed).

The command sequence is supervised regarding the time between:

- Select and execute.
- Select and until the reservation is granted.
- Execute and the final end position of the apparatus.
- Execute and valid close conditions from the synchrocheck.

At error, the command sequence is canceled.

10.1.7.6 Signals

Table 1114: GNRLCSWI Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
L_SEL	BOOLEAN	0	Select signal from local panel
L_OPEN	BOOLEAN	0	Open signal from local panel
L_CLOSE	BOOLEAN	0	Close signal from local panel
AU_OPEN	BOOLEAN	0	Used for local automation function
AU_CLOSE	BOOLEAN	0	Used for local automation function
RES_EXT	BOOLEAN	0	Reservation is made externally
SYN_INPRO	BOOLEAN	0	Synchronizing function in progress
SYNC_OK	BOOLEAN	1	Closing is permitted at set to true by the synchrocheck
EN_OPEN	BOOLEAN	0	Enables open operation
EN_CLOSE	BOOLEAN	0	Enables close operation
XPOS	GROUP SIGNAL	-	Group signal from XCBR/XSWI

Table 1115: GNRLCSWI Output signals

Name	Type	Description
EXE_OP	BOOLEAN	Execute command for open direction
EXE_CL	BOOLEAN	Execute command for close direction
SELECTED	BOOLEAN	The select conditions are fulfilled
START_SYN	BOOLEAN	Starts the synchronizing function
POSITION	INTEGER	Position indication
OPENPOS	BOOLEAN	Open position indication
INTERMPOS	BOOLEAN	Stopped in intermediate position
CLOSEPOS	BOOLEAN	Closed position indication
CMD_BLKD	BOOLEAN	Commands are blocked
L_CAUSE	INTEGER	Latest value of the error indication during command
XOUT	BOOLEAN	Execution information to XCBR/XSWI

10.1.7.7 Settings

Table 1116: GNRLCSWI Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Control model	Dir Norm SBO Enh	-	-	SBO Enh	Specifies the type for control model according to IEC 61850
Select command time	0.000 - 60.000	s	0.001	30.000	Max time between select and execute signals
Synchrocheck time	0.00 - 600.00	s	0.01	10.00	Allowed time for synchrocheck to fulfil close conditions
Synchronizing time	0.00 - 600.00	s	0.01	0.00	Supervision time to get the signal synchronizing in progress
Cmd response time	0.00 - 600.00	s	0.01	30.00	Max time from command execution to termination

Table 1117: GNRLCSWI Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Pos dependent	Always permit Not perm 00/11	-	-	Always permit	Permission to operate depending on the position

10.1.7.8 Measured values

Table 1118: GNRLCSWI Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
L_SEL	BOOLEAN	0	Select signal from local panel
L_OPEN	BOOLEAN	0	Open signal from local panel
L_CLOSE	BOOLEAN	0	Close signal from local panel
AU_OPEN	BOOLEAN	0	Used for local automation function
AU_CLOSE	BOOLEAN	0	Used for local automation function
RES_EXT	BOOLEAN	0	Reservation is made externally
SYN_INPRO	BOOLEAN	0	Synchronizing function in progress
SYNC_OK	BOOLEAN	1	Closing is permitted at set to true by the synchrocheck
EN_OPEN	BOOLEAN	0	Enables open operation
EN_CLOSE	BOOLEAN	0	Enables close operation

10.1.7.9 Monitored data

Table 1119: GNRLCSWI Monitored data

Name	Type	Values (Range)	Unit	Description
EXE_OP	BOOLEAN	0=FALSE 1=TRUE	-	Execute command for open direction
EXE_CL	BOOLEAN	0=FALSE 1=TRUE	-	Execute command for close direction
SELECTED	BOOLEAN	0=FALSE 1=TRUE	-	The select conditions are fulfilled
START_SYN	BOOLEAN	0=FALSE 1=TRUE	-	Starts the synchronizing function
OPENPOS	BOOLEAN	0=FALSE 1=TRUE	-	Open position indication
INTERMPOS	BOOLEAN	0=FALSE 1=TRUE	-	Stopped in intermediate position
CLOSEPOS	BOOLEAN	0=FALSE 1=TRUE	-	Closed position indication
CMD_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Commands are blocked

10.1.7.10 Technical revision history

Table 1120: GNRLCSWI technical revision history

Technical revision	Change
B	Default value for input `SYNC_OK` changed to TRUE from FALSE

10.1.8 Circuit breaker DAXCBR

10.1.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit breaker	DAXCBR	I <-> O CB	I <->O CB

10.1.8.2 Function block

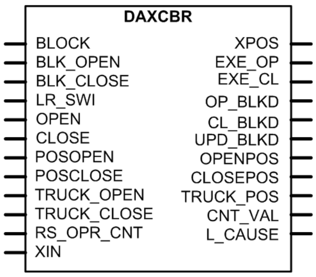


Figure 569: Function block

10.1.8.3 Functionality

The circuit breaker function DAXCBR provides the actual status of the positions for the apparatus and also perform the control operations, that is, pass all the commands to the primary apparatuses in the form of circuit breakers with the output boards and also supervising the switching operation and position.

The intended users of DAXCBR are the other functions such as switch controller, protection functions, autoreclosure function or the IEC 61850 clients residing in another IED or an operator place. DAXCBR executes commands and evaluate the block conditions and different time supervision conditions. DAXCBR performs an execution command only if all the conditions indicate to allow a switch operation. If erroneous conditions occur, DAXCBR indicates an appropriate “cause” value.

DAXCBR has an operation counter for closing and opening command. The operator can read the counter value remotely from an operator place. The value is reset from a binary input or remotely from the operator place.

10.1.8.4 Operation principle

Local/Remote switch

The `LR_SWI` binary input signal is included in this function to indicate the local or remote switch position from the switchyard provided with the I/O board. If the signal is set to TRUE, the change of positions is only allowed from switchyard level. If the signal value is FALSE, commands from IED or higher level are permitted. When the signal value is set to TRUE, all the commands are rejected from internal IED clients.

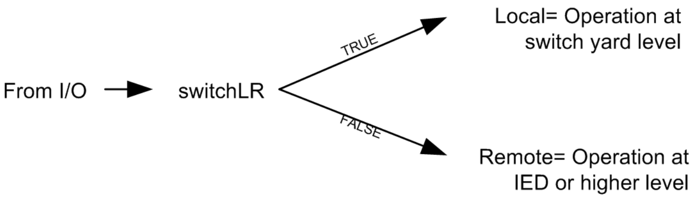


Figure 570: Functionality of Local/Remote switch

Blocking principle

The function includes several blocking principles. The basic principle for all these blocking signals is that they affect the commands from all other clients, for example, the operator place, protection functions and autoreclosure.

The blocking principles are:

- The activation of `BLK_OPEN` input blocks the open command and activates the `OP_BLKD` output. This block signal also affects the `OPEN` input for an immediate command.
- The activation of `BLK_CLOSE` input blocks the close command and activates the `CL_BLKD` output. This block signal also affects the `CLOSE` input for an immediate command.
- The circuit breaker position update can be blocked via 61850 communication or by activation of `BLK_UPD` input of QCCBAY function. The status of this can be seen at `UPD_BLK` output.
- The function can be blocked with the `BLOCK` input or from DO (Data Object) Beh (Behavior, IEC61850). If *DO Beh* is set to blocked, the function remains active but no outputs or reports are generated, control commands are rejected and the functional and configuration data is visible. The DO Beh can be set to blocked by DO Mod of the LN function or with the DO Mod of LLN0 of the logical device (LD) where the DAXCBR resides.

The blocking outputs are stored in a non-volatile memory.

Substitution

The substitution part is used for manual setting of positions. A typical use of substitution is that an operator enters a value manually as the real process value is erroneous for some reason. The function uses manually entered value instead of the value for positions determined by the process.

It is always possible to use substitution independently of the position indication and status information of the I/O board. When substitution is enabled, position values are blocked for updating and other signals related to the position are reset. The substituted values are stored in a non-volatile memory.

Time diagrams

There are two timers in this function to supervise the execute phase. The *Start moving timer* setting supervises time after the breaker starts moving. If the breaker fails to open before *Start moving time* is elapsed, the `L_CAUSE` output is set to '-31' indicating "switch not start moving". The intermediate timer measures the time spent in intermediate position. If the breaker remains in intermediate position for a time greater than the value of the *Intermediate time* setting, the `L_CAUSE` output is set to '-32' indicating "persisting intermediate state".

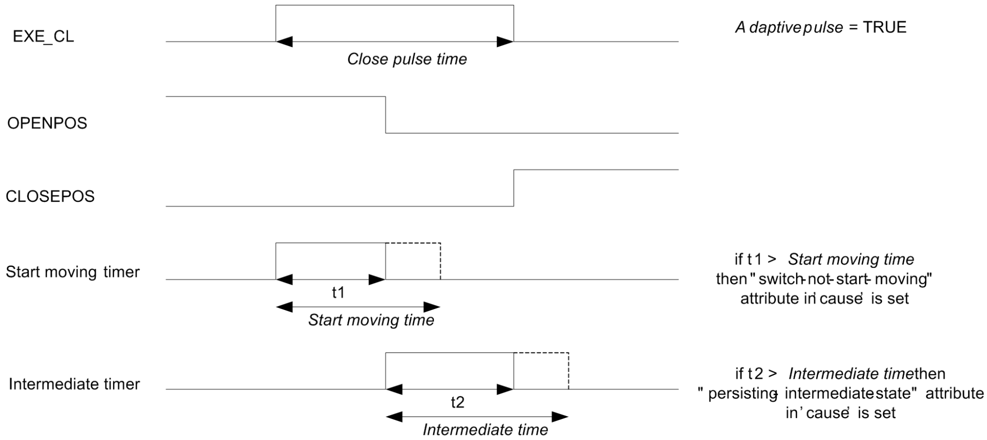


Figure 571: The start moving timer and intermediate timer during the execute phase

The output pulses for open and close command can have different pulse lengths. The *Open pulse time* and *Close pulse time* timer settings are for the length of the execute output pulses to be sent to the primary equipment. The pulses can also be set to be adaptive with the configuration parameter *Adaptive pulse*. The adaptive parameter affects both execute output pulses.

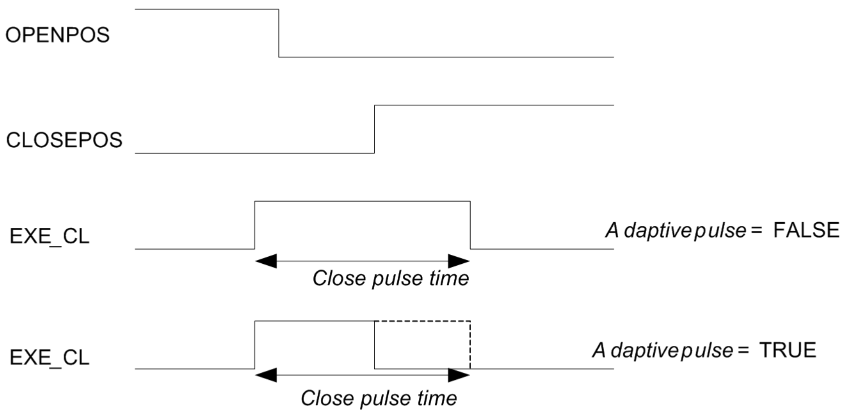


Figure 572: Execute output pulse

If the pulse is set to be adaptive, it is not possible for the pulse to exceed *Open pulse time* or *Close pulse time*.

The execute output pulses are reset when:

- A new expected final position is reached and the configuration setting parameter *Adaptive pulse* is set to true.
- The open pulse time or close pulse time have elapsed.
- An error occurs due to the switch not starting to move, that is, if the value of *Start moving time* setting has elapsed.

If the start position indicates bad state (OPENPOS=1 and CLOSEPOS =1) when a command is executed, the execute output pulse resets only when *Open pulse timer* or *Close pulse timer* have elapsed.

One exception from the first item above occurs when the primary device is in open position and an open command is executed or if the primary device is in close position and a close command is executed. In these cases, with the additional condition that the configuration parameter *Adaptive pulse* is true, the execute output pulse is always activated and resets when *Start moving time* has elapsed. If the configuration parameter *Adaptive pulse* is set to false, the execution output remains active until the pulse duration timer has elapsed.

An example of when a primary device is open and an open command is executed can be shown.

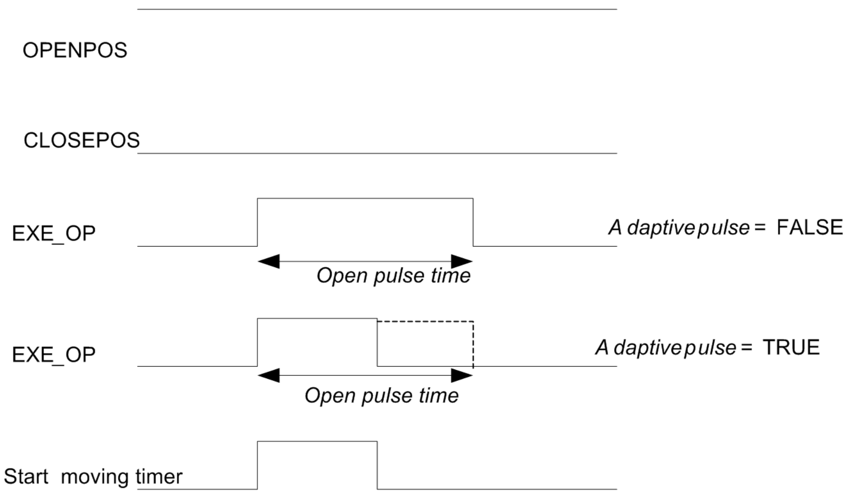


Figure 573: An example of open command with open position indication

Position Indicators

The binary input signal indicating the open and close position of the disconnector or earth switch are connected to the POSOPEN and POSCLOSE inputs respectively. Based on these inputs, the OPENPOS and CLOSEPOS binary outputs get activated if the disconnector or earth switch is in open or close position respectively.

Command inputs and counter

The pulse signal for the immediate opening and closing command of breaker is given to the function with the OPEN and CLOSE inputs respectively. The activation of OPEN and CLOSE inputs activates the EXE_OP and EXE_CL outputs of the function, whose pulse length is defined by the *Open pulse time* and *Close pulse time* setting respectively. The OPEN and CLOSE inputs of the function is connected from the switch controller function GNRLCSWI outputs EXE_OP and EXE_CL respectively.

The number of circuit breaker operations are available with the CNT_VAL output. The activation of the RS_OPR_CNT input resets the counter. The number of operations are stored in nonvolatile memory.

Error handling

Depending on the error that occurs during the command sequence, the error signal is set with a value. The table describes vendor specific cause values in addition to these specified in IEC 61850-8-1 standard. The cause values are listed in order of priority. The L_CAUSE output on the function block indicates the latest value of error during the command.

Table 1121: Values for cause signal in priority order

Cause value	Description
0	no-error
8	blocked-by-mode
2	blocked-by-switching-hierarchy
-24	blocked-for-open-command
-25	blocked-for-close-command
9	blocked-by-process
12	command-already-in-execution
-31	switch-not-start-moving
-32	persistent-intermediate-state
-33	switch-returned-to-initial-position
-34	switch-in-bad-state
-35	not-expected-final-position

The L_CAUSE output indicates only the cause why operation of the controlled object failed. It does not indicate communication attempts towards it.

When used for non-controllable earth switch, DAXSWI provides only status information.

10.1.8.5 Application

DAXCBR is a component used to close and interrupt an AC power circuit any conditions.

DAXCBR represents a lowest level power switching device with short-circuit breaking capability.

The purpose of this component is to provide the actual status of positions and to perform control operations, that is, to pass all the commands to the primary device with the output I/O-board and to supervise the switching operation and position. This component is the lowest or the closest software component to the physical device. It is used by other functions that need to operate the physical device in 'direct' manner, that is not invoking other functions before operating.

This also means that the properties and knowledge that affect the operation depending on the physical device, are part of this function.

The component has the following functions:

- Local or remote switch intended for a switchyard
- Block or deblock for open and close command respectively
- Update block or deblock of position indication
- Substitution of a position indication
- Supervision timer for the primary device to start moving on a command
- Supervision of allowed time for intermediate position
- Definition of pulse duration for open and close command respectively

10.1.8.6 Signals

Table 1122: DAXCBR Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPEN	BOOLEAN	0	Signal to block the open command
BLK_CLOSE	BOOLEAN	0	Signal to block the close command
LR_SWI	BOOLEAN	0	Local/Remote switch indication from switchyard
OPEN	BOOLEAN	0	Pulsed signal used to immediately open the switch
CLOSE	BOOLEAN	0	Pulsed signal used to immediately close the switch
POSOPEN	BOOLEAN	0	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0	Signal for close position of apparatus from I/O
TRUCK_OPEN	BOOLEAN	0	Signal for open position of truck from I/O
TRUCK_CLOSE	BOOLEAN	0	Signal for close position of truck from I/O
RS_OPR_CNT	BOOLEAN	0	Resets the operation counter
XIN	BOOLEAN	0	Execution information from CSWI

Table 1123: DAXCBR Output signals

Name	Type	Description
XPOS	GROUP SIGNAL	Group connection to CSWI
EXE_OP	BOOLEAN	Executes the command for open direction
EXE_CL	BOOLEAN	Executes the command for close direction
OP_BLKD	BOOLEAN	Indication that the function is blocked for open commands
CL_BLKD	BOOLEAN	Indication that the function is blocked for close commands
UPD_BLKD	BOOLEAN	The update of position indication is blocked
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
TRUCK_POS	INTEGER	Truck position indication
CNT_VAL	INTEGER	The value of the operation counter
L_CAUSE	INTEGER	Latest value of the error indication during command

10.1.8.7 Settings

Table 1124: DAXCBR Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Start moving time	0.000 - 60.000	s	0.001	0.100	Supervision time for the apparatus to move after a command
Intermediate time	0.000 - 60.000	s	0.001	0.150	Allowed time for intermediate position

Table 1125: DAXCBR Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Open pulse time	0.000 - 60.000	s	0.001	0.200	Output pulse length for open command
Close pulse time	0.000 - 60.000	s	0.001	0.200	Output pulse length for close command
Adaptive pulse	Not adaptive Adaptive	-	-	Not adaptive	The output resets when a new correct end position is reached
Suppress mid Pos	Off On	-	-	On	If 'On' mid-pos is suppressed and Intermediate time is used

10.1.8.8 Measured values

Table 1126: DAXCBR Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPEN	BOOLEAN	0	Signal to block the open command
BLK_CLOSE	BOOLEAN	0	Signal to block the close command
LR_SWI	BOOLEAN	0	Local/Remote switch indication from switchyard
OPEN	BOOLEAN	0	Pulsed signal used to immediately open the switch
CLOSE	BOOLEAN	0	Pulsed signal used to immediately close the switch
POSOPEN	BOOLEAN	0	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0	Signal for close position of apparatus from I/O
TRUCK_OPEN	BOOLEAN	0	Signal for open position of truck from I/O
TRUCK_CLOSE	BOOLEAN	0	Signal for close position of truck from I/O
RS_OPR_CNT	BOOLEAN	0	Resets the operation counter

10.1.8.9 Monitored data

Table 1127: DAXCBR Monitored data

Name	Type	Values (Range)	Unit	Description
EXE_OP	BOOLEAN	0=FALSE 1=TRUE	-	Executes the command for open direction
EXE_CL	BOOLEAN	0=FALSE 1=TRUE	-	Executes the command for close direction
SUBSTED	BOOLEAN	0=FALSE 1=TRUE	-	Indication that the position is substituted
OP_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Indication that the function is blocked for open commands
CL_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Indication that the function is blocked for close commands
UPD_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	The update of position indication is blocked
POSITION	INTEGER	-	-	Apparatus position indication
OPENPOS	BOOLEAN	0=FALSE 1=TRUE	-	Apparatus open position
CLOSEPOS	BOOLEAN	0=FALSE 1=TRUE	-	Apparatus closed position
BLOCKED	BOOLEAN	0=FALSE 1=TRUE	-	The function is active but the functionality is blocked

10.1.8.10 Technical revision history

Table 1128: DAXCBR technical revision history

Technical revision	Change
B	Added possibility to map output `POSITION` in GDE for symbol type “Breaker Indication Only”

10.1.9 Circuit switch DAXSWI

10.1.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Disconnector	DAXSWI	I <-> O DC	I <->O DC

10.1.9.2 Function block

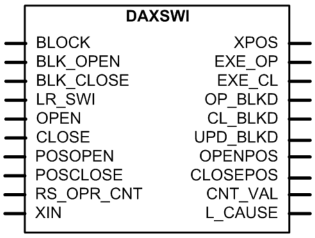


Figure 574: Function block

10.1.9.3 Functionality

The circuit switch function DAXSWI provides the actual status of positions for the apparatus and to perform the control operations, that is, passing all the commands to the primary apparatuses in the form of disconnector / earthswitch with the output boards and also supervise the switching operation and position.

The intended users of DAXSWI are other functions like switch controller, protection functions, autoreclosure function or IEC 61850 clients residing in another IED or at an operator place. DAXSWI executes commands, evaluates block conditions and different time supervision conditions. DAXSWI performs an execution command only if all conditions indicate a switch operation to be allowed. If erroneous conditions occur, DAXSWI indicates an appropriate “cause” value.

DAXSWI has an operation counter for closing and opening command. The operator can read the counter value remotely from an operator place. The value is reset from a binary input or remotely from the operator place.

10.1.9.4 Operation principle

Local/Remote switch

The `LR_SWI` binary input signal is included in this function to indicate the local or remote switch position from the switchyard provided with the I/O board. If the signal is set to TRUE, the change of positions is only allowed from switchyard level. If the signal value is FALSE, commands from IED or higher level are permitted. When the signal value is set to TRUE, all the commands are rejected from internal IED clients.

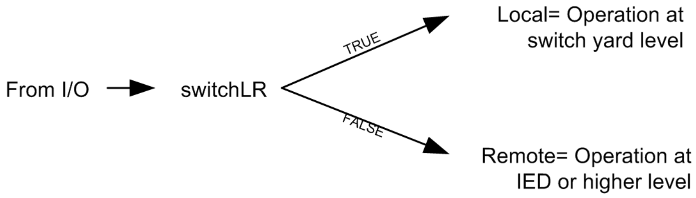


Figure 575: Functionality of Local/Remote switch

Blocking principle

The function includes several blocking principles. The basic principle for all these blocking signals is that they affect the commands from all other clients, for example, the operator place, protection functions and autoreclosure.

The blocking principles are:

- The activation of `BLK_OPEN` input blocks the open command and activates the `OP_BLKD` output. This block signal also affects the `OPEN` input for an immediate command.
- The activation of `BLK_CLOSE` input blocks the close command and activates the `CL_BLKD` output. This block signal also affects the `CLOSE` input for an immediate command.
- The circuit breaker position update can be blocked via 61850 communication or by activation of `BLK_UPD` input of QCCBAY function. The status of this can be seen at `UPD_BLK` output.
- The function can be blocked with the `BLOCK` input or from DO (Data Object) Beh (Behavior, IEC61850). If *DO Beh* is set to blocked, the function remains active but no outputs or reports are generated, control commands are rejected and the functional and configuration data is visible. The DO Beh can be set to blocked by DO Mod of the LN function or with the DO Mod of LLN0 of the logical device (LD) where the DAXCBR resides.

The blocking outputs are stored in a non-volatile memory.

Substitution

The substitution part is used for manual setting of positions. A typical use of substitution is that an operator enters a value manually as the real process value is erroneous for some reason. The function uses manually entered value instead of the value for positions determined by the process.

> It is always possible to use substitution independently of the position indication and status information of the I/O board. When substitution is enabled, position values are blocked for updating and other signals related to the position are reset. The substituted values are stored in a non-volatile memory.

Time diagrams

There are two timers in this function to supervise the execute phase. The *Start moving timer* setting supervises time after the breaker starts moving. If the breaker fails to open before *Start moving time* is elapsed, the L_CAUSE output is set to '-31' indicating "switch not start moving". The intermediate timer measures the time spent in intermediate position. If the breaker remains in intermediate position for a time greater than the value of the *Intermediate time* setting, the L_CAUSE output is set to '-32' indicating "persisting intermediate state".

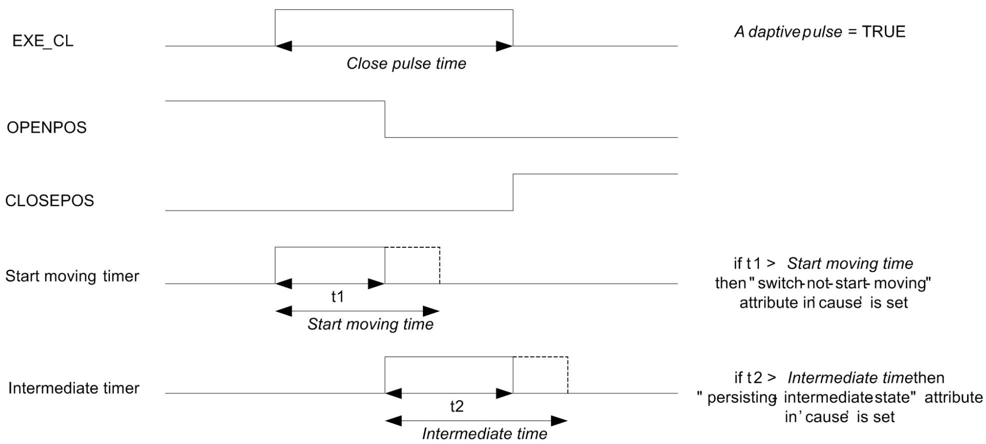


Figure 576: The start moving timer and intermediate timer during the execute phase

The output pulses for open and close command can have different pulse lengths. The *Open pulse time* and *Close pulse time* timer settings are for the length of the execute output pulses to be sent to the primary equipment. The pulses can also be set to be adaptive with the configuration parameter *Adaptive pulse*. The adaptive parameter affects both execute output pulses.

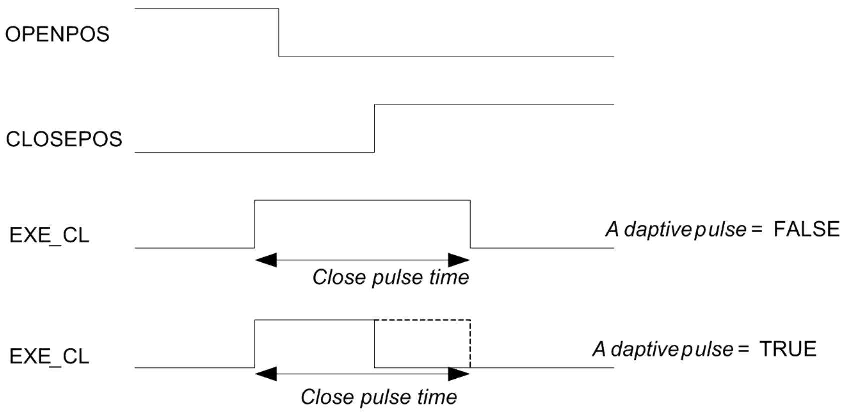


Figure 577: Execute output pulse

If the pulse is set to be adaptive, it is not possible for the pulse to exceed *Open pulse time* or *Close pulse time*.

The execute output pulses are reset when:

- A new expected final position is reached and the configuration setting parameter *Adaptive pulse* is set to true.
- The open pulse time or close pulse time have elapsed.
- An error occurs due to the switch not starting to move, that is, if the value of *Start moving time* setting has elapsed.

If the start position indicates bad state (OPENPOS=1 and CLOSEPOS =1) when a command is executed, the execute output pulse resets only when *Open pulse timer* or *Close pulse timer* have elapsed.

One exception from the first item above occurs when the primary device is in open position and an open command is executed or if the primary device is in close position and a close command is executed. In these cases, with the additional condition that the configuration parameter *Adaptive pulse* is true, the execute output pulse is always activated and resets when *Start moving time* has elapsed. If the configuration parameter *Adaptive pulse* is set to false, the execution output remains active until the pulse duration timer has elapsed.

An example of when a primary device is open and an open command is executed can be shown.

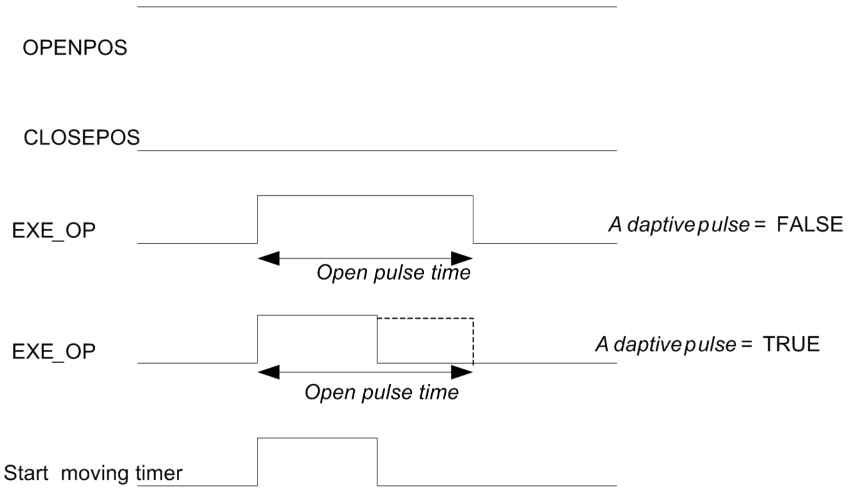


Figure 578: An example of open command with open position indication

Position Indicators

The binary input signal indicating the open and close position of the disconnector or earth switch are connected to the POSOPEN and POSCLOSE inputs respectively. Based on these inputs, the OPENPOS and CLOSEPOS binary outputs get activated if the disconnector or earth switch is in open or close position respectively.

Command inputs and counter

The pulse signal for the immediate opening and closing command of breaker is given to the function with the OPEN and CLOSE inputs respectively. The activation of OPEN and CLOSE inputs activates the EXE_OP and EXE_CL outputs of the function, whose pulse length is defined by the *Open pulse time* and *Close pulse time* setting respectively. The OPEN and CLOSE inputs of the function is connected from the switch controller function GNRLCSWI outputs EXE_OP and EXE_CL respectively.

The number of circuit breaker operations are available with the CNT_VAL output. The activation of the RS_OPR_CNT input resets the counter. The number of operations are stored in nonvolatile memory.

Error handling

Depending on the error that occurs during the command sequence, the error signal is set with a value. The table describes vendor specific cause values in addition to these specified in IEC 61850-8-1 standard. The cause values are listed in order of priority. The L_CAUSE output on the function block indicates the latest value of error during the command.

Table 1129: Values for cause signal in priority order

Cause value	Description
0	no-error
8	blocked-by-mode
2	blocked-by-switching-hierarchy
-24	blocked-for-open-command
-25	blocked-for-close-command
9	blocked-by-process
12	command-already-in-execution
-31	switch-not-start-moving
-32	persistent-intermediate-state
-33	switch-returned-to-initial-position
-34	switch-in-bad-state
-35	not-expected-final-position

The L_CAUSE output indicates only the cause why operation of the controlled object failed. It does not indicate communication attempts towards it.

When used for non-controllable earth switch, DAXSWI provides only status information.

10.1.9.5 Application

DAXSWI is a component used to close and interrupt an AC power circuit under normal conditions. It is opened or closed only after DAXCBR is opened.

DAXSWI represents lowest level power switching devices without short-circuit breaking capability, for example disconnectors, air-break switches and earth switches.

The purpose of this component is to provide the actual status of positions and to perform control operations, that is to pass all the commands to the primary device via output I/O-board and to supervise the switching operation and position. This component is the lowest or the closest software component to the physical device. It is used by other functions that need to operate the physical device in "direct" manner, that is, not invoking other functions before operating.

This also means that the properties and knowledge that affect the operation depending on the physical device are part of this function.

The component has the following functions:

- Local or remote switch intended for a switchyard
- Block or deblock for open and close command respectively
- Update block or deblock of position indication
- Substitution of a position indication
- Supervision timer for the primary device to start moving on a command
- Supervision of allowed time for intermediate position
- Definition of pulse duration for open and close command respectively

10.1.9.6 Signals

Table 1130: DAXSWI Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPEN	BOOLEAN	0	Signal to block the open command
BLK_CLOSE	BOOLEAN	0	Signal to block the close command
LR_SWI	BOOLEAN	0	Local/Remote switch indication from switchyard
OPEN	BOOLEAN	0	Pulsed signal used to immediately open the switch
CLOSE	BOOLEAN	0	Pulsed signal used to immediately close the switch
POSOPEN	BOOLEAN	0	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0	Signal for close position of apparatus from I/O
RS_OPR_CNT	BOOLEAN	0	Resets the operation counter
XIN	BOOLEAN	0	Execution information from CSWI

Table 1131: DAXSWI Output signals

Name	Type	Description
XPOS	GROUP SIGNAL	Group connection to CSWI
EXE_OP	BOOLEAN	Executes the command for open direction
EXE_CL	BOOLEAN	Executes the command for close direction
OP_BLKD	BOOLEAN	Indication that the function is blocked for open commands
CL_BLKD	BOOLEAN	Indication that the function is blocked for close commands
UPD_BLKD	BOOLEAN	The update of position indication is blocked
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
CNT_VAL	INTEGER	The value of the operation counter
L_CAUSE	INTEGER	Latest value of the error indication during command

10.1.9.7 Settings

Table 1132: DAXSWI Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Switch type	Load Break Disconnector Earthing Switch HS Earth Switch	-	-	Disconnector	Switch Type
Start moving time	0.100 - 60.000	s	0.001	3.000	Supervision time for the apparatus to move after a command
Intermediate time	0.100 - 60.000	s	0.001	15.000	Allowed time for intermediate position

Table 1133: DAXSWI Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Open pulse time	0.100 - 60.000	s	0.001	0.200	Output pulse length for open command
Close pulse time	0.100 - 60.000	s	0.001	0.200	Output pulse length for close command
Adaptive pulse	Not adaptive Adaptive	-	-	Not adaptive	The output resets when a new correct end position is reached
Suppress mid Pos	Off On	-	-	On	If 'On' mid-pos is suppressed and Intermediate time is used

10.1.9.8 Measured values

Table 1134: DAXSWI Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	Block of function
BLK_OPEN	BOOLEAN	0	Signal to block the open command
BLK_CLOSE	BOOLEAN	0	Signal to block the close command
LR_SWI	BOOLEAN	0	Local/Remote switch indication from switchyard
OPEN	BOOLEAN	0	Pulsed signal used to immediately open the switch
CLOSE	BOOLEAN	0	Pulsed signal used to immediately close the switch
POSOPEN	BOOLEAN	0	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0	Signal for close position of apparatus from I/O
RS_OPR_CNT	BOOLEAN	0	Resets the operation counter

10.1.9.9 Monitored data

Table 1135: DAXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
EXE_OP	BOOLEAN	0=FALSE 1=TRUE	-	Executes the command for open direction
EXE_CL	BOOLEAN	0=FALSE 1=TRUE	-	Executes the command for close direction
SUBSTED	BOOLEAN	0=FALSE 1=TRUE	-	Indication that the position is substituted
OP_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Indication that the function is blocked for open commands
CL_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	Indication that the function is blocked for close commands
UPD_BLKD	BOOLEAN	0=FALSE 1=TRUE	-	The update of position indication is blocked
POSITION	INTEGER	-	-	Apparatus position indication
OPENPOS	BOOLEAN	0=FALSE 1=TRUE	-	Apparatus open position
CLOSEPOS	BOOLEAN	0=FALSE 1=TRUE	-	Apparatus closed position
BLOCKED	BOOLEAN	0=FALSE 1=TRUE	-	The function is active but the functionality is blocked

10.1.9.10 Technical revision history

Table 1136: DAXSWI technical revision history

Technical revision	Change
B	Added possibility to map output POSITION in GDE for symbol type "Isolator Indication Only"

10.2 Reservation

10.2.1 General principles of reservation

The purpose of the reservation functionality is primarily to transfer interlocking information between the IEDs in a safe way and to prevent double operation in a bay, switchyard part or a complete substation.

The reservation is activated in two ways. It starts when a circuit breaker or disconnector control function from the same bay is selected or if a circuit breaker or disconnector control function from another bay is selected. It is only possible to select the function if no other function is already selected.

The configuration of the reservation is done with the station bus and GOOSE communication according to the application example. The reservation can also be realized with external wiring.

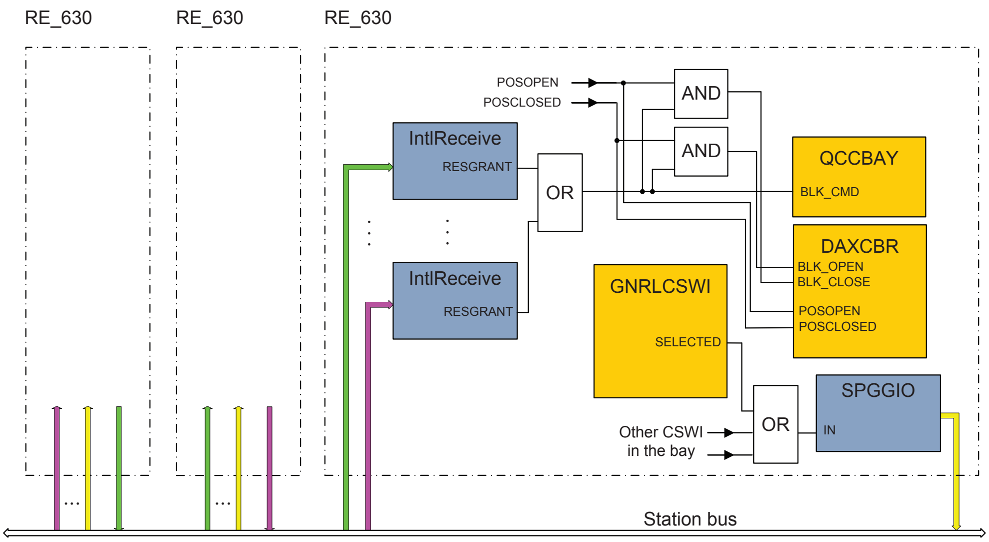


Figure 579: Application principles for reservation over the station bus, example 1

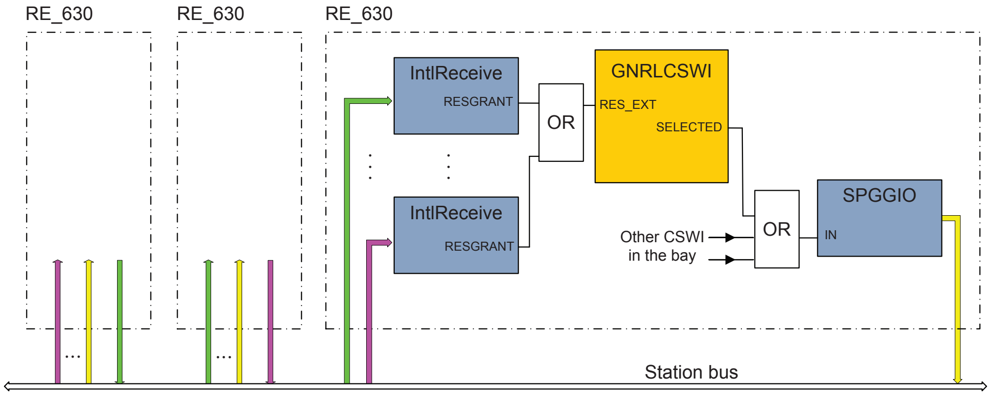


Figure 580: Application principles for reservation over the station bus, example 2

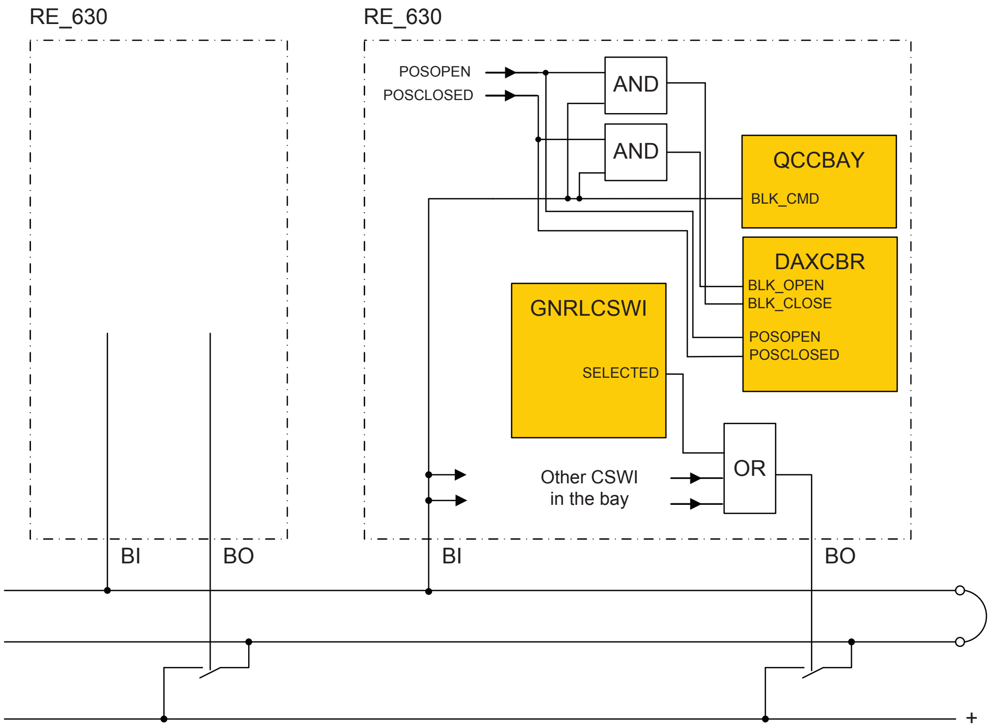


Figure 581: Application principles for reservation with external wiring, example 1

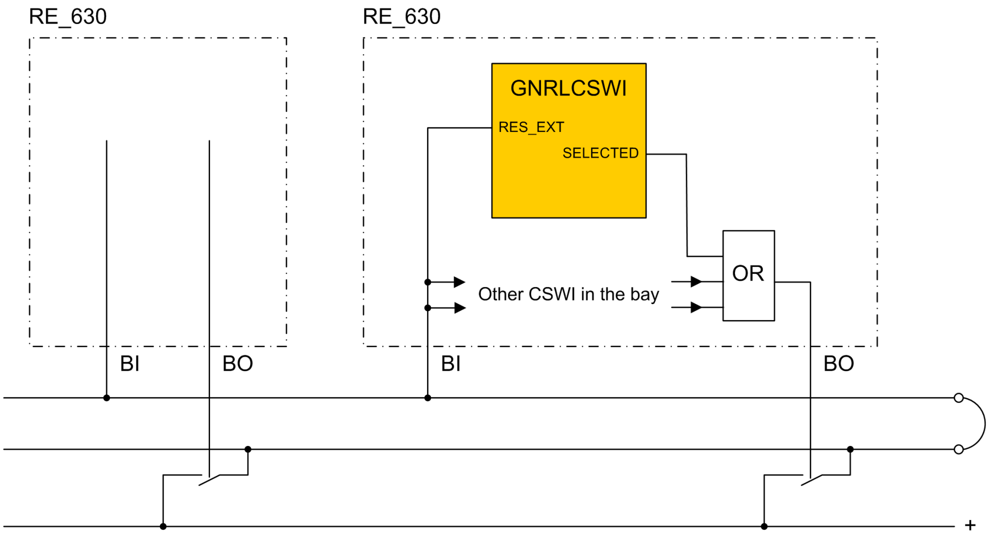


Figure 582: Application principles for reservation with external wiring, example 2

10.3 Interlocking

10.3.1 General principles of interlocking

The interlocking function consists of the software modules located in each control IED. The function is distributed and does not depend on any central function. The communication between modules in different bays is performed with the station bus.

The reservation functionality is used to ensure that Medium Voltage (MV) apparatuses that affect the interlock are blocked during the time gap, which arises between position updates. This is done with the communication system, reserving all MV apparatuses that influence the interlocking condition of an intended operation. The reservation is maintained until the operation is performed.

After the selection and reservation of an apparatus, the function has complete data on the status of all apparatuses in the switchyard that are affected by the selection. The other operators cannot interfere with the reserved apparatus or the status of switching devices that affect the function.

The interlocking logic is implemented case by case using configurable logic with the graphical configuration tool PCM600.

The open or closed positions of the MV apparatuses are inputs to software modules distributed in the control IEDs. Each module contains an interlocking logic for a bay. The specific interlocking conditions and connections between standard interlocking modules are performed with an engineering tool. The bay-level interlocking signals can include the information such as:

- Positions of MV apparatuses (sometimes per phase)
- Valid positions (if evaluated in the control module)
- External release (to add special conditions for release)
- Line voltage (to block operation of line earthing switch)
- Output signals to release the MV apparatus

The example of an interlocking module is connected to the surrounding functions within a bay is as shown in the figure.

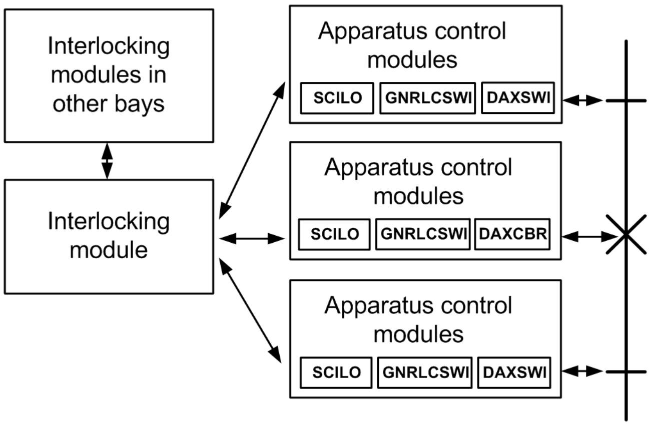


Figure 583: Interlocking module on bay level

The bays communicate the station bus convey the information such as:

- Unearthed busbars
- Busbars connected together
- Other bays connected to the busbar
- Received data from other bays is valid or not

When an invalid data such as intermediate position, loss of a control terminal, or input board error are used as conditions for the interlocking condition in a bay, the release for execution of the function is not given.

On the station HMI an override function exists, which can be used to bypass the interlocking function in cases where not all the data required for the condition is valid.

For interlocking the general rules that normally apply are:

- The interlocking conditions for opening or closing of disconnectors and earthing switches are always identical.
- The earthing switches on the line feeder end, for example, rapid earthing switches, are normally interlocked only with reference to the conditions in the

bay where they are located, not with reference to switches on the other side of the line. A line voltage indication may be included into the line interlocking modules. If there is no line voltage supervision within the bay, then the appropriate inputs must be set to no voltage. The operator must consider this when operating.
- The earthing switches can only be operated on isolated sections for example, without load or voltage. The circuit breaker contacts are not used to isolate a section, that is, the status of the circuit breaker is irrelevant as far as the earthing switch operation is concerned.
- The disconnectors does not have the current interrupting capacity. The disconnectors connected in series with a circuit breaker can only be operated if the circuit breaker is open, or if the disconnectors operate in parallel with other closed connections. The other disconnectors can be operated if one side is completely isolated or if the disconnectors operate in parallel with the other closed connections or if they are earthed on both sides.

10.3.2 Application

The main purpose of switchgear interlocking is:

- To avoid the dangerous or damaging operation of switchgear.
- To enforce the restrictions on the operation of the substation for other reasons, for example, load configuration. The examples of the latter are to limit the number of parallel transformers to a maximum of two or to ensure that energizing is always from one side, for example, the high voltage side of a transformer.

This document deals with only few of the interlocking restrictions caused by switching devices other than the one to be controlled. The switch interlock because of device alarms, is not included in this document.

The disconnectors and earthing switches have a limited switching capacity. The disconnectors therefore only operate:

- With basically zero current: The circuit is open on one side and has a small extension. The capacitive current is small, for example, less than 5A and power transformers with inrush current are not allowed.
- To connect or disconnect a parallel circuit carrying load current: The switching voltage across the open contacts is thus virtually zero due to the parallel circuit, that is, less than 1 percent of rated voltage. The paralleling of power transformers is not allowed.

The earthing switches are allowed to connect and disconnect earthing of isolated points. Due to the capacitive or inductive coupling there may be some voltage, for example, less than 40 percent of rated voltage before earthing and some current, for example, less than 100 A after earthing of the line.

The circuit breakers are usually not interlocked. The closing is interlocked against running the disconnectors in the same bay and the bus-coupler opening is interlocked during the busbar transfer.

The positions of all switching devices in a bay and from some other bays determine the conditions for operational interlocking. The conditions from other stations are usually not available. Therefore, a line earthing switch is usually not fully interlocked. The operator must be convinced that the line is not energized from the other side before closing the earthing switch. As an option, a voltage indication can be used for interlocking. Care must be taken to avoid a dangerous enable condition at the loss of a VT secondary voltage, for example, a blown fuse.

The switch positions used by the operational interlocking logic are obtained from the auxiliary contacts or position sensors. For each end position, that is, open or closed, a true indication is needed – thus forming a double indication. The apparatus control function continuously checks its consistency. If neither condition is high, that is, 1 or TRUE, the switch is in an intermediate position, for example, moving. This dynamic state continues for some time, which in the case of disconnectors is may be up to 10 seconds. If both the indications stay low for a longer period, the position indication is interpreted as unknown. If both indications stay high, something is wrong, and the state is again treated as unknown. In both cases an alarm is sent to the operator. The indications from position sensors is self-checked and system faults are indicated by the fault signal. In the interlocking logic, the signals are used to avoid dangerous enable or release conditions. When the switching state of a switching device cannot be determined operation is not permitted.

10.3.3 Logical node for interlocking SCILO

10.3.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Interlocking interface	SCILO	3	3

10.3.3.2 Function block

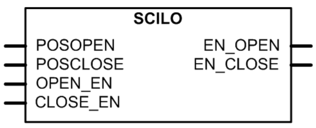


Figure 584: Function block

10.3.3.3 Functionality

The interlock switching function SCILO is used to enable a switching operation if the interlocking conditions permit. SCILO does not provide any interlocking functionality by itself . The interlocking conditions are generated by means of configurable logic or in separate function blocks containing the interlocking logic.

10.3.3.4 Operation principle

The switching interlock function SCILO has a logic to enable the open and close commands respectively if the interlocking conditions are fulfilled. If the switch has a defined end position, for example, open, then the appropriate enable signal `EN_OPEN` is false. The enable signals `EN_OPEN` and `EN_CLOSE` are true at the same time only in the intermediate and bad position state and if they are enabled by the interlocking function. The position inputs come from the logical nodes circuit breaker/switch function (DAXCBR / DAXSWI) and the enable signals from the interlocking logic. The outputs are connected to the logical node of the switch controller function (GNRLCSWI). One instance per switching device is needed.

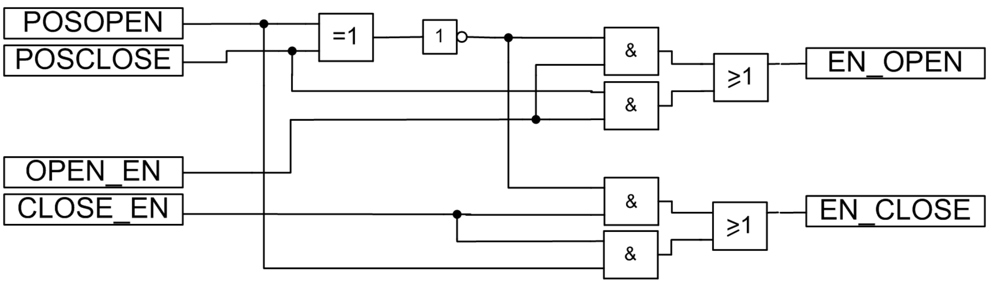


Figure 585: Logic diagram for SCILO

10.3.3.5 Application

SCILO is used in configuration between the interlocking logic and the switch controller function GNRLCSWI regardless whether the interlocking is implemented using ready-made interlocking modules or by means of configurable logic. SCILO implements the interface towards IEC 61850 communication.

10.3.3.6 Signals

Table 1137: SCILO Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0	Open position of switch device
POSCLOSE	BOOLEAN	0	Closed position of switch device
OPEN_EN	BOOLEAN	0	Open operation from interlocking logic is enabled
CLOSE_EN	BOOLEAN	0	Close operation from interlocking logic is enabled

Table 1138: SCILO Output signals

Name	Type	Description
EN_OPEN	BOOLEAN	Open operation at closed or intermediate or bad position is enabled
EN_CLOSE	BOOLEAN	Close operation at open or intermediate or bad position is enabled

10.3.4 Position evaluation POS_EVAL

10.3.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Position evaluation	POS_EVAL	-	-

10.3.4.2 Function block

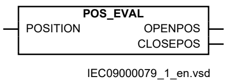


Figure 586: POS_EVAL function block

10.3.4.3 Functionality

Position evaluation (POS_EVAL) function converts the input position data signal POSITION, consisting of value, time and signal status, to binary signals OPENPOS or CLOSEPOS.

The output signals are used by other functions in the interlocking scheme.

10.3.4.4 Operation principle

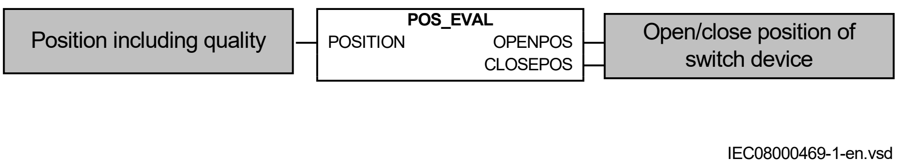


Figure 587: Logic diagram

Only the value, open/close, and status is used in this function. Time information is not used.

Input position (Value)	Signal quality	Output OPENPOS	Output CLOSEPOS
0 (Breaker intermediate)	Good	0	0
1 (Breaker open)	Good	1	0
2 (Breaker closed)	Good	0	1
3 (Breaker faulty)	Good	0	0
Any	Invalid	0	0
Any	Oscillatory	0	0

10.3.4.5 Signals

Table 1139: POS_EVAL Input signals

Name	Type	Default	Description
POSITION	INTEGER	0	Position status including quality

Table 1140: POS_EVAL Output signals

Name	Type	Description
OPENPOS	BOOLEAN	Open position
CLOSEPOS	BOOLEAN	Close position

10.3.4.6 Settings

The function does not have any parameters available in LHMI or PCM600.

10.4 Synchrocheck SYNCRSYN

10.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Synchrocheck function	SYNCRSYN	SYNC	25

10.4.2 Function block

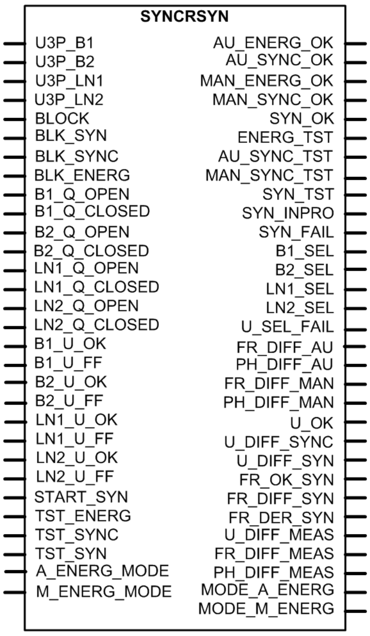


Figure 588: Function block

10.4.3 Functionality

The synchrocheck function SYNCRSYN checks the condition across the circuit breaker from separate power system parts and gives the output signal for closing the circuit breaker. SYNCRSYN includes the functionality of synchronizing, synchrocheck and energizing check.

For the systems which are running asynchronously, a synchronizing function is provided. The main purpose of the synchronizing function is to provide a controlled closing of circuit breakers when two asynchronous systems are going to be connected. It is used for the slip frequencies that are higher than those for synchrocheck and lower than the maximum possible set level for the synchronizing function.

The synchrocheck function checks that the voltages on both sides of the circuit breaker are synchronized. It is used to perform a controlled re-connection of two systems which are divided after islanding and it is also used to perform a controlled re-connection of the system after reclosing.

The energizing check function checks that at least one side is dead to ensure that closing can be done safely.

SYNCRSYN includes a built-in voltage selection scheme for the double bus single circuit breaker arrangement. It is possible to have a manual closing and automatic reclosing using SYNCRSYN with different settings.

10.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

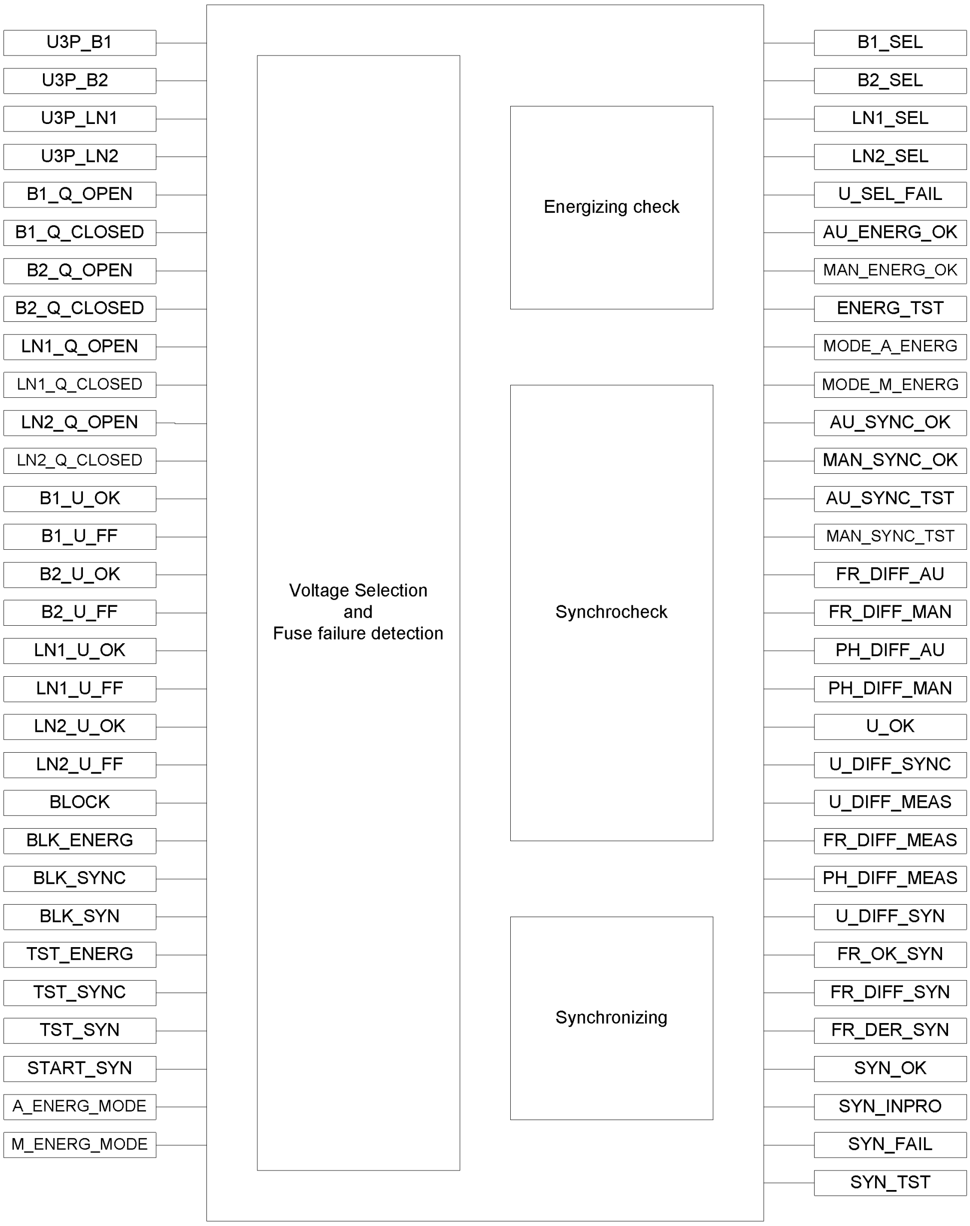


Figure 589: Functional module diagram

Fuse failure supervision

External fuse-failure signals or signals from a tripped fuse switch or an MCB are connected to the binary inputs that are then configured to the inputs of SYNCRSYN. Alternatively, the internal signals from the fuse failure supervision function can also be used when available.

There are two alternative connections possible for the inputs related to the fuse failure supervision. The inputs with the label `U_OK` must be used if the available fuse failure information indicates that the voltage circuit is healthy. The inputs with the label `U_FF` must be used if the available fuse failure information indicates that the voltage circuit is faulty.

The `B1(2)_U_OK` and `B1(2)_U_FF` inputs are to be connected for indicating the fuse failure information related to the busbar voltage. The `LN1(2)_U_OK` and `LN1(2)_U_FF` inputs are to be connected for indicating the fuse failure information related to the line voltage.

In the event of a fuse failure, the energizing check module is blocked. This eventually blocks the synchrocheck and synchronizing functions.

Voltage selection

The voltage selection module includes the selection of appropriate line and bus voltages depending on the type of system configuration. The module includes a fuse supervision feature which supervises the voltage transformer fuses for the selected voltage transformer. The module forms the basic part of SYNCRSYN and determines the parameters which are fed to the synchronizing, synchrocheck and energizing check modules.

The *CB configuration* busbar configuration setting is used to define the type of voltage selection for different configurations.

Table 1141: Description for CB configuration setting

CB configuration setting	Description
"No voltage sel"	No voltage selection
"Double bus"	Single circuit breaker with double bus
"1 1/2 bus 1 CB"	1 1/2 circuit breaker arrangement with the breaker connected to busbar 1
"1 1/2 bus 1 CB"	1 1/2 circuit breaker arrangement with the breaker connected to busbar 2
"Tie CB"	1 1/2 circuit breaker arrangement with the breaker connected to lines 1 and 2

If the *CB configuration* setting is set to "No Voltage Sel", the used default voltages are ULine1 and UBus1. This is also the case when external voltage selection is provided. The fuse failure supervision for the used inputs must also be connected.

The voltage selection made by voltage selection modules and fuse conditions are the inputs for the synchronizing, synchrocheck and energizing check modules. For the disconnector positions it is advisable to use (NO) a and (NC) b type contacts to supply the disconnector with open and closed positions, but it is possible to use an inverter for one of the positions.

The *Phase selection bus* configuration parameter setting is used for the selection of the measuring phase of the voltage for busbars. The voltage can be a single-phase (phase-to-neutral) or two-phase (phase-to-phase) voltage.

The *Phase selection line* configuration parameter setting is used for selection of measuring phase of the voltage for lines. The voltages can be single-phase (phase-to-neutral) or two-phase (phase-to-phase) voltage.

When *Phase selection Bus* is set to "Phase1-Phase-2", "Phase2-Phase3" or "Phase3-Phase1", the monitored values U_BUS_A, U_BUS_B and U_BUS_C show values for phases AB, BC and CA on the bus side. Similarly, when *Phase selection Line* is set to "Phase1-Phase-2", "Phase2-Phase3" or "Phase3-Phase1", the monitored values U_LINE_A, U_LINE_B and U_LINE_C show values for phases AB, BC and CA on the line side.

Voltage selection for a single circuit breaker with double busbars

The auxiliary contacts of the disconnectors are connected to the B1_Q_OPEN and B1_Q_CLOSED inputs for bus 1 and B2_Q_OPEN and B2_Q_CLOSED for bus 2 to select between the bus 1 and bus 2 voltages. If the disconnector connected to bus 2 is closed and the disconnector connected to bus 1 is opened, the bus 2 voltage is used. All other combinations use bus 1 voltage. The B1_SEL and B2_SEL outputs respectively indicate the selected bus voltage for synchronizing.

A check is carried out for the fuse failure signals for the bus 1, bus 2 and line voltage transformers. The B1_U_OK input or B1_U_FF and B2_U_OK or B2_U_FF supervises the fuse for the bus 1 and bus 2 voltage transformers respectively. LN1_U_OK or LN1_U_FF supervises the fuse for the line voltage transformer. The inputs fail (FF) or healthy (OK) can alternatively be used depending on the available signal. If a fuse failure is detected in either of the selected bus or line voltage source, the output signal U_SEL_FAIL is set. The activation of the BLOCK input signal blocks the module and U_SEL_FAIL.

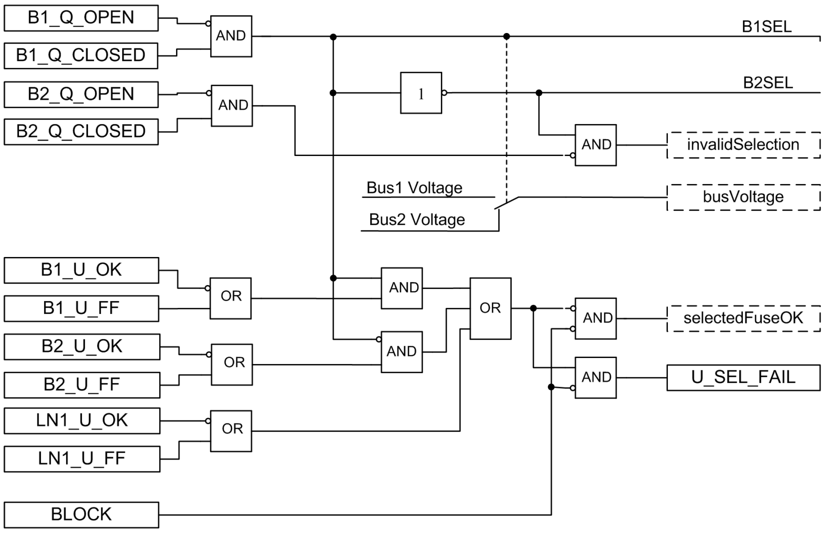


Figure 590: Logic diagram for the voltage selection function of a single circuit breaker with double busbars

Energizing check

The main purpose of the energizing check module is to facilitate the controlled re-connection of the disconnected lines and buses to the energized lines and buses. The energizing function in the module is defined as a situation where a dead section of the network is connected to an energized one. The module can be operated either in auto or manual mode.

The modules compare the amplitudes of the voltages on both sides of a circuit breaker and compares them to the higher and lower threshold limits of the detectors. The separate settable limits for the energized conditions (live) and non-energized conditions (dead) can be set through *Live bus value*, *Dead bus value*, *Live line value* and *Dead line value* for the bus and line voltages respectively. It should be noted that a disconnected line can have a considerable potential either due to an induction from a line running in parallel when fed through the discharging capacitor. This voltage can be as high as 30 percent or more of the base voltage. There is also an amplitude level check *Max energizing V* to ensure that the measured voltages are not too high. The frequencies on both sides of the circuit breaker are also measured; deviation in the frequency should not be more than the set value of the *Frequency deviation* setting.

The setting range of the threshold voltages, such as *Live bus value* or *Live line value* and *Dead bus value* or *Dead line value*, partly overlap each other. The setting conditions are such that the setting of the non-energized threshold value exceeds that of the energized threshold value. The parameters should therefore be set carefully by the user to avoid the described setting.

The energizing check module can be set to operate in either direction across the circuit breaker or the module can be permitted to operate in both directions. The module can be set either in automatic mode or manual mode or both. Both automatic mode and manual mode have four different settable modes. It is possible to set these four modes with the A_ENERG_MODE integer input or the *Live dead mode auto* setting for an automatic mode of operation, and with the M_ENERG_MODE integer input or the *Live dead mode Man* setting for a manual mode of operation. The mode selected with the integer input overrides those provided through a setting.

Table 1142: Mode selection for the energizing check module

Live dead mode auto or Live dead mode Man settings	Integer value at inputs A_ENERG_MODE or M_ENERG_MODE	Description
"Off"	1	The energizing module is disabled
"DLLB"	2	Dead line live bus, the line voltage is below the set value of *Dead line value* and bus voltage is above the set value of *Live bus value*
"LLDB"	3	Live line dead bus, the line voltage is above the set value of *Live line value* and bus voltage is below the set value of *Dead bus value*
"LLDB" or "DLLB"	4	Energizing can be done in both directions, LLDB and DLLB

With the value of the *Dead bus line Man* setting set to "True", the manual closing is enabled when both line and bus voltages are below the set value of the *Dead line value* and *Dead bus value* settings respectively and the *Live dead mode Man* setting is set to "DLLB" or "LLDB" or "LLDB or DLLB".

When the energizing conditions are met, the AU_ENERG_OK and MAN_ENERG_OK outputs are activated depending on the auto or manual modes of selection if the fuse supervision conditions are fulfilled. The AU_ENERG_OK and MAN_ENERG_OK output signals can be delayed independently through the *Energizing time Auto* and *Energizing time Man* settings respectively.

The activation of BLOCK or BLK_ENERG input blocks the energizing check module. The activation of TST_ENERG allows the testing of the module and activates the ENERG_TST output when the energizing conditions are fulfilled.

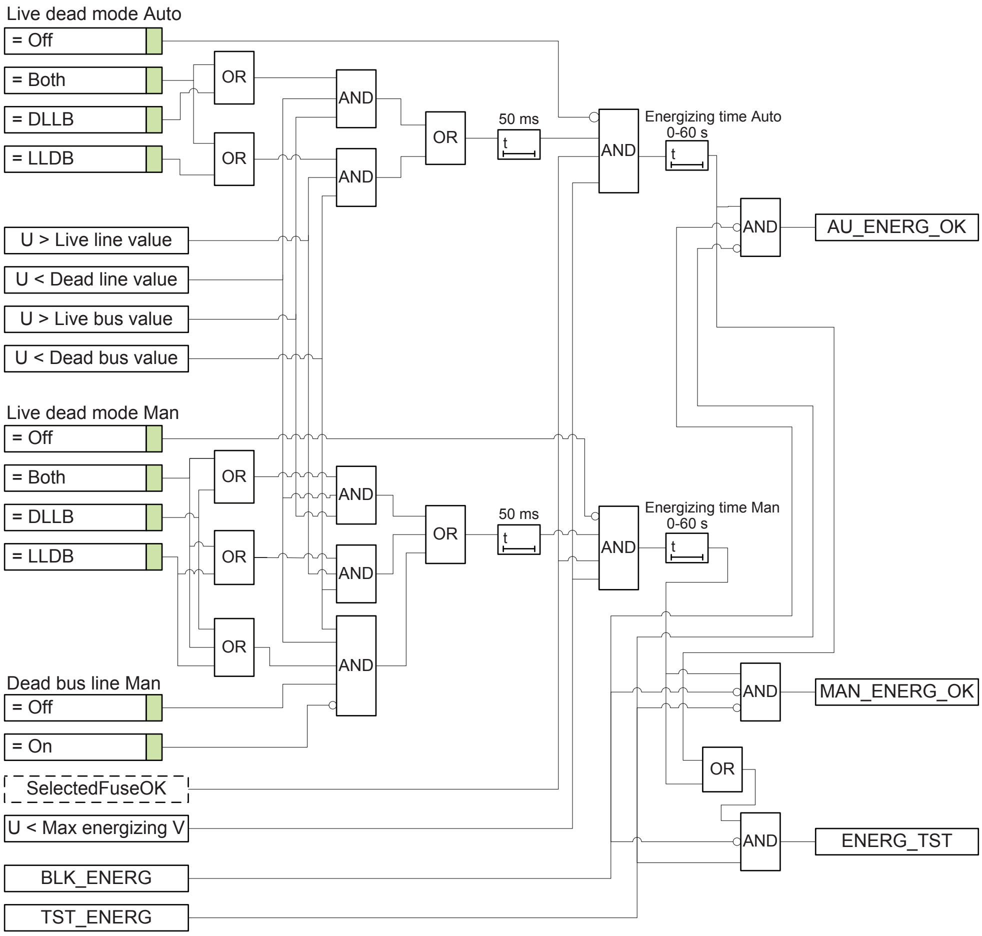


Figure 591: Simplified logic diagram for the energizing function

Synchrocheck

The synchrocheck module is used for the controlled closing of a circuit breaker in an interconnected network. When used, the function gives an enabling signal at satisfying voltage, frequency and phase angle conditions across the breaker to be closed. The function can be used as a condition to be fulfilled before the breaker is closed manually or with the autorecloser function or with both methods.

The synchrocheck module measures the amplitude, frequency and phase angle of the voltages on both sides of a circuit breaker and compares them to the threshold value of the limit detectors. The differences in voltage, frequency and phase angle values between the two sides of the circuit breaker are measured and available for evaluation before the synchronizing is done. If the available bus voltage is phase-to-phase and the line voltage is phase-to-neutral (or the opposite), a compensation is required. This is done with the *Voltage ratio* setting (defined as the ratio of bus voltage to line voltage), which scales up the line voltage to a level equal to the bus voltage. A typical example of the setting is to compensate for the voltage difference caused by connecting the bus voltage as phase-to-phase and the line voltage as phase-to-neutral, in which case the value of the *Voltage ratio* setting needs to be set to 1.73. A compensation for a phase shift caused by a line transformer between the two measurement points of the bus voltage and line voltage can be made with the *Phase shift* setting.

When the *Synchrocheck mode* setting is "ON", the measuring starts. If the value of the *Synchrocheck mode* setting is "OFF", it disables the synchrocheck function and deactivates the AU_SYNC_OK, MAN_SYNC_OK, AU_SYNC_TST and MAN_SYNC_TST outputs.

The synchrocheck module starts the synchronizing check if the voltage at both sides of the breaker is above 80 percent of the base value. When the values of the voltages on both the sides are above 80% of the base value, the measured values are compared to the set value for acceptable frequency, phase angle and voltage difference which are set using *Dif frequency Auto* or *Dif phase angle Auto* for the auto mode or with the *Dif frequency Man* or *Dif phase angle Man* settings for the manual mode and difference voltage settings. If a compensation factor is set due to the use of different voltages on the bus and line, the factor is deducted from the line voltage before the comparison is made for the phase angle values. The phase angle setting must be chosen to allow closing under the maximum load condition.

The frequency on both sides of the circuit breaker is also measured. The frequencies must not deviate from the rated frequency more than ±5 Hz. The frequency difference between the bus frequency and the line frequency is measured and must not exceed the set value of the *Frequency deviation* setting.

The MAN_SYNC_OK and AU_SYNC_OK outputs are activated when the actual measured conditions match the set conditions for the manual and auto synchronizing modes. It is possible to delay independently the MAN_SYNC_OK and AU_SYNC_OK output signals with the *Syn Chk delay Man* and *Syn Chk delay Auto* timer settings respectively to ensure that the synchrocheck conditions remain constant and that the situation is not caused by a temporary interference. If the conditions do not persist for the specified time, the delay timer is reset and the procedure is restarted until the conditions are fulfilled again. The circuit breaker closing is thus not permitted until the synchrocheck situation has remained constant throughout the set delay setting time.

The MAN_SYNC_TST and AU_SYNC_TST outputs are activated when the actual measured conditions match the set conditions for the manual and auto synchronizing modes respectively if the TST_SYNC input is active.

A number of outputs are available as information about a synchronizing condition being checked. The U_OK output indicates that the voltage amplitude at the line and bus sides is above 80 percent of the base value. The activation of the U_DIFF_SYNC output indicates that the voltage difference between the two sides of the circuit breaker is out of limit, and when the FR_DIFF_AU, FR_DIFF_MAN outputs are activated, it indicates that the frequency difference is out of limit for the auto and manual operations respectively. The PH_DIFF_AU and PH_DIFF_MAN outputs are related outputs to indicate the phase angle difference is out of limit for the auto and manual operation.

The activation of the `BLOCK` or `BLK_SYNC` inputs blocks the synchrocheck module.

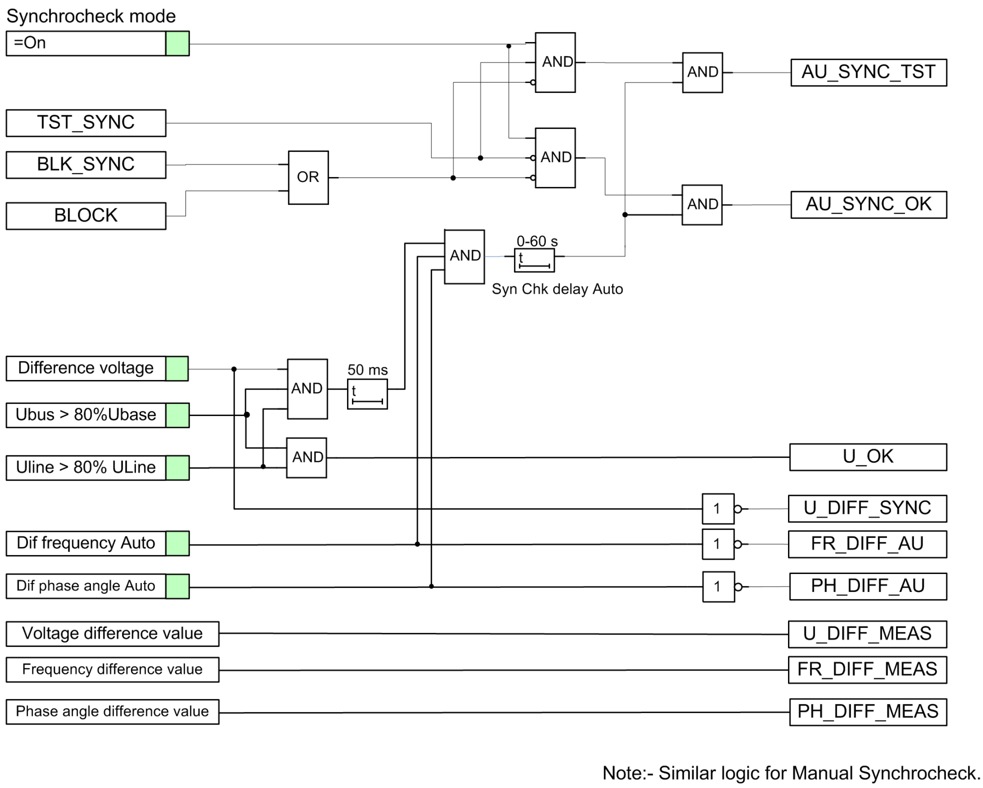


Figure 592: Simplified logic diagram for the synchrocheck function

Synchronizing

The synchronizing module measures the conditions across the circuit breaker. The module also determines the angle change occurring during the closing delay of the circuit breaker from the value of the measured slip frequency. The output is only given when all the measured conditions are simultaneously within their set limits. The issue of the output signal is timed to give closure at the optimal time including the time for the circuit breaker and the closing circuit. The main purpose of the energizing check module is to facilitate the controlled re-connection of disconnected signals.

The synchronizing module measures the amplitude, frequency and phase angle of the voltages on both sides of the circuit breaker and compares them to the threshold limit detectors. The voltage, frequency and phase angle difference values between the two sides of the circuit breaker are measured and available for evaluation before the synchronizing. If the available bus voltage is phase-to-phase and the line voltage is phase-to-neutral (or the opposite), a compensation is required. This is done with the *Voltage ratio* setting (defined as the ratio of bus voltage to line voltage), which scales up the line voltage to a level equal to the bus voltage. A typical example of the setting is to compensate for the voltage difference caused by connecting the bus voltage as phase-phase and the line voltage as phase-neutral, in which case the *Voltage ratio* setting needs to be set to 1.73. A compensation for the phase shift caused by a line transformer between the two measurement points for the bus voltage and line voltage can be made with the *Phase shift* setting. When the *Synchronizing mode* setting is "ON", the measuring starts. If the value of *Synchronizing mode* is "OFF", the synchronizing module is disabled.

The module starts the synchronizing check if the voltage on both sides of the breaker is above 80 percent of the base value which is supervising that the voltages on both sides are live; also indicated by a high value of the `U_OK_SYN` output. When the voltages on both sides are above 80 percent of the base value, the module measures and starts comparing various synchronizing parameters.

The voltage difference between the line and bus voltages is measured and compared to an allowable limit defined by the *Dif voltage Syn* setting. The difference is set depending on the network configuration and the expected voltages in the two networks running asynchronously. The `U_DIFF_SYN` output is activated when the voltage difference is out of limit for synchronizing.

The frequency is measured on both the line and the bus side. The frequencies must not deviate from the rated frequency by more than the set value of the *Frequency deviation* setting and the rate of change of frequency should not be more than the *Max Dif Hz rate Syn* setting. It is also required that the difference in frequencies on both sides of the breaker must be between the *Maximum Dif Hz Syn* and *Minimum Dif Hz Syn* settings. If the rate of frequency change for the bus and line frequencies is above the value of the *Max Dif Hz rate Syn* setting, the `FR_DER_SYN` output is activated.

The *Maximum Dif Hz Syn* setting provides the maximum slip frequency at which synchronizing is accepted. The *1/Maximum Dif Hz Syn* setting shows the time for the vector to turn 360˚, (one turn on the synchronoscope) and it is also known as the beat time. A typical value lies between 200...250 mHz which gives a beat time of 4...5 seconds. Higher values should be avoided as the two networks are normally regulated to normal frequency independently, so the frequency difference is small. The setting *Minimum Dif Hz Syn* is the minimum frequency difference where the systems are defined to be asynchronous. At a frequency difference lower than this value, the systems are considered to be in parallel. A typical value is 10 mHz.

The activation of the `FR_OK_SYN` and `FR_DIFF_SYN` outputs indicates the frequency difference between bus and line is in band or out of band (within the limit of *Minimum Dif Hz Syn – Maximum Dif Hz Syn*) for synchronizing respectively.

The value of *Minimum Dif Hz Syn* is set to the same value as *Dif frequency Man* or *Dif frequency Auto* of the synchrocheck module, depending on whether the functions are used for manual operation, autoreclosing or both.

The measured frequencies between the settings for the maximum and minimum frequency initiate the evaluation of the angle change to allow operation to be sent at the right moment, including the set value of *Closing time* of the circuit breaker time. There is an internal phase angle released to block any incorrect closing pulses. At operation, the `SYN_OK` output is activated with a pulse defined by the *Close pulse time* setting and the function reset. The function also resets if the synchronizing conditions are not fulfilled within the set value of the *Wait Syn time* period. This then prevents the functions from being maintained in operation by mistake for a long time waiting for the conditions to be fulfilled.

The *Closing time* setting of the circuit breaker is set to match the closing time for the circuit breaker and should also include the possible auxiliary relays in the closing circuit. It is important to check that no slow logic components are used in the configuration of the IED as there can be big variations in closing time due to those components.

The *Minimum Syn time* setting time is set to limit the minimum time at which the synchronizing closing attempt is given. The setting gives the `SYN_OK` output if a fulfilled condition occurs within this time when the synchronizing function is started.

The start of synchronizing is initiated by the `START_SYN` input. The `SYN_INPRO` output indicates that the synchronizing process is in progress. If any failure of the synchronizing output occurs, the `SYN_FAIL` output is activated.

The *Wait Syn time* setting is set to reset the operation of the synchronizing function if the synchronizing conditions are not fulfilled within this time. The setting must be set considering the value of the *Minimum Dif Hz Syn* setting which decides the maximum time required to reach phase equality. At a setting of 10 ms the beat time is 100 seconds and the setting thus needs to be at least *Minimum Syn time* plus 100 seconds. If the network frequencies are expected to be outside the limits from the start, a margin needs to be added.

The activation of `TST_SYN` allows the testing of the module and activates the `SYN_TST` output when the synchronizing conditions are fulfilled. The activation of the `BLOCK` or `BLK_SYN` input blocks the synchronizing module.

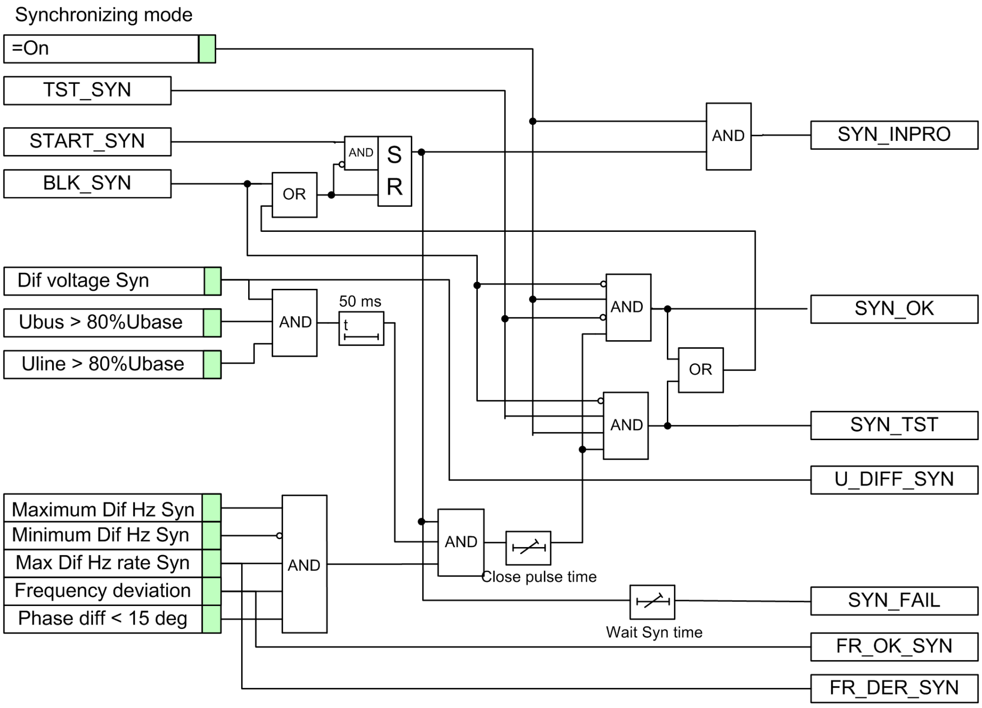


Figure 593: Simplified logic diagram for the synchronizing function

10.4.5 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

10.4.6 Application

Synchronizing

The synchronizing function is needed for the closing of a breaker between asynchronous networks. The breaker close command is issued at the optimum time when the conditions across the breaker are satisfied in order to avoid stress on the network and its components.

The systems are defined to be asynchronous when the frequency difference between a bus and a line is larger than an adjustable parameter. If the frequency difference is less than the threshold value, the systems operate as if they were connected in parallel and synchrocheck function was used.

At power plants, the synchronizing function is needed to permit the manual or automatic closing of the circuit breaker.

The synchronizing function measures the difference between the line and bus voltages. It operates and enables a closing command to the circuit breaker when the calculated closing angle is equal to the measured phase angle and certain conditions are simultaneously fulfilled.

The conditions are:

- The line and bus voltages are over 80 percent of the base value.
- The difference in the voltage between the line and bus sides is smaller than the set value of *Dif voltage Syn*.
- The frequency deviation at the line and bus sides should not exceed the set value of the *Frequency deviation* limit.
- The difference in the frequency between the line and bus sides is less than the set value of *Maximum Dif Hz Syn* and larger than the set value of *Minimum Dif Hz Syn*.
- The rate of change of the frequencies of both the bus and line voltages should be below the set value of *Max Dif Hz rate Syn*.

If the difference in the frequency between the line and bus sides is less than the value of *Minimum Dif Hz Syn*, the synchrocheck module is used.

The synchronizing function compensates for the measured slip frequency as well as the circuit breaker closing delay. The measured frequencies between the settings for the maximum and minimum frequencies initiate the evaluation of the angle change to allow operation to be sent at the right moment including the set closing time of the CB time. There is an internal phase angle release to block any incorrect closing pulses.

At operation, the SYN_OK output activates with a pulse of defined duration and the function resets after the pulse ends. The function also resets if the synchronizing conditions are not fulfilled within the set wait period. This prevents the situation that the function is by mistake maintained in operation a long time for conditions to be fulfilled.

The reference voltage can be phase-to-neutral or phase-to-phase voltages.

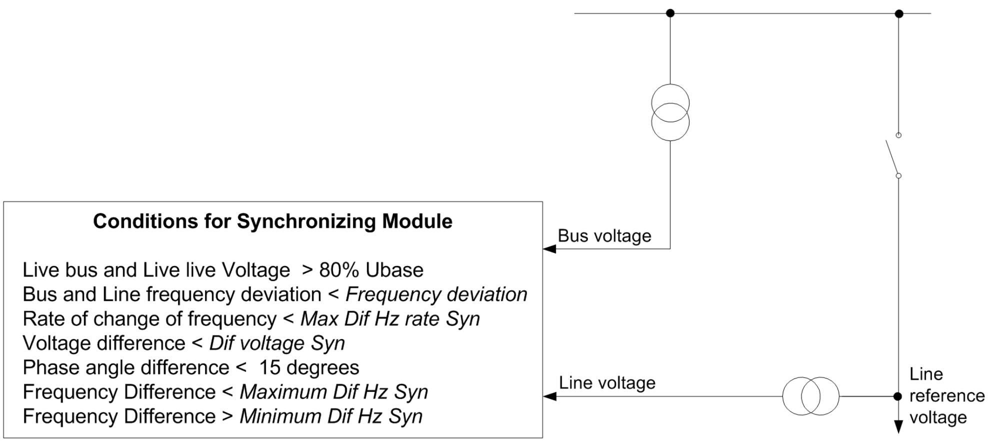


Figure 594: Principle of Synchronizing module and the conditions requirement

The synchronizing module is applied in many configurations. Figure 595, describing the synchronizing in the interconnection of generation and power distribution, shows a situation where the synchronizing function is located to verify the interconnection of power generation and distribution to guarantee that the generation is in synchronism with the power distribution.

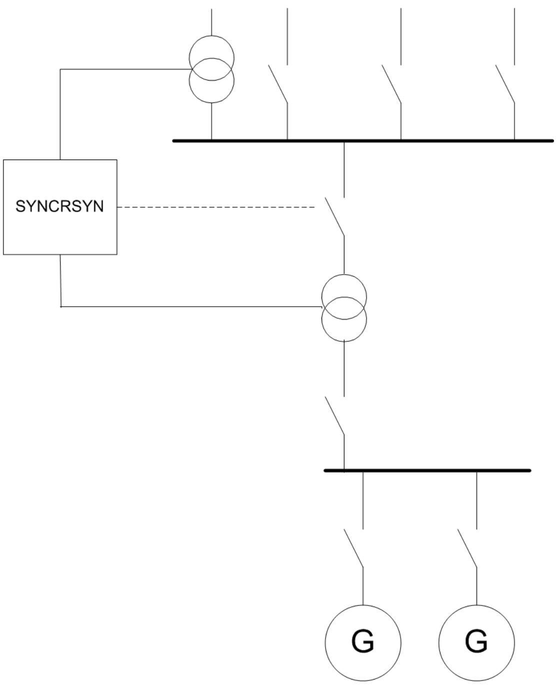


Figure 595: Synchronizing in the interconnection of generation and power distribution

Synchrocheck

The synchrocheck module is used for the controlled closing of a circuit breaker in an interconnected network. When used, the function gives an enable signal at adequate voltage, frequency and phase angle conditions across the breaker to be closed. The function can be used as a condition to be fulfilled before the breaker is closed at the manual closing and/or together with the autorecloser function.

Figure 596 shows two interconnected power systems. The cloud means that the interconnection can be further away, that is, a weak connection through other stations. The need for a synchronization check increases as the meshed system decreases since the risk of the two networks being out of synchronization at manual or automatic closing is greater.

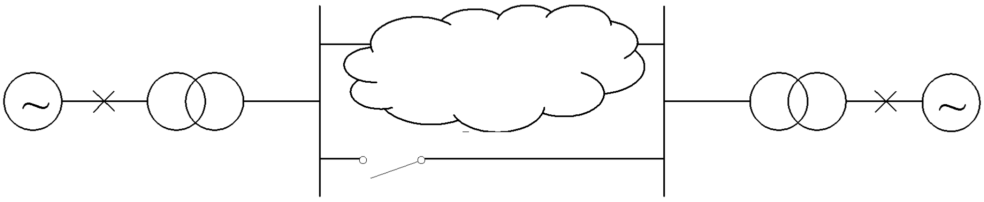


Figure 596: Two interconnected power systems

The synchrocheck module electrically determines if the difference in voltage magnitude, frequency and phase angle between the two sides of the breaker falls within allowable limits. The allowable limits vary with the location on the power system. If the system is far from generation and load, more phase angle difference can be tolerated. The synchrocheck module decides internally whether its conditions for closing are satisfied and either allows or prevents the closing depending on its settings. A typical synchrocheck relay allows closing if the voltage angle across the breaker is less than 30°. A time delay can be set to ensure that the conditions are fulfilled for a minimum period of time.

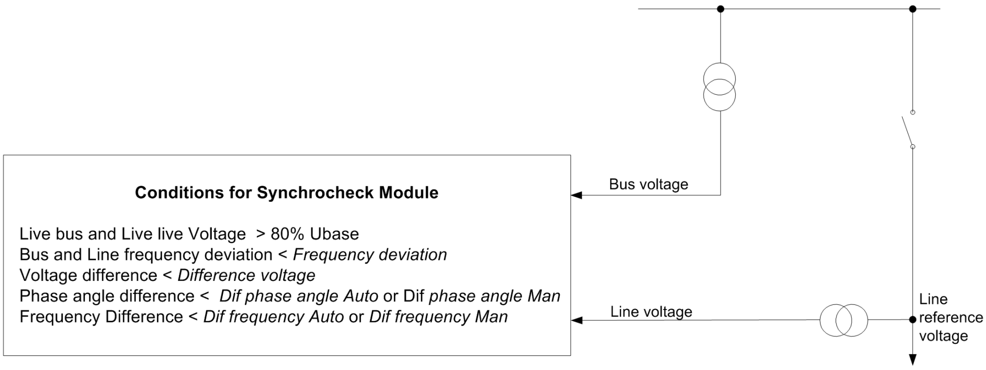


Figure 597: Principle for synchrocheck module and conditions requirement

In stable power systems, the frequency difference is insignificant or zero for manually initiated closing or closing by automatic restoration. At steady conditions, a bigger phase angle difference can be allowed as this is sometimes the case in a long and loaded parallel power line. For this application, a synchrocheck with a long operate time and high sensitivity regarding the frequency difference (3 mHz) and a relatively big phase angle difference setting is accepted.

Another situation is where the operation of the power network is disturbed and a high-speed autoreclosing after the fault clearance takes place. This can cause a power swing in the network and the phase angle difference begins to oscillate. Generally, the frequency difference is the time derivative of the phase angle difference and typically oscillates between positive and negative values. When the circuit breaker needs to be closed by the autoreclosing after the fault clearance, some frequency difference is tolerated, and to a greater extent than in a steady condition as mentioned in the above case. But if a greater phase angle difference is allowed at the same time, there is some risk that autoreclosing takes place when the phase angle difference is big and increasing. In this case it should be safer to close when the phase angle difference is smaller.

To fulfill the requirements, the synchrocheck module is provided with duplicate settings:

- Manual mode for steady conditions
- Auto mode for operation under disturbed conditions

The synchrocheck module can be utilized for various types of network configurations or topologies. The typical examples where the synchrocheck can be utilized are:

Figure 598, depicting synchrocheck in sectionalizer, shows an example of the double busbar system in which the feeding can be from at least two different sources and voltages can therefore be opposite to each other.

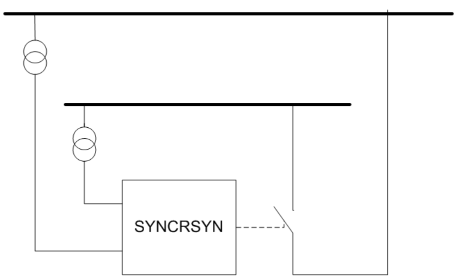


Figure 598: Synchrocheck in sectionalizer

Figure 599 shows the synchrocheck for a doubly fed power line. The closing of the circuit breaker requires that both sides are in synchronism. The energization check is required for the breaker closing first during autoreclosing, and the synchronism check is needed for all the breakers closing afterwards to complete the autoreclose operation.

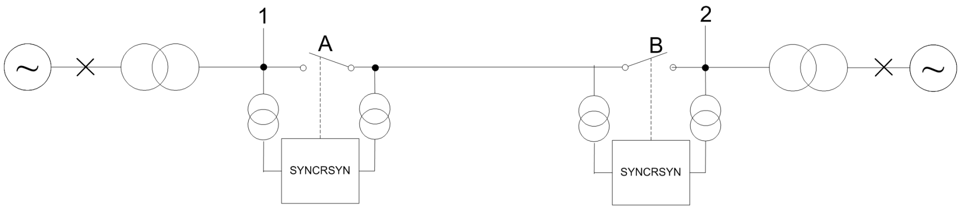


Figure 599: Synchrocheck for doubly fed power line

Many power utilities require the three-phase autoreclosing to be combined with synchrocheck and energizing check. It is checked that if the line is dead, this condition is sufficient to allow autoreclosing to be executed at one end. At the opposite end of the line, usually synchrocheck is applied. The autoreclosing waits for the line to be energized from the first line end and the synchrocheck conditions are fulfilled. The autoreclosing is completed.

Energizing check

The main purpose of the energizing check module is to facilitate the controlled re-connection of disconnected lines and buses to energized lines and buses. The energizing function of the module is applied in a situation where a dead section of the network is to be connected to an energized section. The module can be operated in auto or manual mode.

The energizing check function measures the bus and line voltages and compares them to both high and low threshold values. The output is given when the measured conditions match the set conditions. Figure 600 shows a power systems network in which the bus side network is live and the line side which is dead needs to be energized by closing the circuit breaker A. For this kind of system, the energizing module checks for various conditions and provides the energizing OK signal if the selected mode for energizing is Dead Line Live Bus "DLLB" or Dead Line Live Bus or Live Line Dead Bus "DLLB or LLDB".

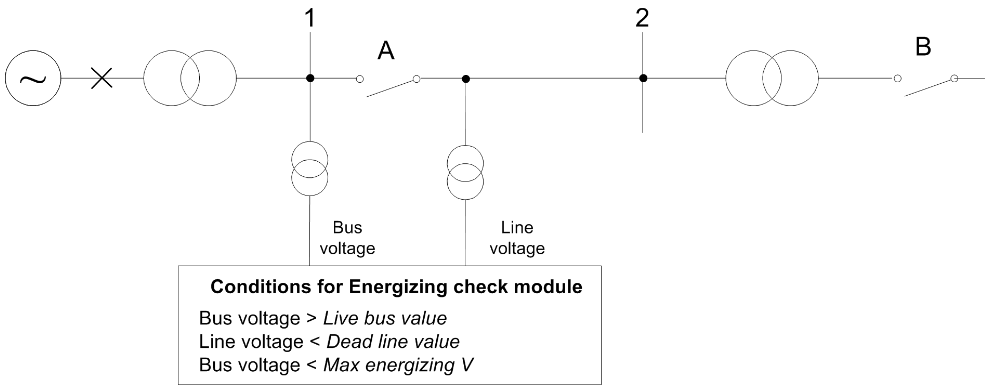


Figure 600: Principle for the energizing check function

The energizing check module can operate in the Dead Line Live Bus (DLLB) direction, Live Line Dead Bus (LLDB) direction or both directions over the circuit breaker. The energizing from different directions can be different for the automatic reclosing and manual closing of the circuit breaker. For the manual closing it is also possible to allow closing when both sides of the breaker are dead.

The equipment is considered energized if the voltage is above a set value, for example 80 percent of the base voltage, and non-energized if it is below a set value, for example 30 percent of the base voltage. A disconnected line has a considerable potential because of the factors, such as induction from a line running in parallel or feeding with the extinguishing capacitors in the circuit breakers. Normally for breakers in radial distribution network the level is well below 30 percent.

When the energizing conditions are satisfied according to the settings, the situation has to remain constant for a certain period of time before the close signal is permitted. The purpose of the delayed operate time is to ensure that the dead side remains de-energized and that the condition is not due to temporary interference.

Fuse failure supervision

The fuse failure supervision module continuously supervises the external fuse failure of the voltage transformer of the busbar. It also supervises the line voltages. The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs that are then configured to the inputs of SYNCRSYN. Alternatively, the internal signals from the fuse failure supervision function can also be used when available.

In the event of a fuse failure, the energizing check module is blocked, which eventually blocks the synchrocheck and synchronizing modules.

Voltage selection

The voltage selection function is used for the connection of appropriate voltages to the energizing check, synchrocheck and synchronizing modules. For example, when an IED is used in a double bus arrangement, the voltage to be selected depends on the status of the breakers and disconnectors. By checking the status of the auxiliary contacts of the disconnectors, the right voltages for the synchrocheck and energizing check functions are selected. The available voltage selection type is for single circuit breaker with the double busbar arrangement. A single circuit breaker with a single busbar does not need any voltage selection functions, nor does a single circuit breaker with double busbars using external voltage selection need any internal voltage selections.

The voltages from busbars and lines must be physically connected to the voltage inputs in the IED and connected, using the control software, to SYNCRSYN available in the IED.

Synchronizing, synchrocheck and energizing check are based on three-phase voltage measurements, but usually the single-phase quantities are satisfactory. Preferably a phase-to-phase voltage is used, but sometimes there is just a single phase-to-earth voltage transformer installed at one side and a phase-to-earth voltage must be used.

10.4.7 Application Examples

SYNCRSYN can be used in different switchyard arrangements with different parameter settings. Below are the examples of how different arrangements are connected to the IED analog inputs and to SYNCRSYN. One function block is used per circuit breaker.

Single circuit breaker with single busbar

There is a voltage transformer on each side of the circuit breaker. The voltage transformer circuit connections are straightforward and no special voltage selection is necessary. The inputs and outputs that are not used in SYCRSYN are dimmed as shown in Figure 601,and the variable *GRP_OFF* taken from the FXDSIGN function block are to be connected to the unused inputs. The voltage selection parameter *CB Configuration* is set to “No voltage sel.”.

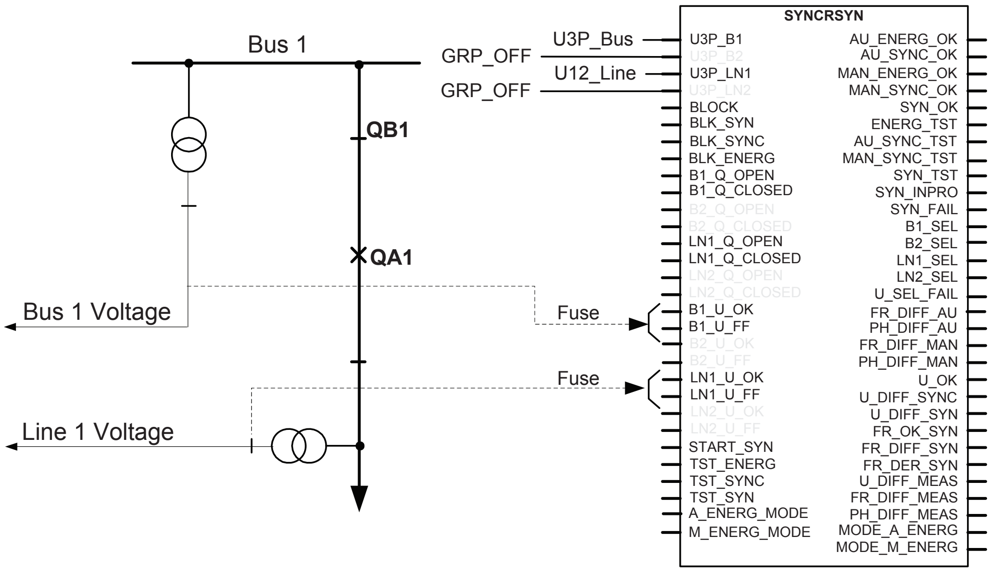


Figure 601: Connection principles for SYNCRSYN block in a single busbar arrangement

Single circuit breaker with double busbar, external voltage selection

In this type of arrangement, no internal voltage selection is required. The voltage selection is made by external relays typically connected according to Figure 602. The suitable voltage and VT fuse failure supervision from the two busbars are selected based on the position of the busbar disconnectors. This means that the connections to the function block are the same as the single busbar arrangement. The voltage selection parameter *CB configuration* is set to “No voltage sel”.

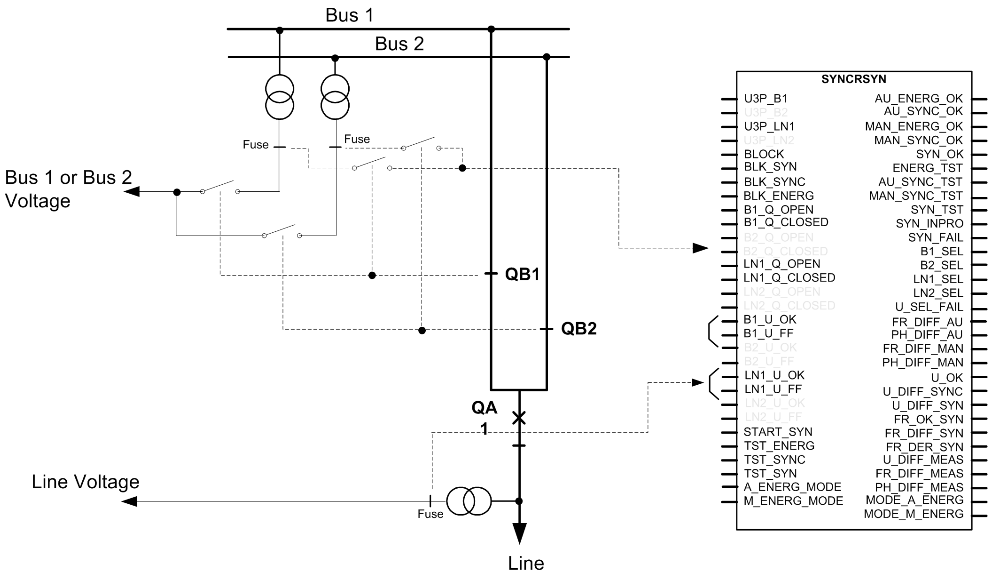


Figure 602: Connection for SYNCRSYN block in a single breaker, double busbar arrangement with external voltage selection

Single circuit breaker with double busbar, internal voltage selection

When the internal voltage selection is needed, two analog input modules are required. The voltage transformer circuit connections are made as shown in Figure 603, and the inputs and outputs not used in SYNCRSYN are dimmed.

The voltage selection parameter *CB configuration* is set to “Double bus”.

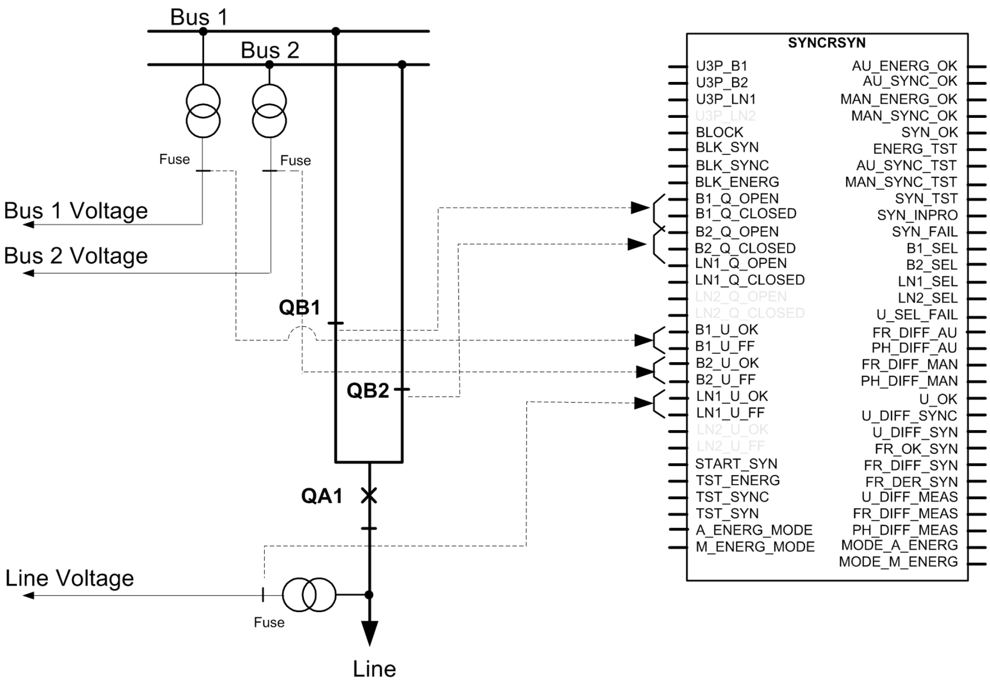


Figure 603: Connection for SYNCRSYN block in a single breaker, double busbar arrangement with internal voltage selection

10.4.8 Signals

Table 1143: SYNCRSYN Input signals

Name	Type	Default	Description
U3P_B1	GROUP SIGNAL	-	Three phase group signal for voltage inputs, busbar 1
U3P_B2	GROUP SIGNAL	-	Three phase group signal for voltage inputs, busbar 2
U3P_LN1	GROUP SIGNAL	-	Three phase group signal for voltage inputs, line 1
U3P_LN2	GROUP SIGNAL	-	Three phase group signal for voltage inputs, line 2
BLOCK	BOOLEAN	0	General block
BLK_SYN	BOOLEAN	0	Block synchronizing
BLK_SYNC	BOOLEAN	0	Block synchro check
BLK_ENERG	BOOLEAN	0	Block energizing check
B1_Q_OPEN	BOOLEAN	0	Open status for CB or disconnector connected to bus1
B1_Q_CLOSED	BOOLEAN	0	Close status for CB or disconnector connected to bus1
B2_Q_OPEN	BOOLEAN	0	Open status for CB or disconnector connected to bus2
Table continues on next page			

Name	Type	Default	Description
B2_Q_CLOSED	BOOLEAN	0	Close status for CB or disconnector connected to bus2
LN1_Q_OPEN	BOOLEAN	0	Open status for CB or disconnector connected to line1
LN1_Q_CLOSED	BOOLEAN	0	Close status for CB or disconnector connected to line1
LN2_Q_OPEN	BOOLEAN	0	Open status for CB or disconnector connected to line2
LN2_Q_CLOSED	BOOLEAN	0	Close status for CB or disconnector connected to line2
B1_U_OK	BOOLEAN	0	Bus1 voltage transformer OK
B1_U_FF	BOOLEAN	0	Bus1 voltage transformer fuse failure
B2_U_OK	BOOLEAN	0	Bus2 voltage transformer OK
B2_U_FF	BOOLEAN	0	Bus2 voltage transformer fuse failure
LN1_U_OK	BOOLEAN	0	Line1 voltage transformer OK
LN1_U_FF	BOOLEAN	0	Line1 voltage transformer fuse failure
LN2_U_OK	BOOLEAN	0	Line2 voltage transformer OK
LN2_U_FF	BOOLEAN	0	Line2 voltage transformer fuse failure
START_SYN	BOOLEAN	0	Start synchronizing
TST_ENERG	BOOLEAN	0	Set energizing check in test mode
TST_SYNC	BOOLEAN	0	Set synchro check in test mode
TST_SYN	BOOLEAN	0	Set synchronizing in test mode
A_ENERG_MODE	INTEGER	0	Input for setting of automatic energizing mode
M_ENERG_MODE	INTEGER	0	Input for setting of manual energizing mode

Table 1144: SYNCRSYN Output signals

Name	Type	Description
AU_ENERG_OK	BOOLEAN	Automatic energizing check OK
AU_SYNC_OK	BOOLEAN	Auto synchro check OK
MAN_ENERG_OK	BOOLEAN	Manual energizing check OK
MAN_SYNC_OK	BOOLEAN	Manual synchro check OK
SYN_OK	BOOLEAN	Synchronizing OK output
ENERG_TST	BOOLEAN	Energizing check OK test output
AU_SYNC_TST	BOOLEAN	Auto synchro check OK test output
MAN_SYNC_TST	BOOLEAN	Manual synchro check OK test output
SYN_TST	BOOLEAN	Synchronizing OK test output
SYN_INPRO	BOOLEAN	Synchronizing in progress
SYN_FAIL	BOOLEAN	Synchronizing failed
B1_SEL	BOOLEAN	Bus1 selected
B2_SEL	BOOLEAN	Bus2 selected
LN1_SEL	BOOLEAN	Line1 selected

Table continues on next page

Name	Type	Description
LN2_SEL	BOOLEAN	Line2 selected
U_SEL_FAIL	BOOLEAN	Selected voltage transformer fuse failed
FR_DIFF_AU	BOOLEAN	Frequency difference out of limit for Auto operation
PH_DIFF_AU	BOOLEAN	Phase angle difference out of limit for Auto operation
FR_DIFF_MAN	BOOLEAN	Frequency difference out of limit for Manual operation
PH_DIFF_MAN	BOOLEAN	Phase angle difference out of limit for Manual Operation
U_OK	BOOLEAN	Voltage amplitudes above set limits
U_DIFF_SYNC	BOOLEAN	Voltage difference out of limit
U_DIFF_SYN	BOOLEAN	Voltage difference out of limit for synchronizing
FR_OK_SYN	BOOLEAN	Frequency difference in band for synchronizing
FR_DIFF_SYN	BOOLEAN	Frequency difference out of limit for synchronizing
FR_DER_SYN	BOOLEAN	Frequency derivative out of limit for synchronizing
U_DIFF_MEAS	REAL	Calculated difference in voltage
FR_DIFF_MEAS	REAL	Calculated difference in frequency
PH_DIFF_MEAS	REAL	Calculated difference of phase angle
MODE_A_ENERG	INTEGER	Selected mode for automatic energizing
MODE_M_ENERG	INTEGER	Selected mode for manual energizing

10.4.9 Settings

Table 1145: SYNCRSYN Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Dead bus value	0.05 - 0.50	pu	0.01	0.40	Voltage low limit bus for energizing check
Dead line value	0.05 - 0.50	pu	0.01	0.40	Voltage low limit line for energizing check
Live bus value	0.40 - 1.20	pu	0.01	0.80	Voltage high limit bus for energizing check
Live line value	0.40 - 1.20	pu	0.01	0.80	Voltage high limit line for energizing check
Frequency deviation	1 - 5	Hz	1	5	Max allowed Frequency deviation from rated frequency
Difference voltage	0.02 - 0.50	pu	0.01	0.15	Voltage difference limit
Max energizing V	0.80 - 1.40	pu	0.01	1.15	Maximum voltage for energizing
Phase shift	-180 - 180	Deg	5	0	Phase shift
Voltage ratio	0.20 - 5.00	-	0.01	1.00	Voltage ratio
Live dead mode Auto	Off LLDB DLLB LLDB or DLLB	-	-	LLDB	Automatic energizing check mode

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Dif phase angle Auto	5 - 90	Deg	1	25	Phase angle difference limit between bus and line Auto
Dif frequency Auto	0.003 - 1.000	Hz	0.001	0.010	Frequency difference limit between bus and line Auto
Energizing time Auto	0.000 - 60.000	s	0.001	0.100	Time delay for automatic energizing check
Syn Chk delay Auto	0.000 - 60.000	s	0.001	0.100	Time delay output for synchrocheck Auto
Live dead mode Man	Off LLDB DLLB LLDB or DLLB	-	-	LLDB or DLLB	Manual energizing check mode
Dead bus line Man	Off On	-	-	Off	Manual dead bus, dead line energizing
Dif phase angle Man	5 - 90	Deg	1	25	Phase angle difference limit between bus and line Manual
Dif frequency Man	0.003 - 1.000	Hz	0.001	0.010	Frequency difference limit between bus and line Manual
Energizing time Man	0.000 - 60.000	s	0.001	0.100	Time delay for manual energizing check
Syn Chk delay Man	0.000 - 60.000	s	0.001	0.100	Time delay output for synchrocheck Manual

Table 1146: SYNCRSYN Group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Synchrocheck mode	Off On	-	-	On	Operation for synchronism check function Off/On
Synchronizing mode	Off On	-	-	Off	Operation for synchronizing function Off/On
Dif voltage Syn	0.02 - 0.50	pu	0.01	0.10	Voltage difference limit for synchronizing
Maximum Dif Hz Syn	0.050 - 0.250	Hz	0.001	0.200	Maximum frequency difference limit for synchronizing
Minimum Dif Hz Syn	0.003 - 0.250	Hz	0.001	0.010	Minimum frequency difference limit for synchronizing
Max Dif Hz rate Syn	0.000 - 0.500	Hz/s	0.001	0.300	Maximum allowed frequency rate of change
Minimum Syn time	0.000 - 60.000	s	0.001	2.000	Minimum time to accept synchronizing conditions
Wait Syn time	0.00 - 6000.00	s	0.01	600.00	Resets synch if no close has been made before set time

Table 1147: SYNCRSYN Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
CB configuration	No voltage sel. Double bus 1 1/2 bus 1 CB 1 1/2 bus 2 CB Tie CB	-	-	No voltage sel.	Select CB configuration
Phase selection bus	phase1 phase2 phase3 phase1-phase2 phase2-phase3 phase3-phase1	-	-	phase1-phase2	Select phase for buses
Phase selection line	phase1 phase2 phase3 phase1-phase2 phase2-phase3 phase3-phase1	-	-	phase1-phase2	Select phase for lines
Closing time of CB	0.000 - 60.000	s	0.001	0.080	Closing time of the breaker

Table 1148: SYNCRSYN Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Close pulse time	0.050 - 60.000	s	0.001	0.200	Breaker closing pulse duration

10.4.10 Measured values

Table 1149: SYNCRSYN Measured values

Name	Type	Default	Description
BLOCK	BOOLEAN	0	General block
BLK_SYN	BOOLEAN	0	Block synchronizing
BLK_SYNC	BOOLEAN	0	Block synchro check
BLK_ENERG	BOOLEAN	0	Block energizing check
B1_Q_OPEN	BOOLEAN	0	Open status for CB or disconnector connected to bus1
B1_Q_CLOSED	BOOLEAN	0	Close status for CB or disconnector connected to bus1
B2_Q_OPEN	BOOLEAN	0	Open status for CB or disconnector connected to bus2
B2_Q_CLOSED	BOOLEAN	0	Close status for CB or disconnector connected to bus2
LN1_Q_OPEN	BOOLEAN	0	Open status for CB or disconnector connected to line1

Table continues on next page

Name	Type	Default	Description
LN1_Q_CLOSED	BOOLEAN	0	Close status for CB or disconnector connected to line1
LN2_Q_OPEN	BOOLEAN	0	Open status for CB or disconnector connected to line2
LN2_Q_CLOSED	BOOLEAN	0	Close status for CB or disconnector connected to line2
B1_U_OK	BOOLEAN	0	Bus1 voltage transformer OK
B1_U_FF	BOOLEAN	0	Bus1 voltage transformer fuse failure
B2_U_OK	BOOLEAN	0	Bus2 voltage transformer OK
B2_U_FF	BOOLEAN	0	Bus2 voltage transformer fuse failure
LN1_U_OK	BOOLEAN	0	Line1 voltage transformer OK
LN1_U_FF	BOOLEAN	0	Line1 voltage transformer fuse failure
LN2_U_OK	BOOLEAN	0	Line2 voltage transformer OK
LN2_U_FF	BOOLEAN	0	Line2 voltage transformer fuse failure
START_SYN	BOOLEAN	0	Start synchronizing
TST_ENERG	BOOLEAN	0	Set energizing check in test mode
TST_SYNC	BOOLEAN	0	Set synchro check in test mode
TST_SYN	BOOLEAN	0	Set synchronizing in test mode
A_ENERG_MODE	INTEGER	0	Input for setting of automatic energizing mode
M_ENERG_MODE	INTEGER	0	Input for setting of manual energizing mode

10.4.11 Monitored data

Table 1150: SYNCRSYN Monitored data

Name	Type	Values (Range)	Unit	Description
AU_ENERG_OK	BOOLEAN	0=FALSE 1=TRUE	-	Automatic energizing check OK
AU_SYNC_OK	BOOLEAN	0=FALSE 1=TRUE	-	Auto synchro check OK
MAN_ENERG_OK	BOOLEAN	0=FALSE 1=TRUE	-	Manual energizing check OK
MAN_SYNC_OK	BOOLEAN	0=FALSE 1=TRUE	-	Manual synchro check OK
SYN_OK	BOOLEAN	0=FALSE 1=TRUE	-	Synchronizing OK output
ENERG_TST	BOOLEAN	0=FALSE 1=TRUE	-	Energizing check OK test output
AU_SYNC_TST	BOOLEAN	0=FALSE 1=TRUE	-	Auto synchro check OK test output
MAN_SYNC_TST	BOOLEAN	0=FALSE 1=TRUE	-	Manual synchro check OK test output
SYN_TST	BOOLEAN	0=FALSE 1=TRUE	-	Synchronizing OK test output

Table continues on next page

Name	Type	Values (Range)	Unit	Description
SYN_INPRO	BOOLEAN	0=FALSE 1=TRUE	-	Synchronizing in progress
SYN_FAIL	BOOLEAN	0=FALSE 1=TRUE	-	Synchronizing failed
B1_SEL	BOOLEAN	0=FALSE 1=TRUE	-	Bus1 selected
B2_SEL	BOOLEAN	0=FALSE 1=TRUE	-	Bus2 selected
LN1_SEL	BOOLEAN	0=FALSE 1=TRUE	-	Line1 selected
LN2_SEL	BOOLEAN	0=FALSE 1=TRUE	-	Line2 selected
U_SEL_FAIL	BOOLEAN	0=FALSE 1=TRUE	-	Selected voltage transformer fuse failed
FR_DIFF_AU	BOOLEAN	0=FALSE 1=TRUE	-	Frequency difference out of limit for Auto operation
PH_DIFF_AU	BOOLEAN	0=FALSE 1=TRUE	-	Phase angle difference out of limit for Auto operation
FR_DIFF_MAN	BOOLEAN	0=FALSE 1=TRUE	-	Frequency difference out of limit for Manual operation
PH_DIFF_MAN	BOOLEAN	0=FALSE 1=TRUE	-	Phase angle difference out of limit for Manual Operation
U_OK	BOOLEAN	0=FALSE 1=TRUE	-	Voltage amplitudes above set limits
U_DIFF_SYNC	BOOLEAN	0=FALSE 1=TRUE	-	Voltage difference out of limit
U_DIFF_SYN	BOOLEAN	0=FALSE 1=TRUE	-	Voltage difference out of limit for synchronizing
FR_OK_SYN	BOOLEAN	0=FALSE 1=TRUE	-	Frequency difference in band for synchronizing
FR_DIFF_SYN	BOOLEAN	0=FALSE 1=TRUE	-	Frequency difference out of limit for synchronizing
U_DIFF_MEAS	REAL	-	kV	Calculated difference in voltage
FR_DIFF_MEAS	REAL	-	Hz	Calculated difference in frequency
PH_DIFF_MEAS	REAL	-	deg	Calculated difference of phase angle
U_BUS_A	REAL	-	kV	Bus voltage phase A
U_BUS_B	REAL	-	kV	Bus voltage phase B
U_BUS_C	REAL	-	kV	Bus voltage phase C
FR_BUS	REAL	-	Hz	Bus frequency
PH_BUS	REAL	-	deg	Bus phase angle
U_LINE_A	REAL	-	kV	Line voltage phase A
U_LINE_B	REAL	-	kV	Line voltage phase B

Table continues on next page

Name	Type	Values (Range)	Unit	Description
U_LINE_C	REAL	-	kV	Line voltage phase C
FR_LINE	REAL	-	Hz	Line frequency
PH_LINE	REAL	-	deg	Line phase angle
MODE_A_ENERG	INTEGER	0=Off 1=DLLB 2=LLDB 3=LLDB or DLLB	-	Selected mode for automatic energizing
MODE_M_ENERG	INTEGER	0=Off 1=DLLB 2=LLDB 3=LLDB or DLLB	-	Selected mode for manual energizing

10.4.12 Technical data

Table 1151: SYNCRSYN Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	Voltage: ±1.0% or ±0.002 × U_n Frequency: ±10 mHz Phase angle ±2°
Reset time	<50 ms
Reset ratio	Typically 0.96
Operate time accuracy	+90ms/0 ms

10.4.13 Technical revision history

Table 1152: SYNCRSYN technical revision history

Technical revision	Change
B	Internal improvements

10.5 Auto-recloser DARREC

10.5.1 Identification

Function description	IEC 61850 logical node name	IEC 60617 identification	ANSI/IEEE C37.2 device number
Autoreclosing	DARREC	O ->I	79

10.5.2 Function block

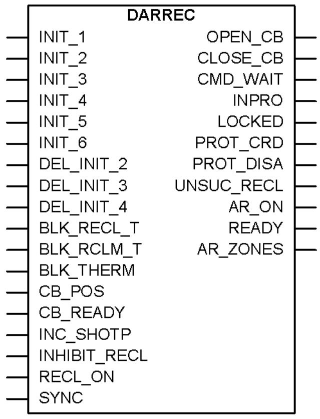


Figure 604: Function block

10.5.3 Functionality

About 80 to 85 percent of faults in the MV overhead lines are transient and automatically cleared with a momentary de-energization of the line. The rest of the faults, 15 to 20 percent, can be cleared by longer interruptions. The de-energization of the fault location for a selected time period is implemented through automatic reclosing, during which most of the faults can be cleared.

In case of a permanent fault, the automatic reclosing is followed by final tripping. A permanent fault must be located and cleared before the fault location can be re-energized.

The auto-reclose function AR can be used with any circuit breaker suitable for auto-reclosing. The function provides five programmable auto-reclose shots which can perform one to five successive auto-reclosings of desired type and duration, for instance one high-speed and one delayed auto-reclosing.

When the reclosing is initiated with starting of the protection function, the auto-reclose function can execute the final trip of the circuit breaker in a short operate time, provided that the fault still persists when the last selected reclosing has been carried out.

10.5.3.1 Protection signal definition

The *Control line* setting defines which of the initiation signals are protection start and trip signals and which are not. With this setting, the user can distinguish the blocking signals from the protection signals. The *Control line* setting is a bit mask, that is, the lowest bit controls the `INIT_1` line and the highest bit the `INIT_6` line. Some example combinations of the *Control line* setting are as follows:

Table 1153: Control line setting definition

Control line setting	INIT_1	INIT_2 DEL_INIT_2	INIT_3 DEL_INIT_3	INIT_4 DEL_INIT_4	INIT_5	INIT_6
0	other	other	other	other	other	other
1	prot	other	other	other	other	other
2	other	prot	other	other	other	other
3	prot	prot	other	other	other	other
4	other	other	prot	other	other	other
5	prot	other	prot	other	other	other
...63	prot	prot	prot	prot	prot	prot

prot = protection signal

other = non-protection signal

When the corresponding bit or bits in both the *Control line* setting and the INIT_X line are TRUE:

- The CLOSE_CB output is blocked until the protection is reset
- If the INIT_X line defined as the protection signal is activated during the discrimination time, the AR function goes to lockout
- If the INIT_X line defined as the protection signal stays active longer than the time set by the *Max trip time* setting, the AR function goes to lockout (long trip)
- The UNSUC_RECL output is activated after a pre-defined two minutes (alarming earth-fault).

10.5.3.2 Zone coordination

Zone coordination is used in the zone sequence between local protection units and downstream devices. At the falling edge of the INC_SHOTP line, the value of the shot pointer is increased by one, unless a shot is in progress or the shot pointer already has the maximum value.

The falling edge of the INC_SHOTP line is not accepted if any of the shots are in progress.

10.5.3.3 Master and slave scheme

With the cooperation between the AR units in the same IED or between IEDs, sequential reclosings of two breakers at a line end in a 1½-breaker, double breaker or ring-bus arrangement can be achieved. One unit is defined as a master and it executes the reclosing first. If the reclosing is successful and no trip takes place, the second unit, that is the slave, is released to complete the reclose shot. With persistent faults, the breaker reclosing is limited to the first breaker.

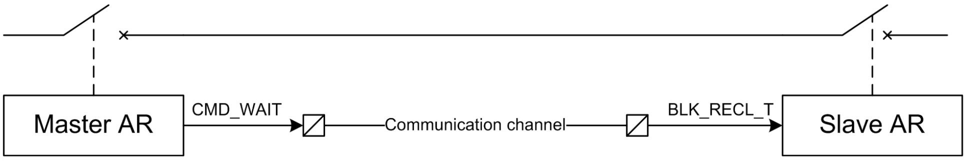


Figure 605: Master and slave scheme

If the AR unit is defined as a master by setting its *Terminal priority* to High (master)":

- The unit activates the CMD_WAIT output to the low priority slave unit whenever a shot is in progress, a reclosing is unsuccessful or the BLK_RCLM_T input is active
- The CMD_WAIT output is reset one second after the reclose command is given or if the sequence is unsuccessful when the reclaim time elapses.

If the AR unit is defined as a slave by setting its terminal priority to low:

- The unit waits until the master releases the BLK_RECL_T input (the CMD_WAIT output in the master). Only after this signal has been deactivated, the reclose time for the slave unit can be started.
- The slave unit is set to a lockout state if the BLK_RECL_T input is not released within the time defined by the *Max wait time* setting , which follows the initiation of an auto-reclose shot.

If the terminal priority of the AR unit is set to "none", the AR unit skips all these actions.

10.5.3.4 Thermal overload blocking

An alarm or start signal from the thermal overload protection (T1PTTR) can be routed to the input BLK_THERM to block and hold the reclose sequence. The BLK_THERM signal does not affect the starting of the sequence. When the reclose time has elapsed and the BLK_THERM input is active, the shot is not ready until the BLK_THERM input deactivates. Should the BLK_THERM input remain active longer than the time set by the setting *Max block time*, the AR function goes to lockout.

If the BLK_THERM input is activated when the auto wait timer is running, the auto wait timer is reset and the timer restarted when the BLK_THERM input deactivates.

10.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The reclosing operation can be enabled and disabled with the *Reclosing operation* setting. This setting does not disable the function, only the reclosing functionality. The setting has three parameter values: “On”, “External Ctl” and ”Off”. The setting value “On” enables the reclosing operation and “Off” disables it. When the setting value “External Ctl” is selected, the reclosing operation is controlled with the RECL_ON input .

The operation of the auto-reclose function can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

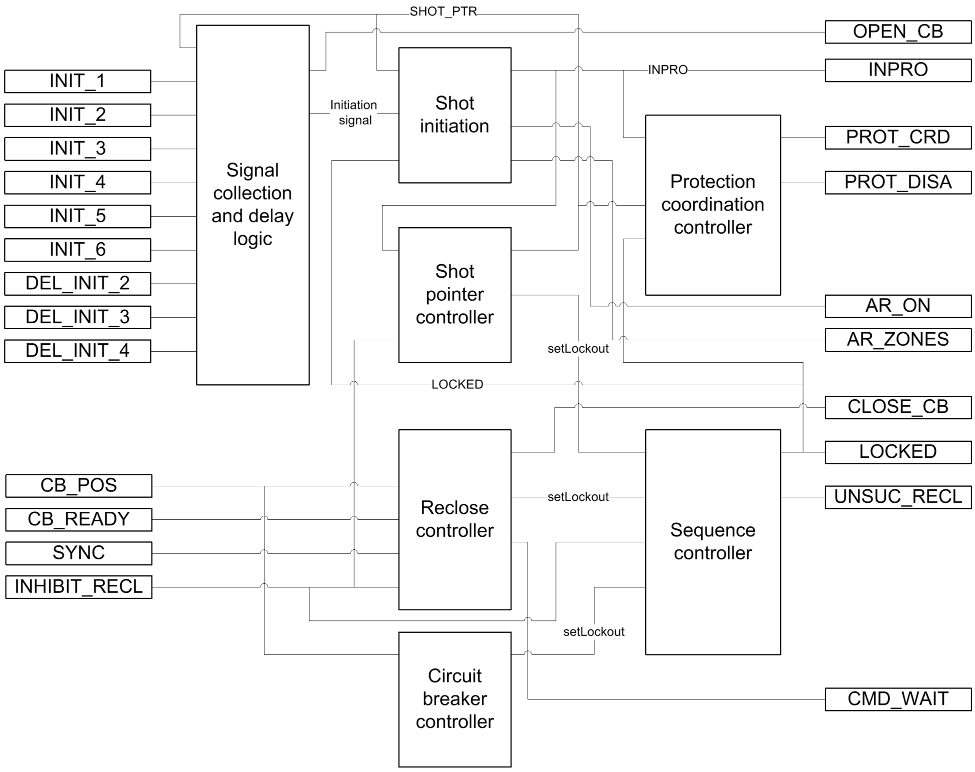


Figure 606: Functional module diagram

10.5.4.1 Signal collection and delay logic

When the protection trips, the initiation of auto-reclose shots is in most applications executed with the INIT_1...6 inputs. The DEL_INIT2...4 inputs are not used. In some countries, starting the protection stage is also used for the shot initiation. This is the only time when the DEL_INIT inputs are used.

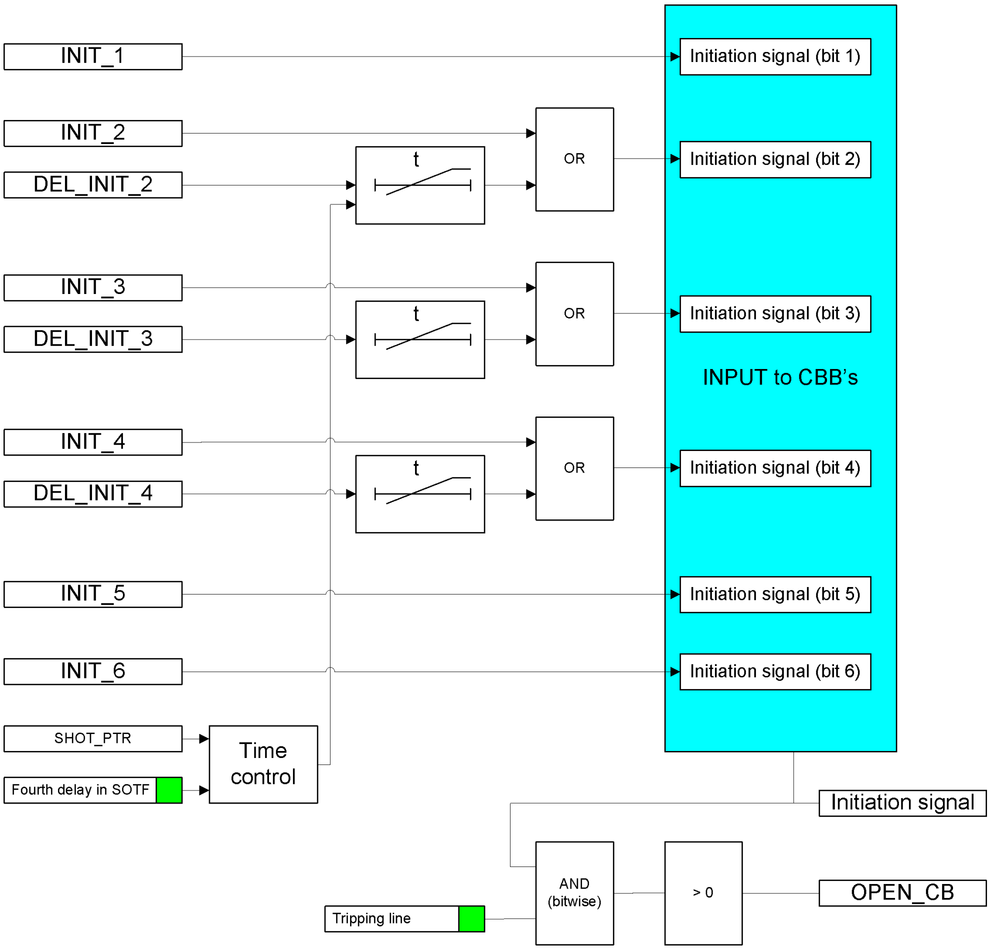


Figure 607: Schematic diagram of delayed initiation input signals

In total, the AR function contains six separate initiation lines used for the initiation or blocking of the auto-reclose shots. These lines are divided into two types of channels. In three of these channels, the signal to the AR function can be delayed, whereas the other three channels do not have any delaying capability.

Each channel that is capable of delaying a start signal has four time delays. The time delay is selected based on the shot pointer in the AR function. For the first reclose attempt, the first time delay is selected; for the second attempt, the second time delay and so on. For the fourth and fifth attempts, the time delays are the same.

Time delay settings for the `DEL_INIT_2` signal are as follows:

- *Str 2 delay shot 1*
- *Str 2 delay shot 2*
- *Str 2 delay shot 3*
- *Str 2 delay shot 4*

Time delay settings for the `DEL_INIT_3` signal are as follows:

- *Str 3 delay shot 1*
- *Str 3 delay shot 2*
- *Str 3 delay shot 3*
- *Str 3 delay shot 4*

Time delay settings for the DEL_INIT_4 signal are as follows:

- *Str 4 delay shot 1*
- *Str 4 delay shot 2*
- *Str 4 delay shot 3*
- *Str 4 delay shot 4*

Normally, only two or three reclose attempts are made. The third and fourth times are used to provide the so called fast final trip to lockout.

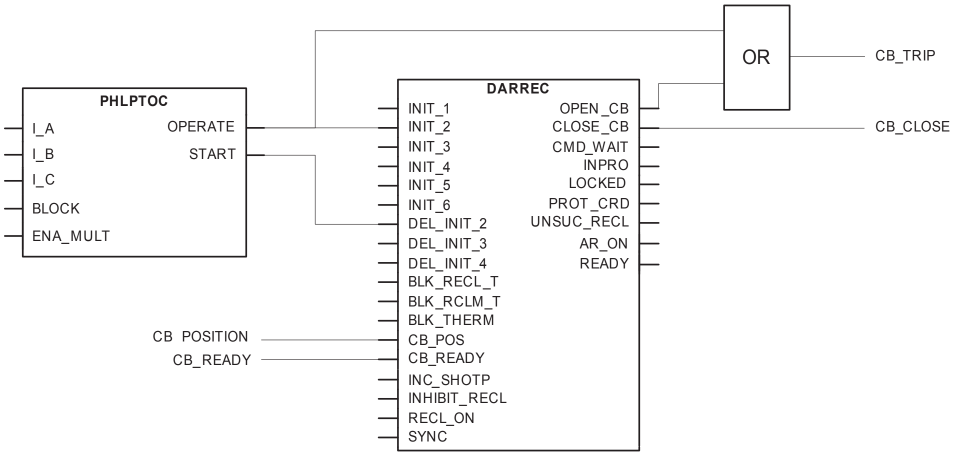


Figure 608: Auto-reclose configuration example

Delayed DEL_INIT_2...4 signals are used only when the auto-reclose shot is initiated with the start signal of a protection stage. After a start delay, the AR function opens the circuit breaker and an auto-reclose shot is initiated. When the shot is initiated with the trip signal of the protection, the protection function trips the circuit breaker and simultaneously initiates the auto-reclose shot.

If the circuit breaker is manually closed against the fault, that is, if SOTF is used, the fourth time delay can automatically be taken into use. This is controlled with the internal logic of the AR function and the *Fourth delay in SOTF* parameter.

A typical auto-reclose situation is where one auto-reclose shot has been performed after the fault was detected. There are two types of such cases: operation initiated with protection start signal and operation initiated with protection trip signal. In both cases, the auto-reclose sequence is successful: the reclaim time elapses and no new sequence is started.

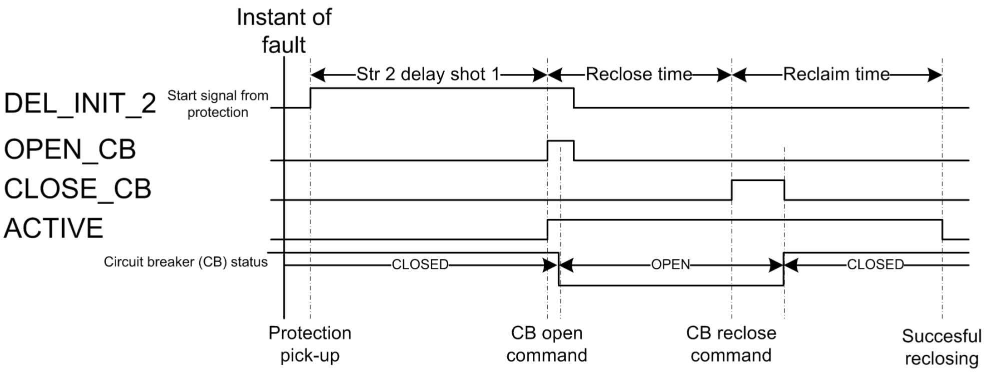


Figure 609: Signal scheme of auto-reclose operation initiated with protection start signal

The auto-reclose shot is initiated with a start signal of the protection function after the start delay time has elapsed. The auto-reclose starts when the *Str 2 delay shot 1* setting elapses.

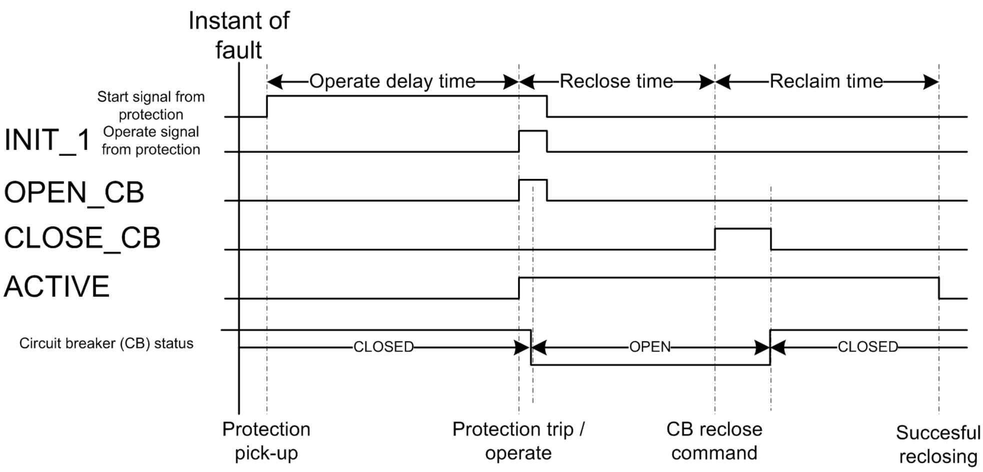


Figure 610: Signal scheme of auto-reclose operation initiated with protection operate signal

The auto-reclose shot is initiated with a trip signal of the protection function. The auto-reclose starts when the protection operate delay time elapses.

Normally, all trip and start signals are used to initiate an auto-reclose shot and trip the circuit breaker. If any of the input signals INIT_X or DEL_INIT_X are used for blocking, the corresponding bit in the *Tripping line* setting must be FALSE. This is to ensure that the circuit breaker does not trip from that signal, that is, the signal does not activate the OPEN_CB output. The default value for the setting is "63", which means that all initiation signals activate the OPEN_CB output. The lowest bit in the *Tripping line* setting corresponds to the INIT_1 input, the highest bit to the INIT_6 line.

10.5.4.2 Shot initiation

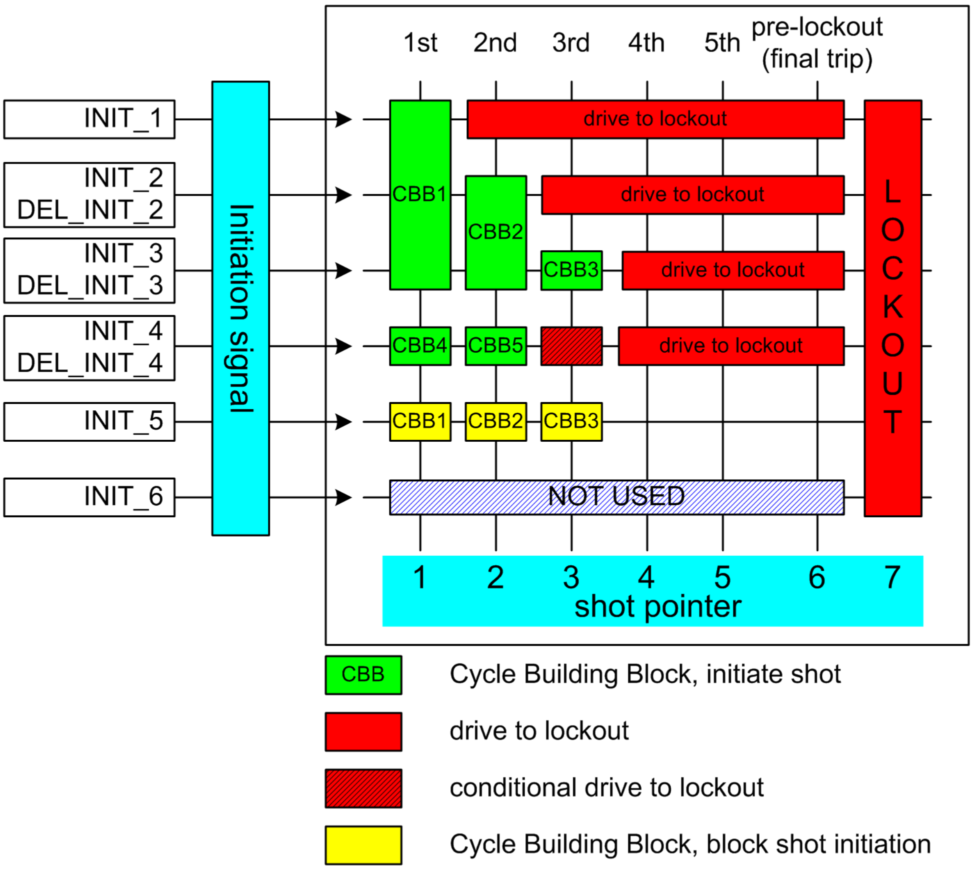


Figure 611: Example of an auto-reclose program with a reclose scheme matrix

In the AR function, each shot can be programmed to locate anywhere in the reclose scheme matrix. The shots are like building blocks used to design the reclose program. The building blocks are called CBBs. All blocks are alike and have settings which give the attempt number (columns in the matrix), the initiation or blocking signals (rows in the matrix) and the reclose time of the shot.

The settings related to CBB configuration are:

- *First...Seventh reclose time*
- *Init signals CBB1…CBB7*
- *Blk signals CBB1…CBB7*
- *Shot number CBB1…CBB7*

The reclose time defines the open and dead times, that is, the time between the `OPEN_CB` and the `CLOSE_CB` commands. The *Init signals CBBx* setting defines the initiation signals. The *Blk signals CBBx* setting defines the blocking signals that are related to the CBB (rows in the matrix). The *Shot number CBB1…CBB7* setting defines which shot is related to the CBB (columns in the matrix). For example, CBB1 settings are:

- *First reclose time* = 1.0s
- *Init signals CBB1* = 7 (three lowest bits: 111000 = 7)
- *Blk signals CBB1* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB1* = 1

CBB2 settings are:

- *Second reclose time* = 10s
- *Init signals CBB2* = 6 (the second and third bits: 011000 = 6)
- *Blk signals CBB2* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB2* = 2

CBB3 settings are:

- *Third reclose time* = 30s
- *Init signals CBB3* = 4 (the third bit: 001000 = 4)
- *Blk signals CBB3* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB3* = 3

CBB4 settings are:

- *Fourth reclose time* = 0.5s
- *Init signals CBB4* = 8 (the fourth bit: 000100 = 8)
- *Blk signals CBB4* = 0 (no blocking signals related to this CBB)
- *Shot number CBB4* = 1

If a shot is initiated from the `INIT_1` line, only one shot is allowed before lockout. If a shot is initiated from the `INIT_3` line, three shots are allowed before lockout.

A sequence initiation from the `INIT_4` line leads to a lockout after two shots. In a situation where the initiation is made from both the `INIT_3` and `INIT_4` lines, a third shot is allowed, that is, CBB3 is allowed to start. This is called conditional lockout. If the initiation is made from the `INIT_2` and `INIT_3` lines, an immediate lockout occurs.

The `INIT_5` line is used for blocking purposes. If the `INIT_5` line is active during a sequence start, the reclose attempt is blocked and the AR function goes to lockout.

If more than one CBBs are started with the shot pointer, the CBB with the smallest individual number is always selected. For example, if the `INIT_2` and `INIT_4` lines are active for the second shot, that is, the shot pointer is 2, CBB2 is started instead of CBB5.

Even if the initiation signals are not received from the protection functions, the AR function can be set to continue from the second to the fifth reclose shot. The AR function can, for example, be requested to automatically continue with the sequence when the circuit breaker fails to close when requested. In such a case, the AR function issues a `CLOSE_CB` command. When the wait close time elapses, that is, the closing of the circuit breaker fails, the next shot is automatically started. Another example is the embedded generation on the power line, which can make the synchronism check fail and prevent the reclosing. If the auto-reclose sequence is continued to the second shot, a successful synchronous reclosing is more likely than with the first shot, since the second shot lasts longer than the first one.

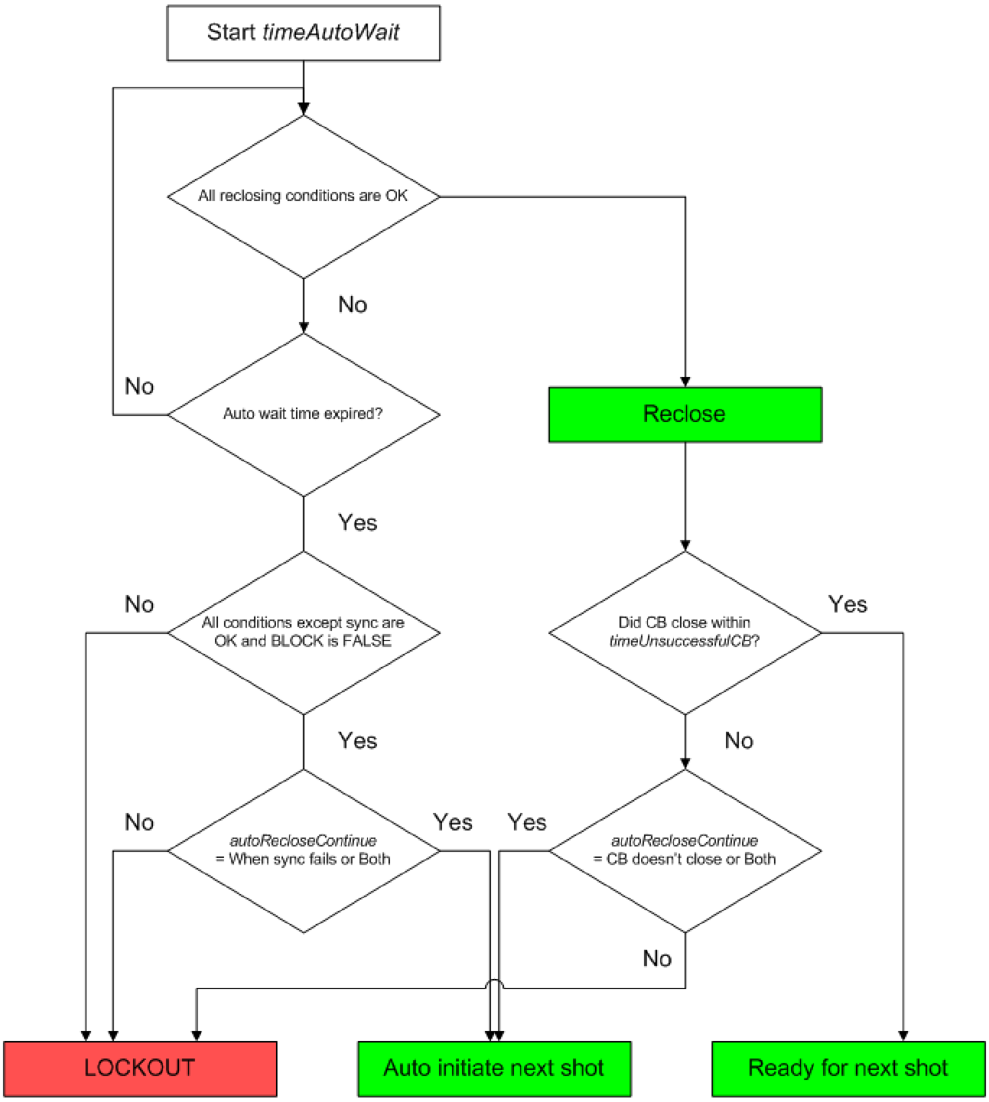


Figure 612: Logic diagram of auto-initiation sequence detection

Automatic initiation can be selected with the *Auto initiation Cnd* setting to be the following:

- Not allowed: no automatic initiation is allowed
- When the synchronization fails, the automatic initiation is carried out when the auto wait time elapses and the reclosing is prevented due to a failure during the synchronism check
- When the circuit breaker does not close, the automatic initiation is carried out if the circuit breaker does not close within the wait close time after issuing the reclose command
- Both: the automatic initiation is allowed when synchronization fails or the circuit breaker does not close.

The *Auto init* parameter defines which INIT_X lines are activated in the auto-initiation. The default value for this parameter is "0", which means that no auto-initiation is selected.

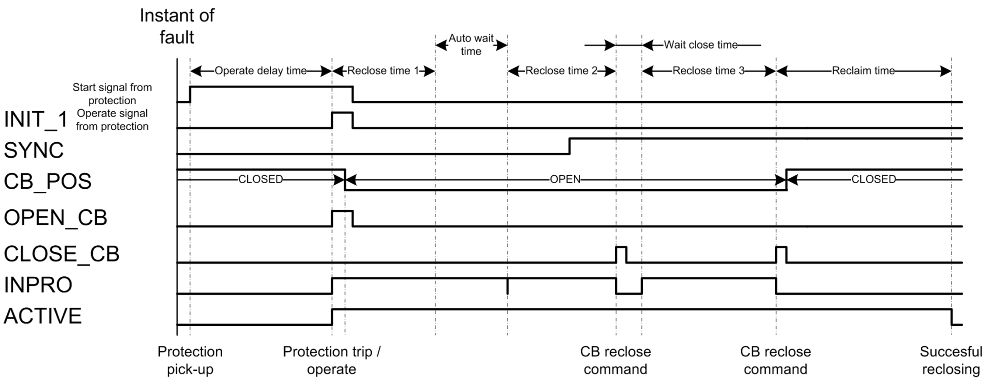


Figure 613: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

In the first shot, the synchronization condition is not fulfilled (SYNC is FALSE). When the auto wait timer elapses, the sequence continues to the second shot. During the second reclosing, the synchronization condition is fulfilled and the close command is given to the circuit breaker after the second reclose time has elapsed.

After the second shot, the circuit breaker fails to close when the wait close time has elapsed. The third shot is started and a new close command is given after the third reclose time has elapsed. The circuit breaker closes normally and the reclaim time starts. When the reclaim time has elapsed, the sequence is concluded successful.

The AR_ZONES output can be connected to distance protection DSTPDIS to enable the dedicated autorecloser specific zones in DSTPDIS while the auto reclosing function is enabled. If the connection is not made, the auto recloser specific zones in DSTPDIS are disabled.

10.5.4.3 Shot pointer controller

The execution of a reclose sequence is controlled by a shot pointer. It can be adjusted with the SHOT_PTR monitored data.

The shot pointer starts from an initial value "1" and determines according to the settings whether or not a certain shot is allowed to be initiated. After every shot, the shot pointer value increases. This is carried out until a successful reclosing or lockout takes place after a complete shot sequence containing a total of five shots.

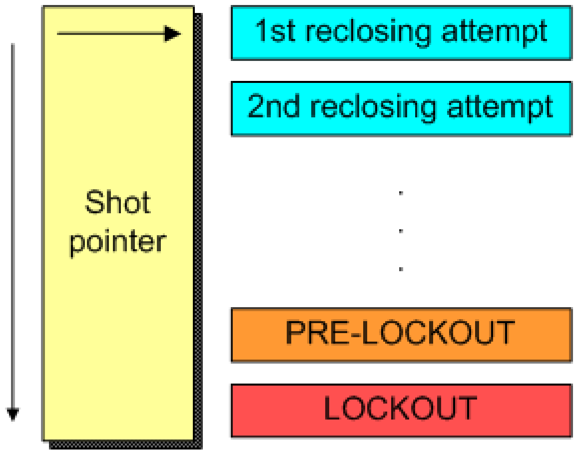


Figure 614: Shot pointer function

Every time the shot pointer increases, the reclaim time starts. When the reclaim time ends, the shot pointer sets to its initial value, unless no new shot is initiated. The shot pointer increases when the reclose time elapses or at the falling edge of the INC_SHOTP signal.

When SHOT_PTR has the value six, the AR function is in a so called pre-lockout state. If a new initiation occurs during the pre-lockout state, the AR function goes to lockout. Therefore, a new sequence initiation during the pre-lockout state is not possible.

The AR function goes to the pre-lockout state in the following cases:

- During SOTF
- When the AR function is active, it stays in a pre-lockout state for the time defined by the reclaim time
- When all five shots have been executed
- When the frequent operation counter limit is reached. A new sequence initiation forces the AR function to lockout.

10.5.4.4 Reclose controller

The reclose controller calculates the reclose, discrimination and reclaim times. The reclose time is started when the INPRO signal is activated, that is, when the sequence starts and the activated CBB defines the reclose time.

When the reclose time has elapsed, the CLOSE_CB output is not activated until the following conditions are fulfilled:

- The SYNC input must be TRUE if the particular CBB requires information about the synchronism
- All AR initiation inputs that are defined protection lines (using the *Control line* setting) are inactive
- The circuit breaker is open
- The circuit breaker is ready for the close command, that is, the CB_READY input is TRUE.

If at least one of the conditions is not fulfilled within the time set with the *Auto wait time* parameter, the auto-reclose sequence is locked.

The synchronism requirement for the CBBs can be defined with the *Synchronisation set* setting, which is a bit mask. The lowest bit in the *Synchronisation set* setting is related to CBB1 and the highest bit to CBB7. For example, if the setting is set to "1", only CBB1 requires synchronism. If the setting is it set to "7", CBB1, CBB2 and CBB3 require the SYNC input to be TRUE before the reclosing command can be given.

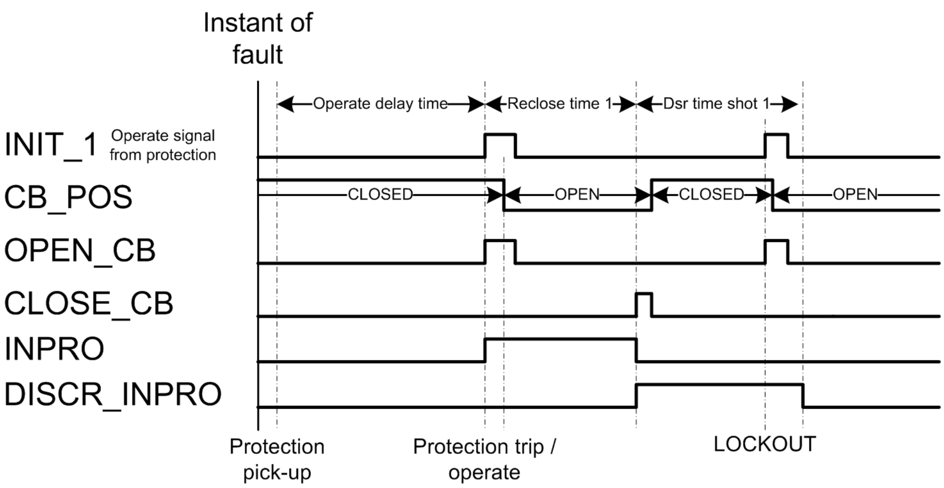


Figure 615: Initiation during discrimination time - AR function goes to lockout

The discrimination time starts when the close command CLOSE_CB has been given. If a start input is activated before the discrimination time has elapsed, the AR function goes to lockout. The default value for each discrimination time is zero. The discrimination time can be adjusted with the *Dsr time shot 1…4* parameter.

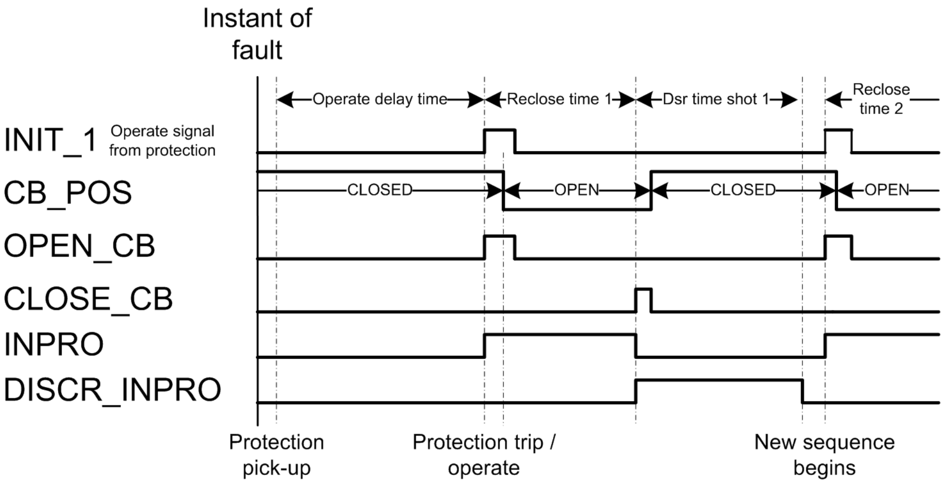


Figure 616: Initiation after elapsed discrimination time - new shot begins

10.5.4.5 Sequence controller

When the LOCKED output is active, the AR function is in lockout. This means that new sequences cannot be initialized, because AR is insensitive to initiation commands. It can be released from the lockout state in the following ways:

- The function is reset through communication with the *RsRec* parameter
- The lockout is automatically reset after the reclaim time, if the *Auto lockout reset* setting is in use.

If the *Auto lockout reset* setting is not in use, the lockout can be released only with the *RsRec* parameter.

The AR function can go to lockout for many reasons:

- The INHIBIT_RECL input is active
- All shots have been executed and a new initiation is made (final trip)
- The time set with the *Auto wait time* parameter expires and the automatic sequence initiation is not allowed because of a synchronization failure
- The time set with the *Wait close time* parameter expires, that is, the circuit breaker does not close or the automatic sequence initiation is not allowed due to a closing failure of the circuit breaker
- A new shot is initiated during the discrimination time
- The time set with the *Max wait time* parameter expires, that is, the master unit does not release the slave unit

- The frequent operation counter limit is reached and new sequence is initiated. The lockout is released when the recovery timer elapses
- The protection trip signal has been active longer than the time set with the *Max wait time* parameter since the shot initiation
- The circuit breaker is closed manually during an auto-reclose sequence and the manual close mode is FALSE.

10.5.4.6 Protection coordination controller

The `PROT_CRD` output is used for controlling the protection functions. In several applications, such as fuse-saving applications involving down-stream fuses, tripping and initiation of shot 1 should be fast (instantaneous or short-time delayed). The tripping and initiation of shots 2, 3 and definite tripping time should be delayed.

In this example, two overcurrent elements PHLPTOC and PHIPTOC are used. PHIPTOC is given an instantaneous characteristic and PHLPTOC is given a time delay.

The `PROT_CRD` output is activated, if the `SHOT_PTR` value is the same or higher than the value defined with the *Protection crd limit* setting and all initialization signals have been reset. The `PROT_CRD` output is reset under the following conditions:

- If the cut-out time elapses
- If the reclaim time elapses and the AR function is ready for a new sequence
- If the AR function is in lockout or disabled, that is, if the value of the *Protection crd mode* setting is "AR inoperative" or "AR inop, CB man".

The `PROT_CRD` output can also be controlled with the *Protection crd mode* setting. The setting has the following modes:

- "no condition": the `PROT_CRD` output is controlled only with the *Protection crd limit* setting
- "AR inoperative": the `PROT_CRD` output is active, if the AR function is disabled or in the lockout state, or if the `INHIBIT_RECL` input is active
- "CB close manual": the `PROT_CRD` output is active for the reclaim time if the circuit breaker has been manually closed, that is, the AR function has not issued a close command
- "AR inop, CB man": both the modes "AR inoperative" and "CB close manual" are effective
- "always": the `PROT_CRD` output is constantly active

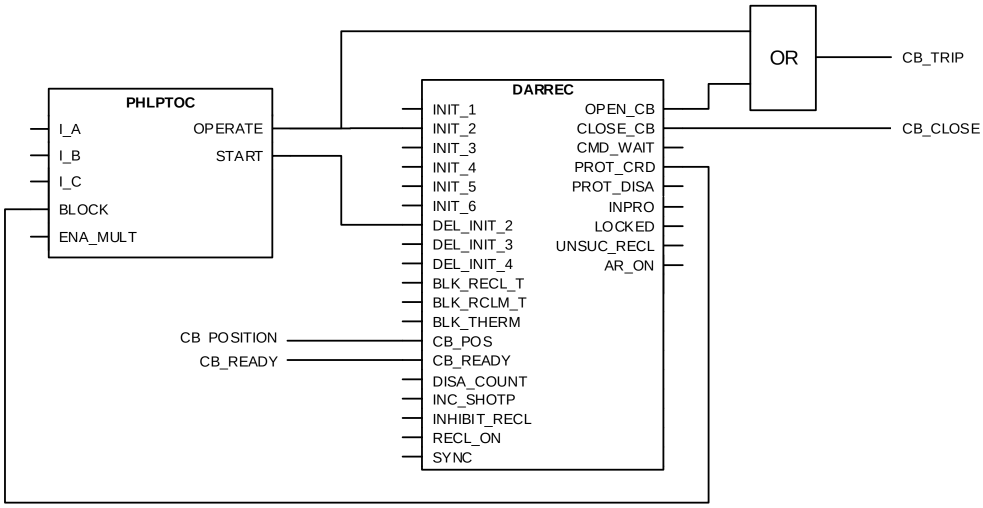


Figure 617: Configuration example of using the `PROT_CRD` *output for protection blocking*

If the *Protection crd limit* setting has the value "1", the instantaneous three-phase overcurrent protection function PHIPTOC is disabled or blocked after the first shot.

The protection functions can also be controlled with the `PROT_DISA` output. The `PROT_DISA` output signal is a bit mask that is controlled with the *Disable shot 1…5* settings. The *Disable shot 1* setting defines the bits that are active at the first shot, the *Disable shot 2* setting defines the bits that are active at the second shot and so on. The `PROT_DISA` signal is updated when the `SHOT_PTR` value is updated. In this way, the user can, for example, control the protection functions to initiate a complex auto-reclose sequence to be executed in a desired order. However, this output is not needed in most auto-reclose applications due to a simple protection scheme.

The protection functions can also be controlled with the `PROT_DISA` output. The `PROT_DISA` output signal is a bit mask that is controlled with the *Disable shot 1…5* settings. The *Disable shot 1* setting defines the bits that are active at the first shot, the *Disable shot 2* setting defines the bits that are active at the second shot and so on. The `PROT_DISA` signal is updated when the `SHOT_PTR` value is updated. In this way, the user can, for example, control the protection functions to initiate a complex autoreclose sequence to be executed in a desired order. However, this output is not needed in most autoreclose applications due to a simple protection scheme.

The `PROT_DISA` output follows the *Disable shot 5* setting in the pre-lockout and lockout states and in SOTF.

The `PROT_DISA` signal is reset when the cutout time elapses. The signal is reset to the value defined with the *Disable pro signal* parameter.

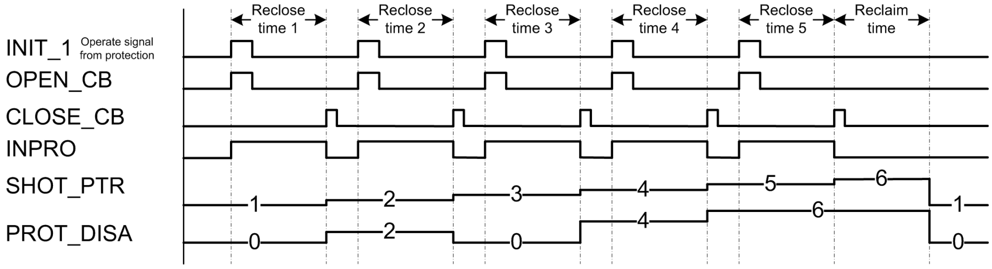


Figure 618: Signal scheme of PROT_DISA signal behavior

The *Disable shot x* settings have the following values in the sequence:

Table 1154: Disable shot x values

Setting	Value
Disable shot 1	"0"
Disable shot 2	"2"
Disable shot 3	"0"
Disable shot 4	"4"
Disable shot 5	"6"

Since the PROT_DISA output is a bit mask integer, the bits must be extracted from it with the integer-to-bit conversion INT_TO_BIT in the configuration.

10.5.4.7 Circuit breaker controller

Circuit breaker controller contains two features: SOTF and frequent-operation counter. SOTF protects the AR function in permanent faults.

The circuit breaker position information is controlled with the *CB closed Pos status* setting. The setting value "TRUE” means that when the circuit breaker is closed, the CB_POS input is TRUE. When the setting value is “FALSE”, the CB_POS input is FALSE, provided that the circuit breaker is closed. The reclose command pulse time can be controlled with the *Close pulse time* setting: the CLOSE_CB output is active for the time set with the *Close pulse time* setting. The CLOSE_CB output is deactivated also when the circuit breaker is detected to be closed, that is, when the CB_POS input changes from open state to closed state. The *Wait close time* setting defines the time after the CLOSE_CB command activation, during which the circuit breaker should be closed. If the closing of circuit breaker does not happen during this time, the auto-reclose function is driven to lockout or, if allowed, an auto-initiation is activated.

The main motivation for auto-reclosing to begin with is the assumption that the fault is temporary by nature, and that a momentary de-energizing of the power line and an automatic reclosing restores the power supply. However, when the power line is manually energized and an immediate protection trip is detected, it is very likely that the fault is of a permanent type. A permanent fault is, for example, energizing a power line into a forgotten earthing after a maintenance work along the power line. In such cases, SOTF is activated, but only for the reclaim time after energizing the power line and only when the circuit breaker is closed manually and not by the AR function.

SOTF disables any initiation of an auto-reclose shot. The energizing of the power line is detected from the `CB_POS` information.

SOTF is activated when the AR function is enabled or when the AR function is started and the SOTF should remain active for the reclaim time.

When SOTF is detected, the output `SOTF` is active.

If the *Manual close mode* setting is set to FALSE and the circuit breaker has been manually closed during an auto-reclose shot, the AR unit goes to an immediate lockout.

If the *Manual close mode* setting is set to TRUE and the circuit breaker has been manually closed during an auto-reclose shot (the `INPRO` is active), the shot is considered as completed.

When SOTF starts, reclaim time is restarted, provided that it is running.

The frequent-operation counter is intended for blocking the auto-reclose function in cases where the fault causes repetitive auto-reclose sequences during a short period of time. For instance, if a tree causes a short circuit and, as a result, there are auto-reclose shots within a few minutes interval during a stormy night. These types of faults can easily damage the circuit breaker if the AR function is not locked by a frequent-operation counter.

The frequent-operation counter has three settings:

- *Frq Op counter limit*
- *Frq Op counter time*
- *Frq Op recovery time*

The *Frq Op counter limit* setting defines the number of reclose attempts that are allowed during the time defined with the *Frq Op counter time* setting. If the set value is reached within a pre-defined period defined with the *Frq Op counter time* setting, the AR function goes to lockout when a new shot begins, provided that the counter is still above the set limit. The lockout is released after the recovery time has elapsed. The recovery time can be defined with the *Frq Op recovery time* setting .

If the circuit breaker is manually closed during the recovery time, the reclaim time is activated after the recovery timer has elapsed.

10.5.5 Application

Modern electric power systems can deliver energy to users very reliably. However, different kind of faults can occur. Protection relays play an important role in detecting failures or abnormalities in the system. They detect faults and give commands for corresponding circuit breakers to isolate the defective element before excessive damage or a possible power system collapse occurs. A fast isolation also limits the disturbances caused for the healthy parts of the power system.

The faults can be transient, semi-transient or permanent. Permanent fault, for example in power cables, means that there is a physical damage in the fault location that must first be located and repaired before the network voltage can be restored.

In overhead lines, the insulating material between phase conductors is air. The majority of the faults are flash-over arcing faults caused by lightning, for example. Only a short interruption is needed for extinguishing the arc. These faults are transient by nature.

A semi-transient fault can be caused for example by a bird or a tree branch falling on the overhead line. The fault disappears on its own if the fault current burns the branch or the wind blows it away.

Transient and semi-transient faults can be cleared by momentarily de-energizing the power line. Using the auto-reclose function minimizes interruptions in the power system service and brings the power back on-line quickly and effortlessly.

The basic idea of the auto-reclose function is simple. In overhead lines, where the possibility of self-clearing faults is high, the auto-reclose function tries to restore the power by reclosing the breaker. This is a method to get the power system back into normal operation by removing the transient or semi-transient faults. Several trials, that is, auto-reclose shots are allowed. If none of the trials is successful and the fault persists, definite final tripping follows.

The auto-reclose function can be used with every circuit breaker that has the ability for a reclosing sequence. In DARREC auto-reclose function the implementing method of auto-reclose sequences is patented by ABB

Table 1155: *Important definitions related to auto-reclosing*

auto-reclose shot	an operation where after a preset time the breaker is closed from the breaker tripping caused by protection
auto-reclose sequence	a predefined method to do reclose attempts (shots) to restore the power system
SOTF	If the protection detects a fault immediately after an open circuit breaker has been closed, it indicates that the fault was already there. It can be, for example, a forgotten earthing after maintenance work. Such closing of the circuit breaker is known as switch on to fault. Autoreclosing in such conditions is prohibited.
final trip	Occurs in case of a permanent fault, when the circuit breaker is opened for the last time after all programmed auto-reclose operations. Since no auto-reclosing follows, the circuit breaker remains open. This is called final trip or definite trip.

10.5.5.1 Shot initiation

In some applications, the START signal is used for initiating or blocking autoreclose shots, in other applications the OPERATE command is needed. In its simplest, the auto-reclose function is initiated after the protection has detected a fault, issued a trip and opened the breaker. One input is enough for initiating the function.

The function consists of six individual initiation lines INIT_1, INIT_2 .. INIT_6 and delayed initiation lines DEL_INIT_x. The user can use as many of the initiation lines as required. Using only one line makes setting easier, whereas by using multiple lines, higher functionality can be achieved. Basically, there are no differences between the initiation lines, except that the lines 2, 3 and 4 have the delayed initiation DEL_INIT inputs, and lines 1, 5 and 6 do not.

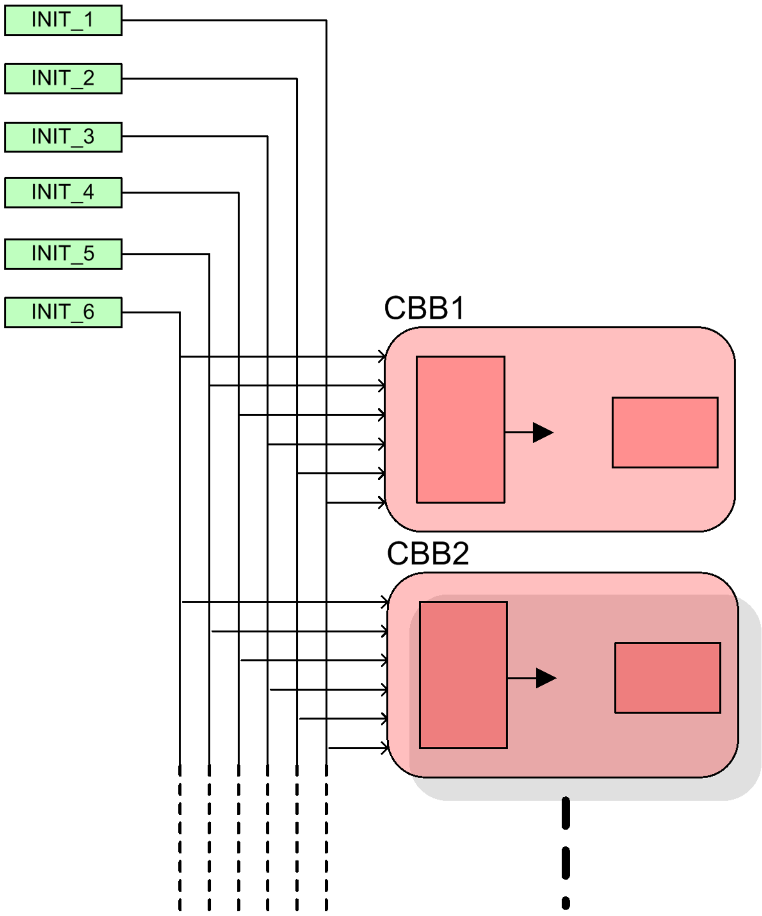


Figure 619: Simplified CBB initiation diagram

INIT_1...6	initiation lines
CBB1...CBB2	first two cycle building blocks

The operation of a CBB consists of two parts: initiation and execution. In the initiation part, the status of the initiation lines is compared to the CBB settings. In order to allow the initiation at any of the initiation line activation, the corresponding switch in the *Init signals CBB_* parameter must be set to TRUE. In order to block the initiation, the corresponding switch in the *Blk signals CBB_* parameter must be set to TRUE.

If any of the initiation lines set with the *Init signals CBB_* parameter is active and no initiation line causes blocking, the CBB requests for execution.

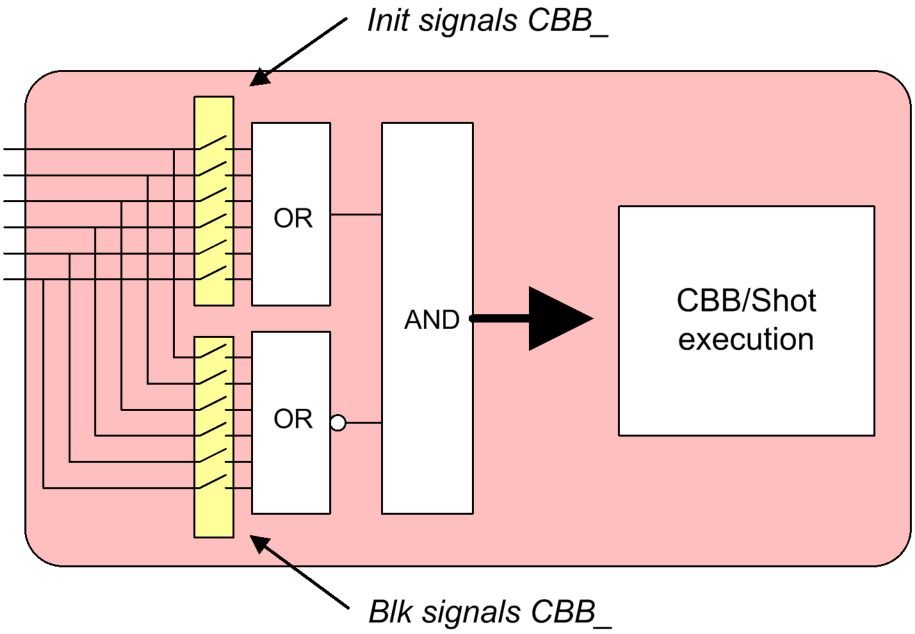


Figure 620: Simplified CBB diagram

Each CBB has individual *Init signals CBB_* and *Blk signals CBB_* settings. Therefore, each initiation line can be used for both initiating and blocking any or all auto-reclose shots.

Other conditions that must be fulfilled before any CBB can be initiated are, for example, the closed position of the circuit breaker.

10.5.5.2 Sequence

The auto reclose sequence is implemented by using CBBs. The highest possible amount of CBBs is seven. If the user wants to have, for example, a sequence of three shots, only the first three CBBs are needed. Using building blocks instead of fixed shots gives enhanced flexibility, allowing multiple and adaptive sequences.

Each CBB is identical. The *Shot number CBB_* setting defines at which point in the auto-reclose sequence the CBB should be performed, that is, whether the particular CBB is going to be the first, second, third, fourth or fifth shot.

During the initiation of a CBB, the conditions of initiation and blocking are checked. This is done for all CBBs simultaneously. Each CBB that fulfils the initiation conditions requests an execution.

The function also keeps track of shots already performed, that is, at which point the auto-reclose sequence is from shot 1 to lockout. For example, if shots 1 and 2 have already been performed, only shots 3 to 5 are allowed.

Additionally, the *Enable shot jump* setting gives two possibilities:

- Only such CBBs that are set for the next shot in the sequence can be accepted for execution. For example, if the next shot in the sequence should be shot 2, a request from CBB set for shot 3 is rejected.
- Any CBB that is set for the next shot or any of the following shots can be accepted for execution. For example, if the next shot in the sequence should be shot 2, also CBBs that are set for shots 3, 4 and 5 are accepted. In other words, shot 2 can be ignored.

In case there are multiple CBBs allowed for execution, the CBB with the smallest number is chosen. For example, if CBB2 and CBB4 request an execution, CBB2 is allowed to execute the shot.

The auto-reclose function can perform up to five auto-reclose shots or cycles.

10.5.5.3 Configuration examples

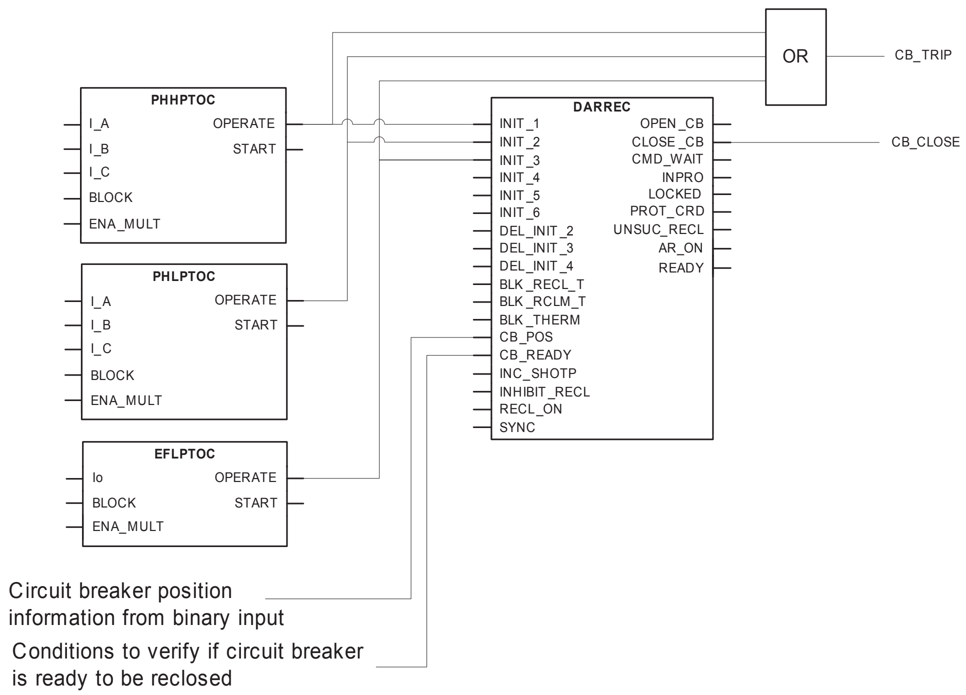


Figure 621: Example connection between protection and autoreclose functions in IED configuration

It is possible to create several sequences for a configuration.

Autoreclose sequences for overcurrent and non-directional earth-fault protection applications where high speed and delayed autoreclosings are needed can be as follows:

Example 1.

The sequence is implemented by two shots which have the same reclosing time for all protection functions, namely I>>, I> and Io>. The initiation of the shots is done by activating the operating signals of the protection functions.

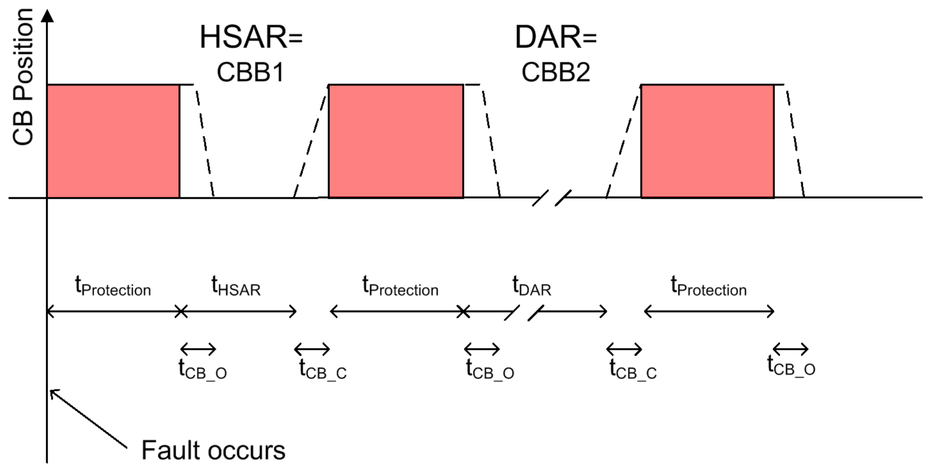


Figure 622: Autoreclose sequence with two shots

t_{HSAR}	Time delay of high-speed autoreclosing, here: *First reclose time*
t_{DAR}	Time delay of delayed autoreclosing, here: *Second reclose time*
$t_{Protection}$	Operating time for the protection stage to clear the fault
t_{CB_O}	Operating time for opening the circuit breaker
t_{CB_C}	Operating time for closing the circuit breaker

In this case, the sequence needs two CBBs. The reclosing times for shot 1 and shot 2 are different, but each protection function initiates the same sequence. The CBB sequence is as follows:

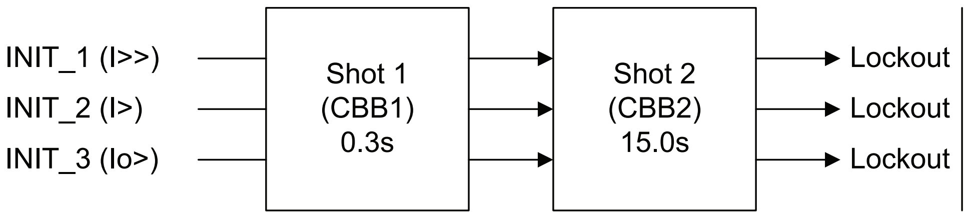


Figure 623: Two shots with three initiation lines

Table 1156: Settings for configuration example 1

Setting name	Setting value
Shot number CBB1	1
Init signals CBB1	7 (lines 1,2 and 3 = 1+2+4 = 7)
First reclose time	0.3s (an example)
Shot number CBB2	2
Init signals CBB2	7 (lines 1,2 and 3 = 1+2+4 = 7)
Second reclose time	15.0s (an example)

Example 2

There are two separate sequences implemented with three shots. Shot 1 is implemented by CBB1 and it is initiated with the high stage of the overcurrent protection (I>>). Shot 1 is set as a high-speed autoreclosing with a short time delay. Shot 2 is implemented with CBB2 and meant to be the first shot of the autoreclose sequence initiated by the low stage of the overcurrent protection (I>) and the low stage of the non-directional earth-fault protection (Io>). It has the same reclosing time in both situations. It is set as a high-speed autoreclosing for corresponding faults. The third shot, which is the second shot in the autoreclose sequence initiated by I> or Io>, is set as a delayed autoreclosing and executed after an unsuccessful high-speed autoreclosing of a corresponding sequence.

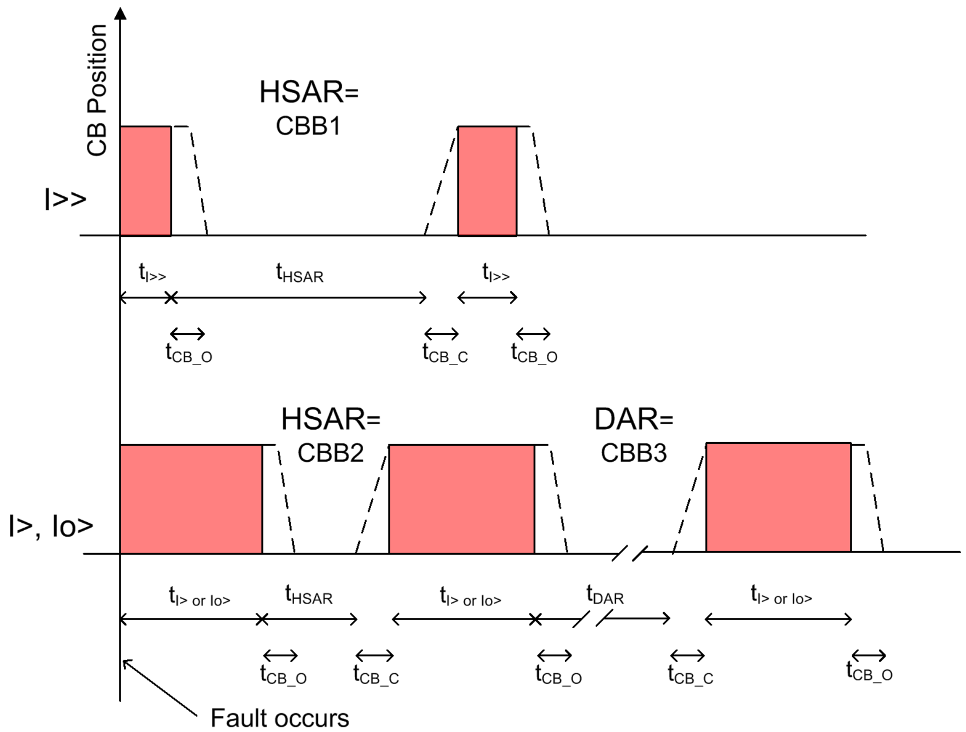


Figure 624: Autoreclose sequence with two shots with different shot settings according to initiation signal

t_{HSAR}	Time delay of high-speed autoreclosing, here: *First reclose time*
t_{DAR}	Time delay of delayed autoreclosing, here: *Second reclose time*
$t_{I>>}$	Operating time for the I>> protection stage to clear the fault
$t_{I>}$ or $_{Io>}$	Operating time for the I> or Io> protection stage to clear the fault
t_{CB_O}	Operating time for opening the circuit breaker
t_{CB_C}	Operating time for closing the circuit breaker

In this case, the number of needed CBBs is three, that is, the first shot's reclosing time depends on the initiation signal. The CBB sequence is as follows:

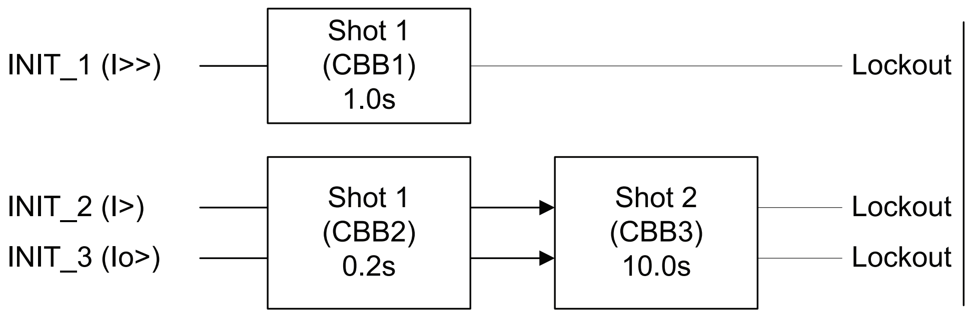


Figure 625: Three shots with three initiation lines

If the sequence is initiated from the `INIT_1` line, that is, the overcurrent protection high stage, the sequence is one shot long. On the other hand, if the sequence is initiated from the `INIT_2` or `INIT_3` lines, the sequence is two shots long.

Table 1157: Settings for configuration example 2

Setting name	Setting value
Shot number CBB1	1
Init signals CBB1	1 (line 1)
First reclose time	1.0s (an example)
Shot number CBB2	1
Init signals CBB2	6 (lines 2 and 3 = 2+4 = 6)
Second reclose time	0.2s (an example)
Shot number CBB3	2
Init signals CBB3	6 (lines 2 and 3 = 2+4 = 6)
Third reclose time	10.0s

10.5.5.4 Delayed initiation lines

The auto-reclose function consists of six individual auto-reclose initiation lines `INIT_1...INIT 6` and three delayed initiation lines:

- DEL_INIT_2
- DEL_INIT_3
- DEL_INIT_4

DEL_INIT_2 and INIT_2 are connected together with an OR-gate, as are inputs 3 and 4. Inputs 1, 5 and 6 do not have any delayed input. From the auto-reclosing point of view, it does not matter whether INIT_x or DEL_INIT_x line is used for shot initiation or blocking.

The auto-reclose function can also open the circuit breaker from any of the initiation lines. It is selected with the *Tripping line* setting. As a default, all initiation lines activate the OPEN_CB output.

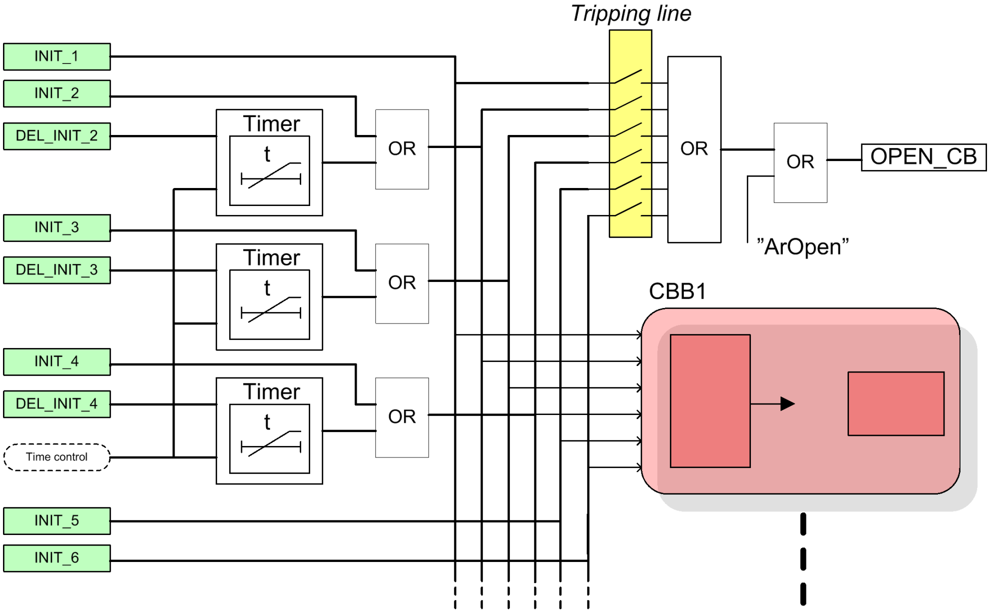


Figure 626: Simplified logic diagram of initiation lines

Each delayed initiation line has four different time settings:

Table 1158: Settings for delayed initiation lines

Setting name	Description and purpose
Str x delay shot 1	Time delay for the DEL_INIT_x line, where x is the number of the line 2, 3 or 4. Used for shot 1.
Str x delay shot 2	Time delay for the DEL_INIT_x line, used for shot 2.
Str x delay shot 3	Time delay for the DEL_INIT_x line, used for shot 3.
Str x delay shot 4	Time delay for the DEL_INIT_x line, used for shots 4 and 5. Optionally, can also be used with SOTF.

10.5.5.5 Shot initiation from protection start signal

In it simplest, all auto-reclose shots are initiated by protection trips. As a result, all trip times in the sequence are the same. This is why using protection trips may not be the optimal solution. Using protection start signals instead of protection trips for initiating shots shortens the trip times.

Example 1

When a two-shot-sequence is used, the start information from the protection function is routed to the `DEL_INIT 2` input and the operate information to the `INIT_2` input. The following conditions have to apply:

- protection operate time = 0.5s
- *Str 2 delay shot 1* = 0.05s
- *Str 2 delay shot 2* = 60s
- *Str 2 delay shot 3* = 60s

Operation in a permanent fault:

1. Protection starts and activates the `DEL_INIT 2` input.
2. After 0.05 seconds, the first autoreclose shot is initiated. The function opens the circuit breaker: the `OPEN_CB` output activates. The total trip time is the protection start delay + 0.05 seconds + the time it takes to open the circuit breaker.
3. After the first shot, the circuit breaker is reclosed and the protection starts again.
4. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time, activating the `INIT 2` input. The second shot is initiated.
5. After the second shot, the circuit breaker is reclosed and the protection starts again.
6. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time. No further shots are programmed after the final trip. The function is in lockout and the sequence is considered unsuccessful.

Example 2

The delays can be used also for fast final trip. The conditions are the same as in Example 1, with the exception of *Str 2 delay shot 3* = 0.10 seconds.

The operation in a permanent fault is the same as in Example 1, except that after the second shot when the protection starts again, *Str 2 delay shot 3* elapses before the protection operate time and the final trip follows. The total trip time is the protection start delay + 0.10 seconds + the time it takes to open the circuit breaker.

10.5.5.6 Fast trip in Switch on to fault

The *Str _ delay shot 4* parameter delays can also be used to achieve a fast and accelerated trip with SOTF. This is done by setting the *Fourth delay in SOTF* parameter to "1" and connecting the protection start information to the corresponding `DEL_INIT_` input.

When the function detects a closing of the circuit breaker, that is, any other closing except the reclosing done by the function itself, it always prohibits shot initiation for the time set with the *Reclaim time* parameter. Furthermore, if the *Fourth delay in SOTF* parameter is "1", the *Str _ delay shot 4* parameter delays are also activated.

Example 1

The protection operation time is 0.5 seconds, the *Fourth delay in SOTF* parameter is set to "1" and the *Str 2 delay shot 4* parameter is 0.05 seconds. The protection start signal is connected to the `DEL_INIT_2` input.

If the protection starts after the circuit breaker closes, the fast trip follows after the set 0.05 seconds. The total trip time is the protection start delay + 0.05 seconds + the time it takes to open the circuit breaker.

10.5.6 Counters

The AR function contains six counters. Their values are stored in a semi-retain memory. The counters are increased at the rising edge of the reclose command. The counters count the following situations:

- `COUNTER`: counts every reclose command activation
- `CNT_SHOT1`: counts reclose commands that are executed from shot 1
- `CNT_SHOT2`: counts reclose commands that are executed from shot 2
- `CNT_SHOT3`: counts reclose commands that are executed from shot 3
- `CNT_SHOT4`: counts reclose commands that are executed from shot 4
- `CNT_SHOT5`: counts reclose commands that are executed from shot 5

The counters are disabled through communication with the *DsaCnt* parameter. When the counters are disabled, the values are not updated.

The counters are reset through communication with the *RsCnt* parameter.

10.5.7 Signals

Table 1159: DARREC Input signals

Name	Type	Default	Description
INIT_1	BOOLEAN	0	AR initialization / blocking signal 1
INIT_2	BOOLEAN	0	AR initialization / blocking signal 2
INIT_3	BOOLEAN	0	AR initialization / blocking signal 3
INIT_4	BOOLEAN	0	AR initialization / blocking signal 4
INIT_5	BOOLEAN	0	AR initialization / blocking signal 5
INIT_6	BOOLEAN	0	AR initialization / blocking signal 6
DEL_INIT_2	BOOLEAN	0	Delayed AR initialization / blocking signal 2
DEL_INIT_3	BOOLEAN	0	Delayed AR initialization / blocking signal 3
DEL_INIT_4	BOOLEAN	0	Delayed AR initialization / blocking signal 4
BLK_RECL_T	BOOLEAN	0	Blocks and resets reclose time
BLK_RCLM_T	BOOLEAN	0	Blocks and resets reclaim time
BLK_THERM	BOOLEAN	0	Blocks and holds the reclose shot from the thermal overload
CB_POS	BOOLEAN	0	Circuit breaker position input
CB_READY	BOOLEAN	0	Circuit breaker status signal
INC_SHOTP	BOOLEAN	0	A zone sequence coordination signal
INHIBIT_RECL	BOOLEAN	0	Interrupts and inhibits reclosing sequence
RECL_ON	BOOLEAN	0	Level sensitive signal for allowing (high) / not allowing (low) reclosing
SYNC	BOOLEAN	0	Synchronizing check fulfilled

Table 1160: DARREC Output signals

Name	Type	Description
OPEN_CB	BOOLEAN	Open command for circuit breaker
CLOSE_CB	BOOLEAN	Close (reclose) command for circuit breaker
CMD_WAIT	BOOLEAN	Wait for master command
INPRO	BOOLEAN	Reclosing shot in progress, activated during dead time
LOCKED	BOOLEAN	Signal indicating that AR is locked out
PROT_CRD	BOOLEAN	A signal for coordination between the AR and the protection
PROT_DISA	INTEGER	A word type signal for disabling protection functions
UNSUC_RECL	BOOLEAN	Indicates an unsuccessful reclosing sequence
READY	BOOLEAN	Indicates that the AR is ready for a new sequence
ACTIVE	BOOLEAN	Reclosing sequence is in progress
AR_ZONES	GROUP SIGNAL	Ar zones

10.5.8 Settings

Table 1161: DARREC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Off / On
Reclosing operation	Off External Ctl On	-	-	Off	Reclosing operation (Off / External Ctrl / On)
Terminal priority	None Low (follower) High (master)	-	-	None	Terminal priority
Synchronisation set	0 - 127	-	1	0	Configures synchrony check for CBB
Auto initiation Cnd	not allowed when sync fails CB doesn't close Both	-	-	when sync fails	Auto initiation condition
Init signals CBB1	0 - 63	-	1	0	Sets INIT inputs which initiate CBB1
Init signals CBB2	0 - 63	-	1	0	Sets INIT inputs which initiate CBB2
Init signals CBB3	0 - 63	-	1	0	Sets INIT inputs which initiate CBB3
Init signals CBB4	0 - 63	-	1	0	Sets INIT inputs which initiate CBB4
Init signals CBB5	0 - 63	-	1	0	Sets INIT inputs which initiate CBB5
Init signals CBB6	0 - 63	-	1	0	Sets INIT inputs which initiate CBB6
Init signals CBB7	0 - 63	-	1	0	Sets INIT inputs which initiate CBB7
Frq Op counter limit	0 - 250	-	1	0	Frequent operation counter lockout limit
Reclaim time	0.1 - 1800.0	s	0.1	10.0	Reclaim time
First reclose time	0.00 - 300.00	s	0.01	5.00	First reclose time, CBB1
Second reclose time	0.00 - 300.00	s	0.01	5.00	Second reclose time, CBB2
Third reclose time	0.00 - 300.00	s	0.01	5.00	Third reclose time, CBB3
Fourth reclose time	0.00 - 300.00	s	0.01	5.00	Fourth reclose time, CBB4
Fifth reclose time	0.00 - 300.00	s	0.01	5.00	Fifth reclose time, CBB5
Sixth reclose time	0.00 - 300.00	s	0.01	5.00	Sixth reclose time, CBB6
Seventh reclose time	0.00 - 300.00	s	0.01	5.00	Seventh reclose time, CBB7
Frq Op counter time	1 - 250	Min	1	1	Frequent operation counter time
Frq Op recovery time	1 - 250	Min	1	1	Frequent operation counter recovery time
Close pulse time	0.01 - 10.00	s	0.01	0.20	Close pulse time
Disable Pro signal	0 - 63	-	1	63	Defines bits that are removed from DISA_PROT
Auto init	0 - 63	-	1	0	Defines INIT lines that are activated at auto initiation
Fourth delay in SOTF	Not in use In use	-	-	Not in use	Sets 4th delay into use for all DEL_INIT signals during SOTF

Table 1162: DARREC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
CB closed Pos status	FALSE TRUE	-	-	FALSE	Status (TRUE or FALSE) meaning closed CB in input CB_POS
Manual close mode	Not in use In use	-	-	Not in use	Manual close mode
Control line	0 - 63	-	1	63	Defines INIT inputs which are protection signals
Tripping line	0 - 63	-	1	0	Defines INIT inputs which cause OPEN_CB activation
Protection Crd mode	no condition AR inoperative CB close manual AR inop, CB man always	-	-	AR inop, CB man	Protection coordination mode
Shot number CBB1	0 - 5	-	1	0	Sets shot number CBB1
Shot number CBB2	0 - 5	-	1	0	Sets shot number CBB2
Shot number CBB3	0 - 5	-	1	0	Sets shot number CBB3
Shot number CBB4	0 - 5	-	1	0	Sets shot number CBB4
Shot number CBB5	0 - 5	-	1	0	Sets shot number CBB5
Shot number CBB6	0 - 5	-	1	0	Sets shot number CBB6
Shot number CBB7	0 - 5	-	1	0	Sets shot number CBB7
Blk signals CBB1	0 - 63	-	1	0	Sets INIT inputs which block CBB1
Blk signals CBB2	0 - 63	-	1	0	Sets INIT inputs which block CBB2
Blk signals CBB3	0 - 63	-	1	0	Sets INIT inputs which block CBB3
Blk signals CBB4	0 - 63	-	1	0	Sets INIT inputs which block CBB4
Blk signals CBB5	0 - 63	-	1	0	Sets INIT inputs which block CBB5
Blk signals CBB6	0 - 63	-	1	0	Sets INIT inputs which block CBB6
Blk signals CBB7	0 - 63	-	1	0	Sets INIT inputs which block CBB7
Disable shot 1	0 - 63	-	1	0	Configures bits in PROT_DISA output for first reclose
Disable shot 2	0 - 63	-	1	0	Configures bits in PROT_DISA output for secondreclose
Disable shot 3	0 - 63	-	1	0	Configures bits in PROT_DISA output for third reclose
Disable shot 4	0 - 63	-	1	0	Configures bits in PROT_DISA output for fourth reclose
Disable shot 5	0 - 63	-	1	0	Configures bits in PROT_DISA output for fifth reclose
Protection Crd limit	1 - 5	-	1	1	Protection coordination shot limit
Dsr time shot 1	0.00 - 10.00	s	0.01	0.00	Discrimination time for first reclosing
Dsr time shot 2	0.00 - 10.00	s	0.01	0.00	Discrimination time for second reclosing
Dsr time shot 3	0.00 - 10.00	s	0.01	0.00	Discrimination time for third reclosing
Dsr time shot 4	0.00 - 10.00	s	0.01	0.00	Discrimination time for fourth reclosing
Max Thm block time	0.1 - 1800.0	s	0.1	10.0	Maximum wait time for thermal blockin signal deactivation

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Cut-out time	0.0 - 1800.0	s	0.1	10.0	Cut-out time for protection coordination
Auto wait time	0.00 - 60.00	s	0.01	2.00	Maximum wait time for reclosing condition fulfilling
Wait close time	0.05 - 10.00	s	0.05	0.25	Allowed CB closing time after reclose command
Max wait time	0.1 - 1800.0	s	0.1	10.0	Maximum wait time for BLK_DEAD_T release (from master)
Max trip time	0.1 - 10.0	s	0.1	10.0	Maximum wait time for protection signal deactivation
Str 2 delay shot 1	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_2, first reclosing
Str 2 delay shot 2	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_2, second reclosing
Str 2 delay shot 3	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_2, third reclosing
Str 2 delay shot 4	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_2, fourth reclosing
Str 3 delay shot 1	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_3, first reclosing
Str 3 delay shot 2	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_3, second reclosing
Str 3 delay shot 3	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_3, third reclosing
Str 3 delay shot 4	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_3, fourth reclosing
Str 4 delay shot 1	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_4, first reclosing
Str 4 delay shot 2	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_4, second reclosing
Str 4 delay shot 3	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_4, third reclosing
Str 4 delay shot 4	0.00 - 300.00	s	0.01	0.00	Time delay for DEL_INIT_4, fourth reclosing
Auto lockout reset	Not in use In use	-	-	In use	Automatic lockout reset in use
Enable shot jump	0 - 1	-	1	1	Enable shot jumping

10.5.9 Measured values

Table 1163: DARREC Measured values

Name	Type	Default	Description
INIT_1	BOOLEAN	0	AR initialization / blocking signal 1
INIT_2	BOOLEAN	0	AR initialization / blocking signal 2
INIT_3	BOOLEAN	0	AR initialization / blocking signal 3
INIT_4	BOOLEAN	0	AR initialization / blocking signal 4
INIT_5	BOOLEAN	0	AR initialization / blocking signal 5

Table continues on next page

Name	Type	Default	Description
INIT_6	BOOLEAN	0	AR initialization / blocking signal 6
DEL_INIT_2	BOOLEAN	0	Delayed AR initialization / blocking signal 2
DEL_INIT_3	BOOLEAN	0	Delayed AR initialization / blocking signal 3
DEL_INIT_4	BOOLEAN	0	Delayed AR initialization / blocking signal 4
BLK_RECL_T	BOOLEAN	0	Blocks and resets reclose time
BLK_RCLM_T	BOOLEAN	0	Blocks and resets reclaim time
BLK_THERM	BOOLEAN	0	Blocks and holds the reclose shot from the thermal overload
CB_POS	BOOLEAN	0	Circuit breaker position input
CB_READY	BOOLEAN	0	Circuit breaker status signal
INC_SHOTP	BOOLEAN	0	A zone sequence coordination signal
INHIBIT_RECL	BOOLEAN	0	Interrupts and inhibits reclosing sequence
RECL_ON	BOOLEAN	0	Level sensitive signal for allowing (high) / not allowing (low) reclosing
SYNC	BOOLEAN	0	Synchronizing check fulfilled

10.5.10 Monitored data

Table 1164: DARREC Monitored data

Name	Type	Values (Range)	Unit	Description
OPEN_CB	BOOLEAN	0=FALSE 1=TRUE	-	Open command for circuit breaker
CLOSE_CB	BOOLEAN	0=FALSE 1=TRUE	-	Close (reclose) command for circuit breaker
CMD_WAIT	BOOLEAN	0=FALSE 1=TRUE	-	Wait for master command
INPRO	BOOLEAN	0=FALSE 1=TRUE	-	Reclosing shot in progress, activated during dead time
LOCKED	BOOLEAN	0=FALSE 1=TRUE	-	Signal indicating that AR is locked out
PROT_CRD	BOOLEAN	0=FALSE 1=TRUE	-	A signal for coordination between the AR and the protection
UNSUC_RECL	BOOLEAN	0=FALSE 1=TRUE	-	Indicates an unsuccessful reclosing sequence
FRQ_OPR_CNT	INTEGER	-	-	Frequent operation counter
FRQ_OPR_AL	BOOLEAN	0=FALSE 1=TRUE	-	Frequent operation counter alarm

Table continues on next page

Name	Type	Values (Range)	Unit	Description
STATUS	INTEGER	1=Ready 2=In Progress 3=Successful -1=Not defined -2=Unsuccessful	-	AR status signal for IEC61850
AR_ON	BOOLEAN	0=FALSE 1=TRUE	-	Autoreclosing allowed
READY	BOOLEAN	0=FALSE 1=TRUE	-	Indicates that the AR is ready for a new sequence
ACTIVE	BOOLEAN	0=FALSE 1=TRUE	-	Reclosing sequence is in progress
INPRO_1	BOOLEAN	0=FALSE 1=TRUE	-	Reclosing shot in progress, shot 1
INPRO_2	BOOLEAN	0=FALSE 1=TRUE	-	Reclosing shot in progress, shot 2
INPRO_3	BOOLEAN	0=FALSE 1=TRUE	-	Reclosing shot in progress, shot 3
INPRO_4	BOOLEAN	0=FALSE 1=TRUE	-	Reclosing shot in progress, shot 4
INPRO_5	BOOLEAN	0=FALSE 1=TRUE	-	Reclosing shot in progress, shot 5
DISCR_INPRO	BOOLEAN	0=FALSE 1=TRUE	-	Signal indicating that discrimination time is inprogress
CUTOUT_INPRO	BOOLEAN	0=FALSE 1=TRUE	-	Signal indicating that cut-out time is in progress
SUC_RECL	BOOLEAN	0=FALSE 1=TRUE	-	Indicates a successful reclosing sequence
UNSUC_CB	BOOLEAN	0=FALSE 1=TRUE	-	Indicates an unsuccessful CB closing
CNT_SHOT1	INTEGER	-	-	Resetable operation counter, shot 1
CNT_SHOT2	INTEGER	-	-	Resetable operation counter, shot 2
CNT_SHOT3	INTEGER	-	-	Resetable operation counter, shot 3
CNT_SHOT4	INTEGER	-	-	Resetable operation counter, shot 4
CNT_SHOT5	INTEGER	-	-	Resetable operation counter, shot5
COUNTER	INTEGER	-	-	Resetable operation counter, all shots
SHOT_PTR	INTEGER	-	-	Shot pointer value
MAN_CB_CL	BOOLEAN	0=FALSE 1=TRUE	-	Indicates CB manual closing during reclosing sequence
SOTF	BOOLEAN	0=FALSE 1=TRUE	-	Switch-onto-fault

10.5.11 Technical data

Table 1165: DARREC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

10.5.12 Technical revision history

Table 1166: DARREC technical revision history

Technical revision	Change
B	Default setting value changed from TRUE to FALSE for the *CB closed Pos status* setting
C	• IEC 61850 mapping for output `AR_ON` is added • Output `ACTIVE` is added

10.6 Tap changer control with voltage regulator OLATCC

10.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Tap changer control with voltage regulator	OLATCC	COLTC	90V

10.6.2 Function block

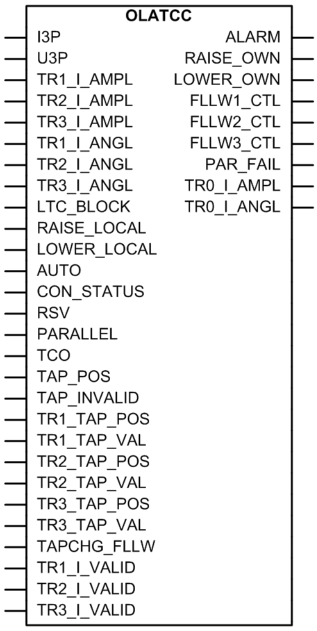


Figure 627: Function block

10.6.3 Functionality

The tap changer control with voltage regulator function OLATCC (on-load tap changer controller) is designed for regulating the voltage of power transformers with on-load tap changers in distribution substations. OLATCC provides a manual or automatic voltage control of the power transformer using the raise and lower signals to the on-load tap changer.

The automatic voltage regulation can be used in single or parallel transformer applications. Parallel operation can be based on Master/Follower (M/F), Negative Reactance Principle (NRP) or Minimizing Circulating Current (MCC).

OLATCC includes the line drop compensation (LDC) functionality, and the load decrease is possible with a dynamic voltage reduction.

Either definite time characteristic (DT) or inverse time characteristic (IDMT) is selectable for delays between the raising and lowering operations.

The function contains a blocking functionality. It is possible to block the voltage control operations with an external signal or with the supervision functionality of the function.

10.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the voltage regulator function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

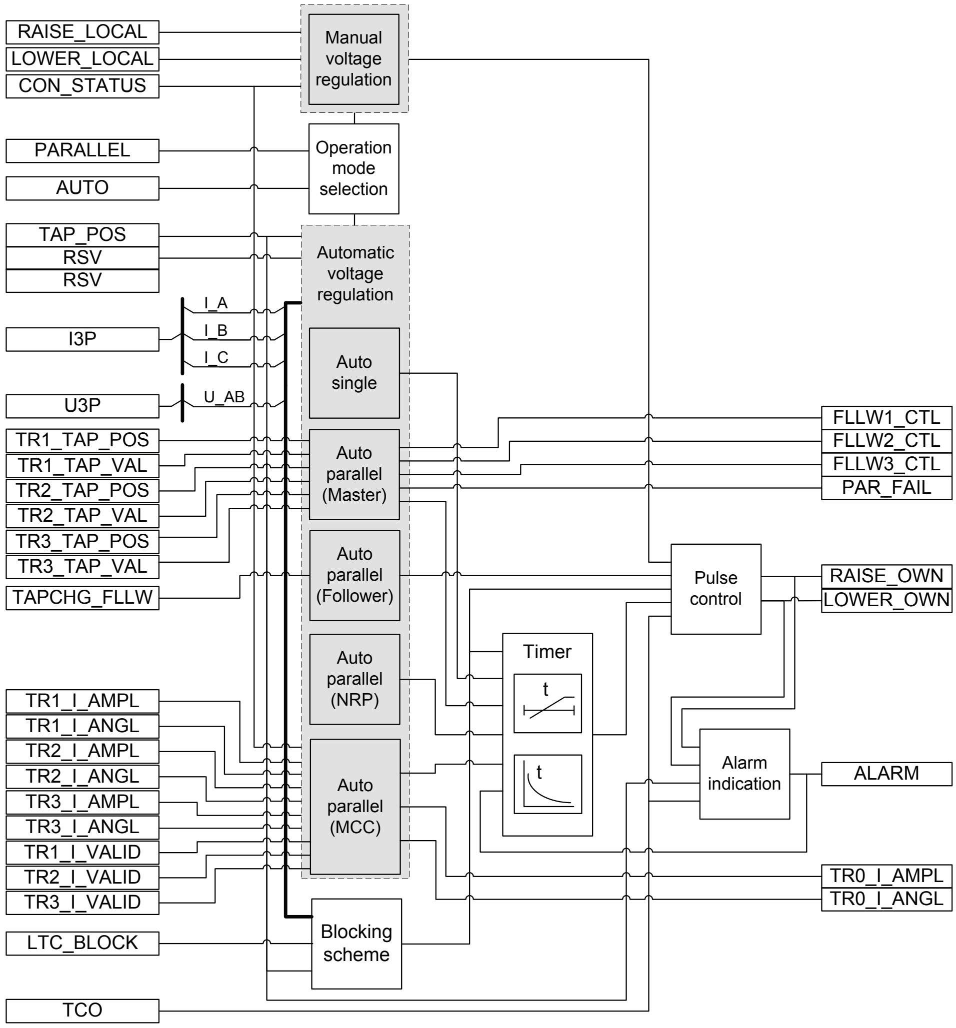


Figure 628: Functional module diagram. Group signals I3P and U3P are used for feeding the necessary analog signals to the function.

10.6.5 Voltage and current measurements

The measured voltage must be a phase-to-phase voltage from the regulated side. Typically, it is the phase-to-phase voltage U_AB from the secondary side of the power transformer. If the phase voltages are measured, the voltage U_AB is calculated internally in the IED.

Currents from the secondary side of the power transformer (I_A – I_C) have several uses.

- The highest phase current value is used for overcurrent blocking. Primary currents are not yet available for this use.
- The currents from the secondary side of the power transformer are used for line drop compensation (average of the connected inputs).
- The currents from the secondary side of the power transformer are used for calculating the circulating current in the Negative Reactance Principle (NRP) and Minimizing Circulating Current (MCC) operation modes.

Both voltage U_AB and the phase currents from the secondary side (I_x, where x is A, B or C) are always measured using the value of the filtered fundamental frequency component (DFT). Hence, the harmonics are always suppressed. Moreover, the measured voltage value is continuously average-filtered with the eight-value-long sliding window where the resulting filtering delay is not compensated. The phase-compensated voltage U_A is always used in calculations, although it is not connected. U_m is the averaged value used for control and its magnitude can be read from the monitored data U_MEAS.

Similarly, the magnitude of the phase current of the own transformer, I_x, and the phase angle difference between the internally phase-compensated voltage U_A and phase current I_x are also average-filtered by the same length-fixed window. The phase angle value can be read from the monitored data ANGL_UA_IA. These currents and phase angle differences are used solely on circulating current calculations.

The angle difference is used in Equation 184, Equation 185 and Equation 187.

There are minimum limits for the voltage and current magnitudes, resulting in the magnitude and phase angle difference values diverging from zero. The voltage magnitude must exceed three percent of U_n and the current I_A must exceed two percent of I_n.

10.6.6 Tap changer position inputs

The position value of the tap changer can be brought to OLATCC as a resistance value, a mA signal or as a binary-coded signal. More information on how the resistance value, the mA signal or a binary-coded interface are implemented can be found in TPOSSLTC in the technical manual of the IED.

The indicated tap changer position of the own transformer is internally connected to the `TAP_POS` input, and the tap changer positions of the parallel transformers are fed to the other `TRx_TAP_POS` inputs. This also defines the connection identity so that follower 1 is connected to `TR1_TAP_POS`, follower 2 is connected to TR2_TAP_POS and follower 3 is connected to TR3_TAP_POS. The own transformer position can be read from the monitored data TAP_POS. The follower tap changer positions can also be read from the input data TRx_TAP_POS, where x is a value between 1 and 3.

The tap changer position value is given in parentheses. For example, (0) indicates that there is no tap changer position connected or the tap changer position value quality is bad. Typically, if no tap changer position is connected, all the TPOSSLTC binary inputs are FALSE by default and the value shown is (0). A value other than zero indicates bad quality. Also, if the state of the input TAP_INVALID is TRUE (1), the bad quality for input TAP_POS is indicated. Correspondingly, if the inputs TR1_TAP_VAL, TR2_TAP_VAL or TR3_I_VAL are FALSE (0), the quality is bad in inputs TR1_TAP_POS, TR2_TAP_POS and TR3_TAP_POS. A bad-quality tap changer position is dealt by OLATCC like an unconnected tap position information.

10.6.7 Operation mode selection

OLATCC has the *Operation mode* and *Auto parallel mode* settings for selecting the desired operation mode. The *Operation mode* setting can have any of the following values: "Manual", "Auto single", "Auto parallel" and "Input control". If the *Operation mode* setting is set to "Input control", the acting operation mode is determined by the inputs PARALLEL and AUTO. The PARALLEL input defines if the transformer (voltage regulator) is in the parallel or single mode. The AUTO input defines the operation status in the single mode. The output signals PARALLEL and AUTO echo fed input signals when the *Operation mode* setting is set to "Input control". Otherwise the PARALLEL and AUTO monitored data represent acting "Parallel or single operation" and "Auto/Manual indication" respectively.

Table 1167: Acting operation mode determined by the operation mode inputs

PARALLEL	**AUTO**	*Operation Mode*
0	0	Manual
0	1	Auto single
1	0 or 1	Auto parallel

Furthermore, if *Operation mode* has been set to "Auto parallel", the second setting parameter *Auto parallel mode* defines the parallel mode and the alternatives are "Master", "Follower", "MCC" or "NRP".

The acting operation mode can be read from the monitored data OPR_MODE_STS.

Command Exclusion

An acting operation mode change using two inputs (PARALLEL and AUTO) and setting group change (either with the input or via menu) is needed when the acting operation mode must be changed automatically, that is, there is a logic which drives these two inputs and setting group change based on the status information from the circuit breakers.

The common Local/Remote (L/R) exclusion concerns the manual raising and lowering commands of OLATCC, that is, it internally proves the exclusion mechanism to prevent the remote commands (from SCADA) when the IED is in local mode.

10.6.8 Manual voltage regulation

The manual raising and lowering commands can be given either via the configuration inputs `LOWER_LOCAL` and `RAISE_LOCAL`, via the HMI of the IED or via remote commands. The acting operation mode of OLATCC must be set to "Manual" and the Local/Remote control LR state monitored data of the IED has to be "Local" to execute the control commands manually from HMI or via configuration inputs. Although OLATCC is set to "Manual" but the LR state is set to "OFF" or "Remote", no manual control commands can be given.

For remote commands, the acting operation mode of the OLATCC function must also be set to "Manual" and the LR state monitored data has to be "Remote".

Voltage control vs. tap changer moving direction

OLATCC has the control settings *Lower block tap* and *Raise block tap*. The *Lower block tap* and *Raise block tap* settings should give the tap changer position that results in the lowest and highest controlled voltage value (usually at the LV side of the transformer). The setting of both *Raise block tap* value higher than *Lower block tap* value and *Lower block tap* value higher than *Raise block tap* value is allowed.

When the value of *Raise block tap* exceeds the *Lower block tap* value, the raise control activates the `RAISE_OWN` output. This results in raising the tap changer position, and the measured voltage rises. Furthermore, the `RAISE_OWN` output value is TRUE. If the own tap changer position is connected (that is, the own tap changer's quality is good), the tap changer alarm is activated if the tap changer does not move upwards in the *Cmd error delay time* setting after the pulse activation, resulting that ALARM_REAS in the monitored data contains a command error value. The *Cmd error delay time* setting default value is 20 seconds.

The lowering control works in a similar way, as shown in Figure 629. In the output data the `LOWER_OWN` output value is TRUE. An alarm is generated if the tap changer does not move downwards in *Cmd error delay time* after the pulse activation (assuming that the own tap changer position is connected).

In the second case, the parameters are set so that the value of *Lower block tap* exceeds the value of *Raise block tap*. The raising control activates the `RAISE_OWN` output. The result should be that the tap changer lowers its position and the measured voltage rises. Furthermore, the `RAISE_OWN` output value is TRUE in the output data. If the own tap changer position is connected, the tap changer alarm is activated if the tap changer does not move downwards in *Cmd error delay time* after the pulse activation, resulting that ALARM_REAS in the monitored data contains a command error value.

The lowering control works in a similar way, as shown in Figure 629. In the output data, the `LOWER_OWN` output value is TRUE. An alarm is generated if the tap changer does not move upwards in *Cmd error delay time* after the pulse activation, assuming that the own tap changer position is connected.

10.6.9 Automatic voltage regulation of single transformer

OLATCC is intended to control the power transformers with a motor-driven on-load tap changer. The function is designed to regulate the voltage at the secondary side of the power transformer. The control method is based on a step-by-step principle, which means that one control pulse at a time is issued to the tap changer mechanism to move it exactly one position upwards or downwards. However, when intermediate steps are not indicated for the tap changer, it does not cause alarm if more than one step change is met.

The purpose of the regulator is to maintain a stable secondary voltage of the power transformer. The basis for this operation is the *Band center voltage* setting. By increasing or decreasing various compensation factors, the regulator calculates a control voltage from the band center voltage as shown in Equation 182. Hence, the control voltage is the desired transformer secondary voltage to be maintained by the regulator. The control voltage is compared to the measured voltage and the difference between the two forms the regulating process error.

Since the tap changer changes the voltage in steps, a certain error has to be allowed. The error, called *Band width voltage*, is also set by the user. A recommended setting for *Band width voltage* should be close to twice the step voltage of the transformer ΔU_{step} and never below it as a minimum. For example, *Band width voltage* is twice the value of ΔU_{step} in Figure 629.

If the measured voltage fluctuates within the control voltage ± half the *Band width voltage* setting, the regulator is inactive. If the measured voltage is outside the half-bandwidth voltage limits, an adjustable delay T1 (*Control delay time 1*) starts, as shown in Figure 629, where the lowering function is an example. The delay T1 remains active as long as the measured voltage is outside the hysteresis limits of half the value of *Band width voltage*. The factory setting for the hysteresis is 10 percent of the set *Band width voltage*.

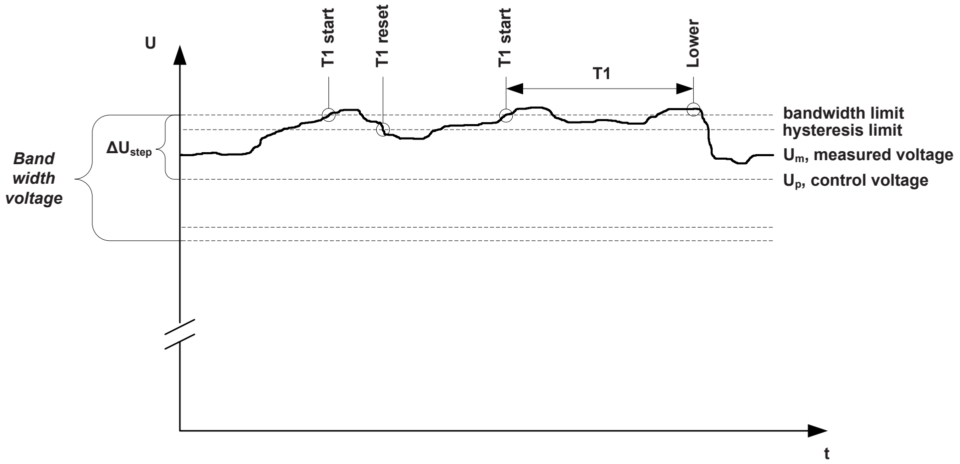


Figure 629: Voltage-regulating function. A control pulse to lower the voltage is issued after the elapsed T1.

If the measured voltage is outside the hysteresis when the delay counter T1 reaches its setting value, the raising or lowering output relay is activated. This activates either output pulse `RAISE_OWN` or `LOWER_OWN`, and the motor drive of the tap changer operates. The status of these outputs can be read from the output data `RAISE_OWN` or `LOWER_OWN`.

If the measured voltage falls or rises within the hysteresis limits during the operating time, the delay counter is reset.

The pulse length can be defined with the *LTC pulse time* setting. The default value is 1.5 seconds.

A short delay same as the typical tap changer operating time is active before the start of the next operating timer is possible. For OLATCC, the delay is set to 6 seconds. If one tap changer operation is not enough to regulate the transformer voltage within the hysteresis limits, a second adjustable delay T2 (*Control delay time 2*), usually with a shorter time setting than T1, starts. This delay is used for the control commands within the same sequence until the recovery of voltage occurs. The delays T1 and T2 can be selected either with definite or inverse time characteristics. In the inverse time mode operation, the operating time depends on the difference between the control voltage and the measured voltage as shown in Equation 188. The bigger the difference in the voltage, the shorter the operating time. More information on the inverse time operation can be found in the OLATCC timer characteristics chapter.

Regulation equation

The simple regulating principle is often complemented by additional features to take the voltage drop of lines into account (line drop compensation), coordinate the regulation of parallel transformers and change the voltage level according to the loading state of the network. The control voltage U_p is calculated according to the equation

$$U_p = U_s + U_z + U_{ci} - U_{rsv}$$

(Equation 182)

U_p	Control voltage
U_s	Set voltage level *Band center voltage*
U_z	Line drop compensation term
U_{ci}	Circulating current compensation term
U_{rsv}	Voltage reduction parameter

U_p can be directly read in the monitored data U_CTL.

The circulating current compensation term is calculated only in the parallel acting operation modes "NRP" and "MCC".

Line Drop Compensation (LDC)

The line drop compensation feature is used to compensate the voltage drop along a line or network fed by the transformer. The compensation setting parameters can be calculated theoretically if the resistance and reactance of the line are known or measured practically from the line drop.

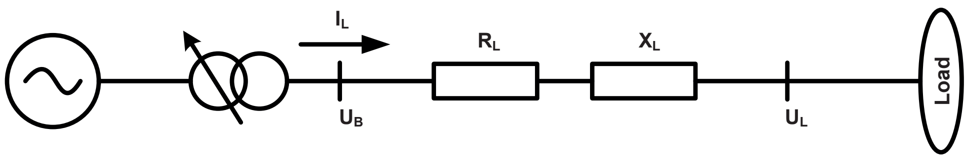


Figure 630: Equivalent electrical circuit for calculating the LDC term

The compensation parameters *Line drop V Ris* (U_r) and *Line drop V React* (U_x), are percentage values of U_n according to the equations.

$$Line\ drop\ V\ Ris = U_r\left[\%\right] = \frac{\sqrt{3} \times I_n \times R}{U_n} \times 100 \quad \left[\%U_n\right]$$

(Equation 183)

$$Line\ drop\ V\ React = U_x\left[\%\right] = \frac{\sqrt{3} \times I_n \times X}{U_n} \times 100 \quad \left[\%U_n\right]$$

(Equation 183)

I_n	Rated current of the power transformer
U_n	Rated main voltage of the power transformer
R	Resistance of the line, Ω/phase
X	Reactance of the line, Ω/phase

The general LDC equation can be calculated.

$$U_z = \frac{I_{injected}}{I_n} \cdot \frac{\left(U_r\left[\%\right]\cos\varphi + U_x\left[\%\right]\sin\varphi\right)}{100} \quad \left[\mathrm{xU_n}\right]$$

(Equation 184)

$I_{injected}$	Average of the currents I_A, I_B and I_C
U_r	Setting *Line drop V Ris*
U_x	Setting *Line drop V React*
φ	Phase angle between U_A and I_A (ANGL_UA_IA in monitored data)

By default, the line drop compensation (LDC) is not active. LDC is activated by setting *LDC enable* to "True". To keep the LDC term within acceptable limits in all situations, OLATCC has a setting parameter *LDC limit*, which has a default value of 0.10 xU_n. As a result, this gives the maximum value for U_z in Equation 182.

If more than one line is connected to the LV busbar, the equivalent impedance is calculated and given as a parameter setting as shown in Figure 630 for the equivalent electrical circuit for calculating LDC. For example, if there are N number of identical lines with identical loads in the substation, the R- and X-values needed for the settings *Line drop V React* and *Line drop V Ris* are obtained by dividing the resistance and the reactance of one line by N. Because the voltage drop is different in lines with different impedances and load currents, it is necessary to make a compromise when setting the *Line drop V React* and *Line drop V Ris* settings. Raising the voltage in the point of lowest voltage must not lead to overvoltage elsewhere.

By default, the line drop compensation is effective only on the normal active power flow direction. If the active power flow in the transformer turns opposite, that is, from the regulated side towards the system in the upper level, the LDC term is ignored, that is, set to zero. In such a case, it is assumed that the feeding units at the regulated side of the transformers maintain proper voltage levels. This can cause a conflict if the transformer tries to reduce the voltage at the substation. Additionally, it is difficult to predict the actual voltage levels in the feeder lines in such a case, and lowering the voltage at the substation can have harmful effects in the far end of the network. However, the *Rv Pwr flow allowed* setting allows also negative LDC terms to be taken into equation.

The topology changes in the network can cause changes to the equivalent impedance value of the network. If the change is substantial, the setting groups can be used to switch between different setting values for *Line drop V React* and *Line drop V Ris*. In practice this means that the boolean-type information from the topology change is connected to the active setting group change.

The use of the LDC equation in the case of parallel transformers is described in the Automatic voltage regulation of parallel transformers chapter.

Reduce Set Voltage (RSV) input

The system frequency decreases when the active power production in the network is smaller than its consumption. Either the power supply has to be increased or some loads have to be shed to restore the power balance.

The simplest way to decrease the load is to reduce the voltage level by giving a lower band center voltage value to the regulators. For this purpose, OLATCC has the setting group parameter *Band reduction*. The `RSV` input activation results in reduction. If this input is set to TRUE, a set target voltage value is decreased by *Band reduction*. If more than one `RSV` reduction steps are desired, the setting group change has to be used where different *Band reduction* values are supported. The decreased value is kept as a target value as long as the `RSV` input is TRUE.

Because the decrease of frequency indicates a need to reduce the load, it is practical to connect the start signal of an underfrequency function block to the `RSV` digital input.

It depends on the load characteristics how much the load is reduced as the voltage drops. For instance, purely resistive loads are proportional to the square of the voltage, whereas motor drives based on frequency controllers may draw constant power despite small voltage changes.

The status of the `RSV` input can be read from the `RSV` input data.

10.6.10 Automatic voltage regulation of parallel transformers

It is likely that a circulating current between transformers occurs if two or more transformers with slightly different ratios are energized in parallel. This is due to the unbalanced short circuit impedances of the parallel transformers. To avoid such currents, the tap changers of the transformers should be adjusted to achieve equilibrium. If the transformers are assumed identical, the tap (voltage) steps and tap positions should also match. In this case, the Master/Follower principle can be used. However, unequally rated transformers with different tap steps can be connected in parallel and these configurations can also be managed by the tap changer control function. For these configurations, the Minimizing Circulating Current (MCC) or Negative Reactance Principle (NRP) should be used. The MCC and NRP principles are also suitable for identical transformers.

The circulating current, which is almost purely inductive, is defined as negative if it flows towards the transformer. U_{ci} in Equation 182 is positive and the control voltage U_p rises as a result to the RAISE_OWN output signal activation if the circulating current level is sufficient (Equation 185 and Equation 187) and the other parameters remain the same. As a result, the voltage rise should diminish the circulating current.

LDC equation and parallel connection

The additional challenge in the parallel connection regarding the line drop compensation is to know the total current which flows through the parallel transformers.

In the Master/Follower mode, it is easier to know the total current than in other parallel modes since the transformers are assumed to have identical ratings, that is, the total current ($I_{injected}$ in Equation 184) is obtained by multiplying the measured load current (the average of the secondary currents I_A, I_B and I_C of the connected own transformer) with the number of parallel transformers. OLATCC can internally conclude the number of parallel transformers from the connected tap changer position inputs. However, if there is no connected position information from the other parallel transformers, the correct number of the parallel transformers, excluding the own transformer, needs to be set with the *Parallel trafos* setting.

In the MCC mode, the horizontal communication transfers the information from the measured load currents between the regulators so that the total current needed in the line drop compensation can be summed up accurately. Here, $I_{injected}$ is defined to be the phasor sum of all the parallel power transformer secondary-side currents. The currents from other transformers must be fed via the TRx_I_AMPL and TRx_I_ANGL inputs. If the state of the input TRx_I_VALID is TRUE (1), the good quality for the corresponding inputs TRx_I_AMPL and TRx_I_ANGL is indicated.

In the NRP mode, the parallel transformers have different ratings and there is no communication between the regulators. Therefore, when setting *Line drop V React* and *Line drop V Ris*, the I_{CT_n1} used in the equation should be the sum of the rated currents of all the transformers operating in parallel. Here, $I_{injected}$ is also defined as the average of the connected secondary currents (I_A, I_B and I_C). The calculated line drop compensation value can be read from the monitored data LDC.

10.6.10.1 Master/Follower principle M/F

The Master/Follower (M/F) operation principle is suitable for power transformers with identical ratings and step voltages. One voltage regulator (master) measures and controls and the other regulators (followers) follow the master, that is, all the tap changers connected in parallel are synchronized. This parallel operation is obtained by connecting the FLLWx_CTL output of the master to the corresponding input TAPCHG_FLLW of the followers via a horizontal GOOSE communication.

The values for the FLLWx_CTL command are 1=Lower follower x and 2=Raise follower x. Consequently, the values for the TAPCHG_FLLW command are 1=Lower and 2=Raise.

If several regulators are to act as masters (one at a time), their outputs also have to be routed to the inputs of other regulators. To start the parallel operation, the master regulator is set to the "Auto master" mode and the followers to the "Auto follower" mode. To implement this setting, a group changing has to be planned.

To keep all the tap changers in the same position, the master needs to know the tap positions of the followers. This way, the circulating current is kept at its minimum. The position values of the followers can be brought to the master either via the horizontal GOOSE communication or TPOSSLTC.

If it is not possible to use horizontal communication between the IEDs and the position information cannot be wired from the parallel transformers, the M/F principle can still be used to regulate two or an unlimited number of transformers in parallel. Since the master cannot detect the tap positions of parallel transformers, it just activates the lowering and raising outputs for all the followers when it controls its own tap changer. This is called blind control. In this case, a number of parallel transformers are regulated as one unit. The tap position inputs 1…3 (TR1_TAP_POS..TR3_TAP_POS) must be left unconnected for the master to know that the tap positions of the followers are unknown. The time delay between successive commands can be set by the *Follower delay time* setting. The default value is six seconds.

When a disconnected transformer is taken into use and the tap position is unknown, the follower should be manually controlled to the same position as the master. This can also take place in the master/follower mode. First, the master gives a control command to its own transformer, that is, it is echoed to the followers (the follower tap positions have to be connected). Thereafter, successive control commands to the followers take place until the master and followers have the same tap positions.

Out-of-step function

The out-of-step function is usually used in the M/F modes only. The out-of-step function means that the master is able to detect the position values of the followers and control them to the same position as the master is. In this case, the master assumes that the followers also have either *Raise block tap* higher than *Lower block tap* or *Lower block tap* higher than *Raise block tap* because this defines what is the given command pulse for a follower. If the master has *Raise block tap* higher than *Lower block tap* and the follower has *Lower block tap* higher than *Raise block tap*, the corresponding TAPCHG_FLLW included control signals should be connected crosswise. This requires an extra logic where dual-point command bits have to be converted, that is, 0=>0, [01]=1=>[10]=2 and [10]=2=>[01]=1.

M/F is the only parallel mode which has an out-of-step functionality. In the MCC and NRP operation modes, the circulating current is minimized, which most probably means different tap positions in the parallel transformers. Moreover, these modes allow different ratings and step voltages for the parallel transformers. Therefore, it is reasonable to apply the out-of-step function only to the M/F operation mode.

The out-of-step function is triggered when the master detects a difference of at least one step between the tap changer positions in the follower and in the master. The master then sends special raising or lowering commands to the diverged follower. If two consecutive commands fail to change the position of the follower to the right direction, the master activates the `PAR_FAIL` output, that is, `PAR_FAIL` is set to TRUE, and stops the special recovery efforts. However, every time the master controls its own tap changer later, it always sends a controlling pulse to the diverged follower too. Furthermore, if the master notices a correct position change after a sent pulse, it restarts the attempt to drive the follower to the same position and deactivates the `PAR_FAIL` output, that is, `PAR_FAIL` is set to FALSE. However, if there still are diverged followers, the reset is not indicated. It is indicated only when no diverged followers exist. Monitoring, and hence the indication of a paralleling failure, is not possible in blind control. The followers with a parallel failure can be read from the monitored data FAIL_FLLW. For example, if only follower 3 is in the parallel failure state, FAIL_FLLW has the value "Follower 3". If both followers 1 and 2 are in the parallel failure state, FAIL_FLLW has the value "Followers 1+2". By default, when no failed followers exist, the value is "No failed followers".

10.6.10.2 Negative Reactance Principle NRP

This parallel control scheme is suitable for power transformers with different ratings and step voltages. Since no communication between the regulators is needed, this principle can be applied even when the parallel transformers are located at different substations. To start the parallel operation, the acting operation mode has to be set to "NRP" for all the regulators of the connection. The acting operation mode can be changed via function block inputs or by setting either locally or remotely.

When applying this principle, each regulator has a phase angle setting φ_{Load} (setting parameter *Load phase angle*) towards which it tries to regulate the current. The setting value is chosen according to the expected power factor of the load (positive setting value equals inductive load). When the actual phase angle of the load current is the same as the setting and the transformers and their tap changer positions are identical, the currents of the two or more transformers are in the same phase as the total load current. If the tap changer positions are different, the circulating current flows and the currents of different transformers either lag or lead the load current. Figure 631 shows that the circulating current is the reactive component which separates the measured current vector from the expected angle value.

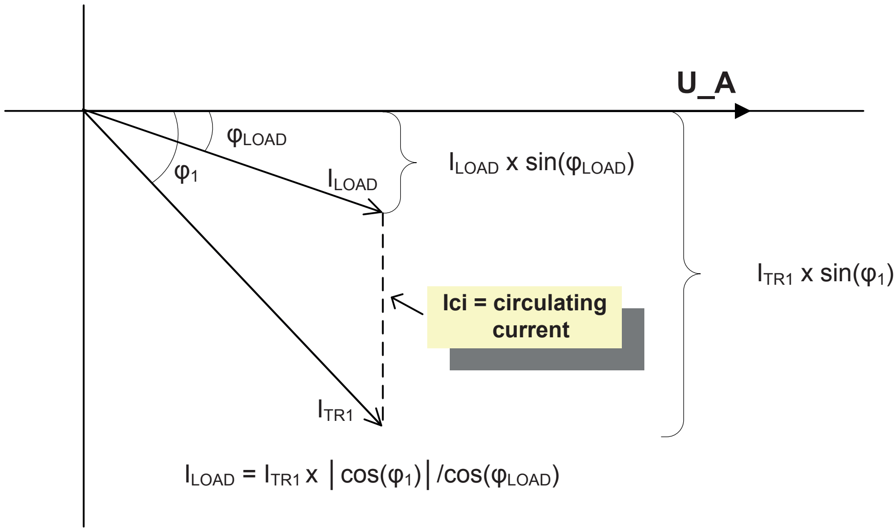


Figure 631: The expected phase angle of the load supplied by the transformers operating in parallel is entered as a setting value φ_{Load}

The regulators calculate the circulating current with the equation

$$I_{ci} = (\sin\varphi_1 - \tan\varphi_{Load} \cdot |\cos\varphi_1|) \cdot I_{TR1}$$

(Equation 185)

I_{TR1}	Average of the currents I_A, I_B and I_C
φ_1	Phase angle between U_A and I_A
φ_{Load}	The set Load phase angle of the load current

In the negative reactance method, the circulating current is minimized by changing the control voltage according to the measured circulating current. The regulator calculates the circulating current compensation term U_{ci} using the equation

$$U_{ci} = \frac{-I_{ci}}{I_n} \cdot \frac{Stability}{100} \cdot U_n$$

(Equation 186)

I_{ci}	Circulating current
Stability	Stability setting (the recommended value depends on the loop impedance)

.

If the transformers operating in parallel have different rated currents, the value of the *Stability factor* setting of the regulator should be proportional to the rated currents, that is, the higher the rated current, the higher the *Stability factor* setting value.

By comparing the reactive components of the currents measured by the different regulators it is possible to find out if the circulating current has been minimized. The circulating current is minimized when the reactive components are equal.

The negative reactance method gives satisfactory results only if the phase angle of the load current is known relatively accurately. If the actual phase angle deviates from the phase angle setting, a regulating error occurs. However, for the cases where there is an occasional stepwise change in the phase angle of the load, the regulating error can be suppressed with the logic. This kind of stepwise change can occur, for example, when a capacitor bank is switched on to compensate a reactive power flow.

Another possibility is to use an automatic setting group change between setting groups in different loading situations. The setting groups then have different set values for the load phase angle.

10.6.10.3 Minimizing Circulating Current principle MCC

The MCC principle is an optimal solution for controlling the parallel transformers of different ratings or step voltages in substations with varying reactive loads. Since this control scheme allows the exchange of data between regulators, the circulating current can be calculated more accurately than with other schemes. However, a maximum of four regulators can be connected in parallel. To start the parallel operation, the acting operation mode parameter has to be set to "MCC" for all the regulators of the connection. Furthermore, the signal `CON_STATUS` must indicate that the transformers are connected to the network. A unit that is minimizing the circulating current must have the acting operation mode set to "MCC". However, units that have the acting operation mode set to "Manual" do not perform any circulating current minimization operations themselves.

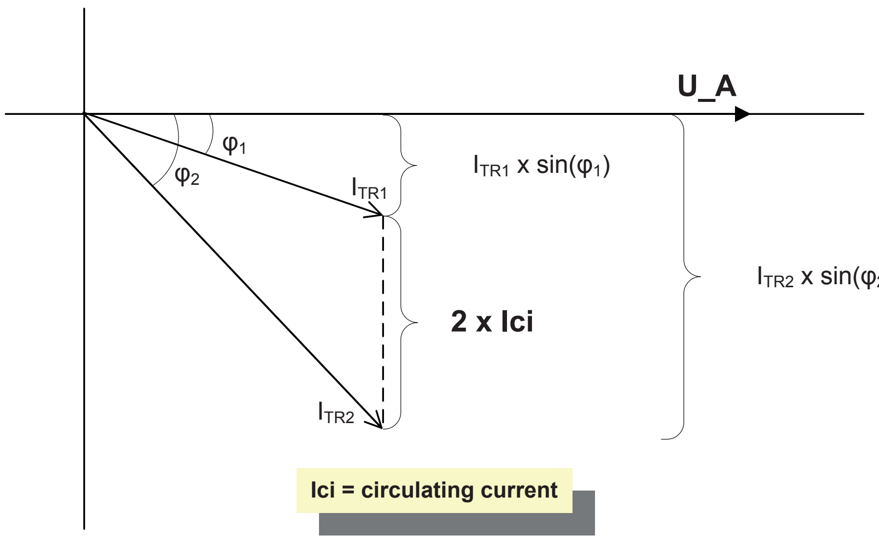


Figure 632: The circulating current between two parallel transformers

In this case, the circulating current can be calculated with the equation

$$I_{ci} = \frac{(\sin\phi_1 \cdot I_{TR1} - \sin\phi_2 \cdot I_{TR2})}{2}$$

(Equation 187)

I_{TR1}	Average primary value of the currents I_A, I_B and I_C measured by regulator 1
I_{TR2}	Average primary value of the currents I_A, I_B and I_C measured by regulator 2
φ_1	Phase angle between U_A and I_A in regulator 1
φ_2	Phase angle between U_A and I_A in regulator 2

The circulation current can be read from the monitored data I_CIR.

Using the circulating current, the compensation term U_{ci} can be calculated with the equation

$$U_{ci} = \frac{-I_{ci}}{I_{CT\_n1}} \cdot \frac{\text{Stability}}{100} \cdot U_n$$

I_{ci}	Circulating current
I_n	Nominal current of the transformer
Stability factor	Stability setting (the recommended value depends on the loop impedance)

Using the circulating current, a compensation term U_{ci} can be calculated using Equation 186. The value of U_{ci}, which can be positive or negative, is considered by adding it to the *Band center voltage* U_s (Equation 182). According to Figure 632 and Equation 187, the phasor information from the other IEDs is needed.

Parallel unit detection and the MCC mode

The network connection status information is essential for the MCC operation mode. The status FALSE needs to be connected to the `CON_STATUS` input to ensure a proper operation of the MCC calculation if the transformer is disconnected but OLATCC remains in the MCC mode. This way the disconnected transformer is excluded from the circulating current calculations.

The `CON_STATUS` input is used to identify if a certain transformer controller is able to send the current information to other transformer controllers for circulating current minimization purposes. As a result, this input has effect only in the MCC or Manual acting operation modes. In these modes, if `CON_STATUS` is TRUE, the information transmission is started. The circulating current information receiving is allowed only in the MCC acting operation mode when `CON_STATUS` is TRUE. PAR_UNIT_MCC can be seen in the monitored data view.

Communication and the MCC mode

The phasor information from the other parallel IEDs is needed for the circular current calculation. Therefore, horizontal GOOSE communication is needed between IEDs when the MCC principle is used.

The transferred current phasor contains the primary value of the measured current. The received current phasor information can be read from the input data `TRx_I_AMPL` and `TRx_I_ANGL` for the magnitude and angle respectively. The value "x" gives the connected parallel transformer number, a value between 1 and 3.

The sent phasor information always represents the difference between the voltage phasor *U_A* and *I_A*. This information regarding the current phasor can be read from the output data `TR0_I_AMPL` and `TR0_I_ANGL`. The allowed acting operation modes for sending data are MCC or Manual, both with the input `CON_STATUS` activated. The communication can be seen to be active when the sent and received phasor magnitude is not clamped to zero. The communication phasor magnitude found to be zero results either from a rejected acting operation mode or too low signal magnitudes (OLATCC Voltage and current measurements chapter). Active `CON_STATUS` indicates that the corresponding transformer is connected to network and its current affects the circular current of other transformers even when it is itself in the manual operating mode.

10.6.11 Timer characteristics

Operation timer functionality

The delay times can be set to follow either the definite time characteristic or the inverse time characteristic with the *Delay characteristic* setting. By default, the "Definite time" type is selected. The timer mode cannot be changed between cycles T1 and T2, only either before T1 has started or after T2 has elapsed.

Table 1168: Different timer mode delays

Timer mode	Setting	Description
T1	*Control delay time 1*	First delay when the measured voltage exceeds or falls below the limit value.
T2	*Control delay time 2*	Second delay when the first control did not bring the measured voltage to a desired level.

The delay after the command pulse activation and the restart of the timer is six seconds. The delay is assumed to be the tap changer operating delay. The timer status can also be read from the monitoring data TIMER_STS, where T1 active gives a value "Lower timer1 on" or "Raise timer1 on" while T2 active gives a value "Lower timer2 on" or "Raise timer2 on". Furthermore, the "Fast lower T on" value indicates that the fast lowering control functionality is active (Blocking scheme chapter).

Activation of operation timer also activates the `TIMER_ON` output.

IDMT type operation

The IDMT timer can be selected by setting *Delay characteristic* to "Inverse time". The minimum time at the inverse time characteristic is limited to 1.0 second. However, the minimum recommended setting of the control delay times T1 and T2 is 10 seconds when the definite time delay is used and 25 seconds when the inverse time delay is used.

The inverse time function is defined by the equations:

$$B = \frac{U_d}{(U_{BW} / 2)}$$

(Equation 188)

U_d	$\lvert U_m - U_p \rvert$, differential voltage
U_{BW}	Setting parameter *Band width voltage*

$$t = \frac{T}{2^{(B-1)}}$$

(Equation 189)

T	T1 or T2

The monitored data UD_CTL shows the differential voltage value $U_m - U_p$. If the value exceeds half of the *Band width voltage* setting and has a negative sign, a raising pulse is issued. The UD_CTL monitored data can also be seen in the DT timer mode.

The hysteresis approach is presented in Figure 629.

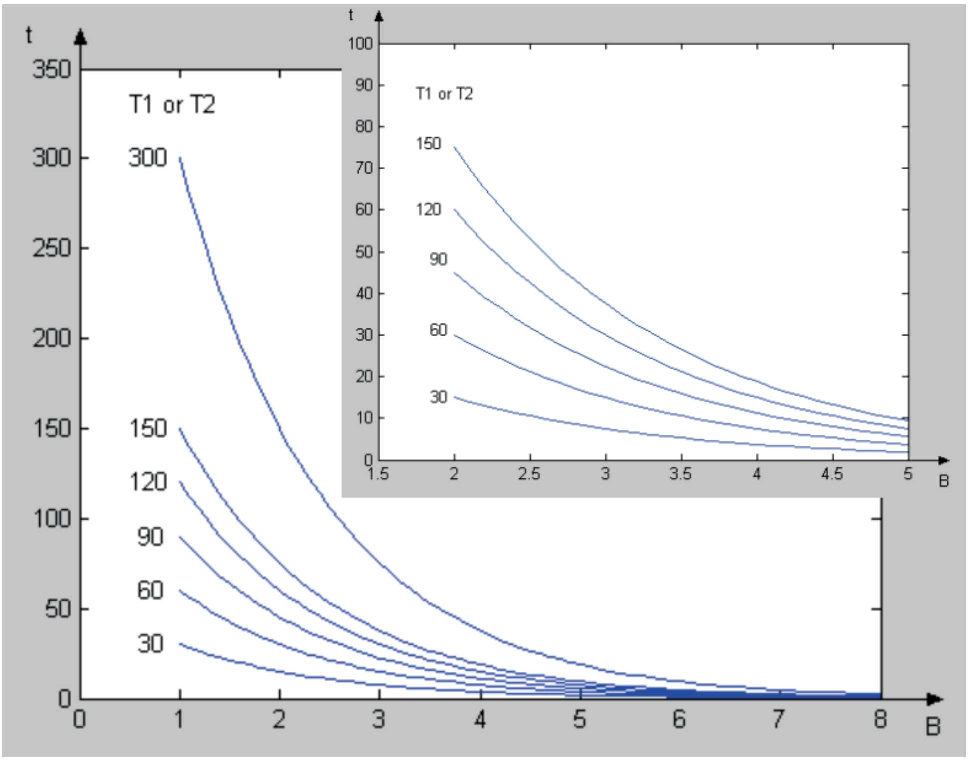


Figure 633: Inverse time characteristic for different values on T1 or T2 (The smaller figure is a zoom-in of the larger one)

10.6.12 Pulse control

The tap changer generates an active operating signal when the tap-changing process is active. This signal is to be connected to the TCO input. The signal is used for alarming purposes. If the signal is active (=TRUE) for more than 15 seconds after the control pulse has been deactivated, an alarm is generated (Alarm indication chapter). If the TCO input is not connected, no alarm is generated.

The control operation is disabled when the TCO input signal is active, unless no tap changer stuck is detected (Alarm indication chapter). Thus, it is not possible for the controller to send new pulses to the tap changer when it is already operating. This is because the tap changers are typically immune to new pulses when they are operating. Furthermore, because the pulses are omitted, the tap changer pulse counter of the controller is not incremented either.

The commands are not tolerated during an active pulse. Therefore the command pulse length (setting *LTC pulse time*) has to be carefully selected, although an active TCO input is used internally to prevent new commands from reaching the tap changer.

To be more certain that no new pulses are to be sent when the tap changer is in operation, the tap changer operating signal can also be connected to the

LTC_BLOCK input. In this case, the external blocking is achieved when an automatic pulse is sent to the operating tap changer. The external LTC_BLOCK has by default no effect when the acting operation mode is set to "Manual".

The status of the TCO input can be read from the TCO input data.

10.6.13 Blocking scheme

The operation of the voltage regulator can be blocked for several reasons. The purpose of blocking is to prevent the tap changer from operating under conditions that can damage the tap changer or exceed other power system-related limits. There is the BLK_STATUS monitored data that does not imply actual blocking but reveals if the coming command pulse is issued or not. The blocking itself happens when the corresponding bit in the signal BLK_STATUS is active and the command pulse is to be started due to a timer elapse or a local command. This is to avoid unnecessary event sending.

The cross (X) in the table defines when the operation is blocked (if the corresponding bit is active in BLK_STATUS). For example, an overvoltage (runback raising voltage) results in blocking only when the acting operation mode is "Manual" and the manual raising command is to be given.

Table 1169: Default blocking schema in OLATCC

Acting operation mode	Command	Load current	Block lowering voltage	Runback raising voltage	High circulating current	External Block	Extreme positions
Manual	Raise	X		X			X
	Lower	X					X
Auto follower	Raise	X	X			X	X
	Lower	X	X			X	X
Auto single, Auto master, NRP, MCC	Raise	X	X		X 1)	X	X 2)
	Lower	X	X		X 1)	X	X 2)

1) Because the circulating current is only calculated in the NRP and MCC modes, it can have a blocking effect only in these modes.
2) However, in these cases pure automatic operation notices that the extreme position has already been reached and there is no need to activate the signal for data set event sending. The automatic follower case can here be compared to a manual case and an event can be sent, that is, the corresponding output is activated.

In addition to the default blocking, the *Custom Man blocking* setting has been added due to different operation practices considering the manual command blocking. The setting can be used to adapt blockings considering the manual overcurrent, undervoltage or external blocking. (The blockings are in the table in columns Load current, Block lowering voltage and External block for the manual operating mode.) The default value for the parameter is "OC". This means that the table explaining the default blocking schema operates as such. However, there are also other alternatives that cause different operation when compared to that table.

Table 1170: Customized manual blocking schema

Manual blocking type	Enumeration	Description
1	Custom disabled	No Load current, blocking of lower (under) voltage or external blocking have effect in the manual.
2	OC	Load current blocking has an effect in the manual operation mode
3	UV	Block lowering (under) voltage blocking has an effect in the manual operation mode
4	OC, UV	Conditions 2 and 3 together: Load current and block lowering (under) voltage blocking have effect in the manual operation mode
5	EXT	External blocking has an effect in the manual operation mode
6	OC, EXT	Conditions 2 and 5 together: Load current and external blocking have effect in the manual operation mode
7	UV, EXT	Conditions 3 and 5 together: Block lowering (under) voltage and external blocking have effect in the manual operation mode
8	OC, UV, EXT	All conditions 2, 3 and 5 together: Load current and block lowering (under) voltage and external blocking have effect in the manual operation mode

If the *Custom Man blocking* setting is "Custom disabled", the blocking schema regarding the acting operation mode "Manual" is as given in Table 1171. Other operation modes follow the default schema.

Table 1171: Blocking schema for selection "Custom disabled"

Acting operation mode	Command	Load current	Block lowering voltage	Runback raising voltage	High circulating current	External Block	Extreme positions
Manual	Raise			X			X
	Lower						X

Table 1172: Blocking schema for selection "OC, UV, EXT"

Acting operation mode	Command	Load current	Block lowering voltage	Runback raising voltage	High circulating current	External Block	Extreme positions
Manual	Raise	X	X	X		X	X
	Lower	X	X			X	X

Table 1173: Blocking schema for selection "UV, EXT"

Acting operation mode	Command	Load current	Block lowering voltage	Runback raising voltage	High circulating current	External Block	Extreme positions
Manual	Raise		X	X		X	X
	Lower		X			X	X

Load current

The load current blocking is mainly used for preventing the tap changer from operating in an overcurrent situation. For example, if the current is not high enough to activate the protective IED of the substation, it can still be fatal for the diverter switch of the tap changer. This operation can be adjusted with the setting parameter *Load current limit*. The maximum of measurements from the secondary-side current phases is used for blocking. By default, both the automatic operation and the manual operation are blocked (Table 1169) when the set limit is exceeded.

The blocking status can be read from the monitored data BLKD_I_LOD.

Block lowering voltage

The block lowering voltage feature blocks both raising and lowering voltage commands if the measured voltage is too low to be corrected by operating the tap changer. Such a situation can occur due to a faulty measuring circuit, an earth fault or an overcurrent situation. By default, only the automatic (also automatic follower) operation is blocked when the undervoltage condition is met (Table 1169). This operation can be adjusted with the setting parameter *Block lower voltage*.

The blocking status can be read from the monitored data BLKD_U_UN.

However, there is no minimum limit for the undervoltage blocking. The blocking is allowed even if the measured voltage is not connected or it has temporarily a very low value. There is a minimum limit for the phase angle calculation based on the voltage phasor magnitude.

Runback raising voltage

The manual raising command is blocked if the overvoltage limit is exceeded (Table 1169). However, in the automatic operation mode, the overvoltage situation triggers the fast lowering feature. More information can be found in the Manual voltage regulation chapter. This operation can be adjusted with the setting parameter *Runback raise V*.

The blocking status can be read from the monitored data RNBK_U_OV.

High Circulating Current

The circulating current value is calculated in the operation modes Negative Reactance Principle (NRP) and Minimizing Circulating Current (MCC). Only the automatic operation in these modes is blocked when the high circulating current is measured (Table 1169). This operation can be adjusted with the setting parameter *Cir current limit*.

The blocking status can be read from the monitored data BLKD_I_CIR.

LTC_BLOCK – external block input

With the PCM600 tool configuration possibilities, a desired blocking condition can be built by connecting an outcome to this input. The blocking status can be read from the monitored data BLKD_LTCBLK. When activated, this input blocks only the automatic operation of the regulator by default (Table 1169). For the fully automatic modes, the signal activation resets the timer, and the monitored data BLKD_LTCBLK is not activated.

Extreme positions

This blocking function supervises the extreme positions of the tap changer. These extreme positions can be adjusted with the setting parameters *Raise block tap* and *Lower block tap*. When the tap changer reaches one of these two positions, the commands in the corresponding direction are blocked (Table 1169). Here it depends on the comparison between the *Raise block tap* and *Lower block tap* settings, which direction is blocked (Voltage control vs. tap changer moving direction section). This blocking affects both the automatic and manual operation modes.

However, as shown in Table 1169, no blocking indication is to be generated in the fully automatic modes. Here "Auto follower" is not a fully automatic mode. The unconnected position information does not cause the total block of OLATCC, only the extreme position blocking is not working.

The blocking status can be seen in the generated events.

Fast lowering control

OLATCC provides the fast lowering control in the automatic operation modes. When the set *Runback raise V* is exceeded, the regulator gives fast lowering control pulses until the voltage drops below the specified limit. This fast lowering control can be seen with the monitoring data TIMER_STS, where the value "Fast lower T on" indicates this functionality to be active.

To allow the fast lowering operation, *Runback raise V* has to be set always to a value higher than the control voltage (U_CTL) plus half of *Band width voltage*.

Typically, the blockings are reset when the corresponding limit with the hysteresis is undershoot or exceeded. Although blocking is reset after undershooting the above-mentioned limit, the fast lowering control operation continues until the measured voltage signal difference undershoots half the *Band width voltage* hysteresis limit (Figure 629). As a result, normal automatic mode operation is not possible before this happens.

Fast lowering control causes successive LOWER_OWN pulses to be activated. The time between consecutive pulse starts is the pulse length plus 1.5 seconds.

- There is no tap changer operating delay (otherwise six seconds) taken into account in this cycle (meaning that some command pulses are ineffective due to tap changer operation, as described in the Pulse control chapter)
- Timer mode set by *Delay characteristic* has no effect here (always the DT timer-type operation). Because the minimum pulse length (the *LTC pulse time* setting) is 0.5 seconds, the shortest interval between successive pulses can be two seconds.

In the automatic follower mode, the fast lowering is not triggered. In this way, the awkward dispersion of position values in different units can be avoided. The master always decides on the fast lowering on behalf of the follower units. Moreover, master and follower should measure an equal voltage level and have similar setting values for the overvoltage blocking limit.

10.6.14 Alarm indication

Tap Changer Monitoring

OLATCC supervises the operation of the tap changer and alarms if the alarm condition is detected. An alarm activation means that the ALARM output is activated and the alarm reason can be read from the monitored data ALARM_REAS. Alarms are in use by default but they can be set not to be in use by setting *Alarms enabled* to "False". Three different alarm conditions and their combinations can be detected by OLATCC.

Command error

OLATCC supervises the tap changer position information of the own transformer when a control pulse is given. If the correct position change (direction depends on the comparison of the settings *Raise block tap* and *Lower block tap*) is not seen by OLATCC in *Cmd error delay time* after the pulse start, the alarm is issued.

If the position information is not connected, no alarm is generated. The alarm is reset when the correct change in position value is detected after a given pulse or if a new command pulse is given.

The monitored data ALARM_REAS is set during an alarm. This means that if the alarm reason is active, ALARM_REAS has the value "Cmd error".

TCO signal fails

If the tap changer operating signal TCO stays active for more than 15 seconds after the output pulse deactivation, OLATCC concludes this as an abnormal condition and assumes that the tap changer is stuck. The alarm is reset when the TCO input signal deactivates. The monitored data ALARM_REAS is set during the alarm. This means that only if alarm reason is active, ALARM_REAS has the value "TCO error".

If the TCO input signal is not connected (indicated by bad quality), this type of alarm is not possible.

Regulator pumping

It is possible that faulty settings cause the regulator to give control pulses too frequently. For example, too low a setting for the *Band width voltage* (Figure 629) can result in a pumping condition where the regulator has problems to bring the regulated voltage to a desired level. To detect this, OLATCC has a setting *Max operations in 1h*, which defines the allowed number of lowering and raising commands during a one-hour sliding time window. The detection is active both in the manual and automatic operation modes. The alarm is reset after the counted number of the operations during the one-hour time window is less than the set value. The number of executed operations per last one hour can be read from the monitored data OP_TM_NUM_H. However, this parameter is updated only in three-minute intervals. Again, the monitored data ALARM_REAS is set during an alarm. This means that only if alarm reason is active, ALARM_REAS has the value "Pump error".

The operation of OLATCC is not blocked during an alarm situation, but all the alarms mentioned above cause the automatic operation to be delayed. In practice, this means that the set delay times T1 and T2 are doubled.

In addition to the alarm detections, OLATCC provides a nonvolatile operation counter parameter (monitored data OPR_CNT) for determining the service intervals of the tap changer. The counter gives the total number of raising and lowering commands given in the manual and automatic modes. All commands, even those that are omitted by the tap changer due to its operation sequence, are calculated in a cumulative counter. This data parameter can be reset via the clear menu parameter *OLATCC counter*.

10.6.15 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The IED supports alternative base value groups for the phase current or voltage-related settings, for example "*Phase Grp 1*", "*Phase Grp 2*" and "*Phase Grp 3*". One of the groups to be used with the *Base value Sel phase* setting must be selected.

10.6.16 Application

OLATCC is used to control the voltage on the load side of the power transformer. Based on the measured voltage and current, the function block determines whether the voltage needs to be increased or decreased. The voltage is regulated by the raising or lowering commands sent to the tap changer.

The basic principle for voltage regulation is that no regulation takes place as long as the voltage stays within the bandwidth setting. The measured voltage is always compared to the calculated control voltage U_p. Once the measured voltage deviates from the bandwidth, the delay time T1 starts. When the set delay time has elapsed, a raising or lowering control pulse is sent to the tap changer. Should the measured voltage still be outside the bandwidth after one tap change, the delay time T2 starts. T2 is normally shorter than T1.

Under certain circumstances, the automatic voltage regulator needs to be enhanced with additional functions such as Line Drop Compensation (LDC) and Reduce Set Voltage (RSV). Also, various parallel operation modes are available to fit applications where two or more power transformers are connected to the same busbar at the same time. The parallel operation modes of OLATCC are Master/Follower (M/F), Minimizing Circulating Current (MCC) and Negative Reactance Principle (NRP).

Example for operating OLATCC manually from LHMI

The tap position of the transformer can be manually raised or lowered by activating the `RAISE_LOCAL` and `LOWER_LOCAL` inputs. The activation can be done either by connecting the binary inputs, or the inputs can be operated also from the LHMI by using the function keys FNKEYMD1 and FNKEYMD2 or by using the I/O buttons with VSGGIO.

Figure 634 shows the configuration connection for operating OLATCC using the function keys FNKYMD1 and FNKEYMD2 from the LHMI.

Here, FNKEYMD1 is used for raising the tap changer position, whereas FNKEYMD2 is used for lowering the tap changer position. For the manual operation, it is required that the *Operation mode* setting of OLATCC is set to "Manual" and the type setting for the function keys 1 and 2 is set to "Control". Manual operation also requires that the IED is in the local mode.

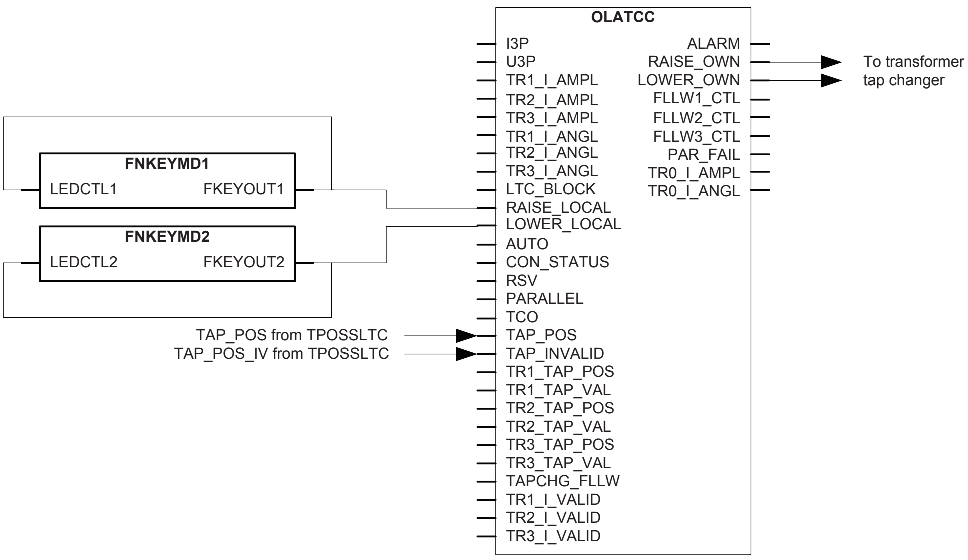


Figure 634: Configuration for manual raising and lowering of tap positions using function keys

Figure 635 shows the configuration connection for operating OLATCC by using the I/O buttons from LHMI with VSGGIO. This also requires that the **Select** button is configured in the graphical display editor and mapped to VSGGIO. The tap changer position is raised using the **I** button and lowered using the **O** button of the LHMI after selecting the configured **Select** button from the single-line diagram.

This requires that the VSGGIO settings are done properly.

Table 1174: VSGGIO setting example

Setting name	Value
Operation	On
CtlModel	Dir Norm
Mode	Pulse
tSelect	30.000
tPulse	1.000
PosUndefined	N/A
Position1	RAISE
Position2	LOWER
PosBadState	BAD_INPUT

The text written in settings *Position1* and *Position2* is the text displayed when the **I** and **O** buttons of LHMI are pressed on the SLD in the **Select** button. When **I** and **O** are pressed simultaneously, the text set with the *PosBadState* setting appears on the SLD in the **Select** button.

For the manual operation, the *Operation* mode setting must be set to "Manual" and the IED must be in the local mode.

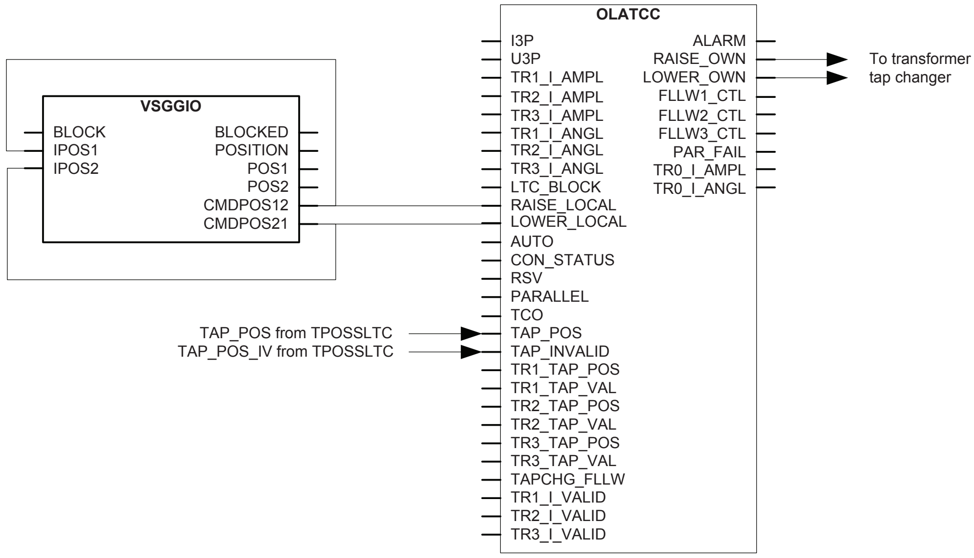


Figure 635: Configuration for manual raising and lowering of tap positions using the I/O buttons

If the tap changer position indicator function TPOSSLTC is used in the configuration, the `TAP_POS` and `TAP_INVALID` inputs of OLATCC should be connected.

Configuration example for the Manual and Auto single modes

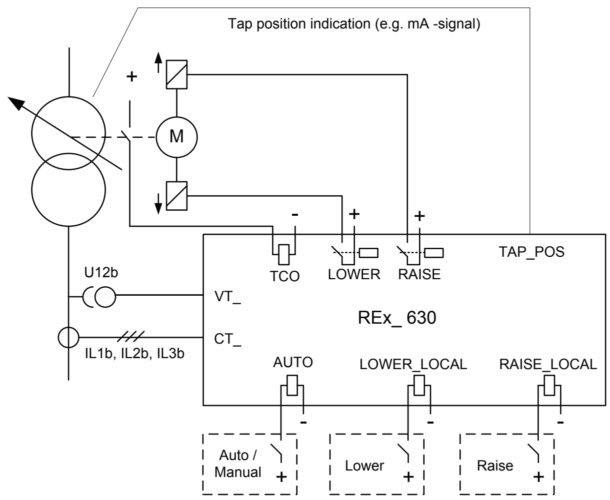


Figure 636: Basic connection diagram for the voltage regulator

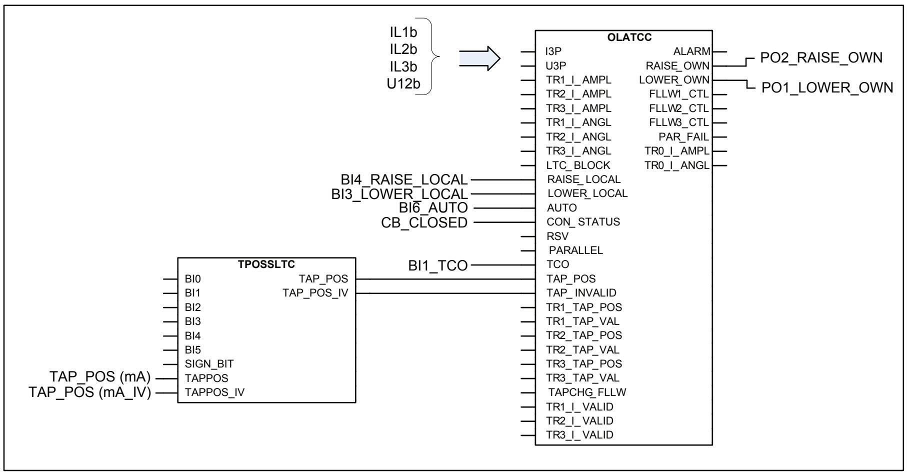


Figure 637: Configuration example for the Manual and Auto single modes

The configuration example uses an mA signal to indicate the current tap position of the local transformer. To take that position information to OLATCC, the measured mA value is connected to the `TAP_POS` input of the TPOSSLTC function. The tap position integer value is transferred from TPOSSLTC to OLATCC with a configuration connection.

Configuration example for the Auto parallel (Master/Follower) mode

The configuration example for Master/Follower describes how the tap position information is transferred from follower to master with the horizontal GOOSE communication. The status information from circuit breakers and an extra logic can be used to change the operation mode via inputs of the master and the follower (*Operation mode* = "Input control").

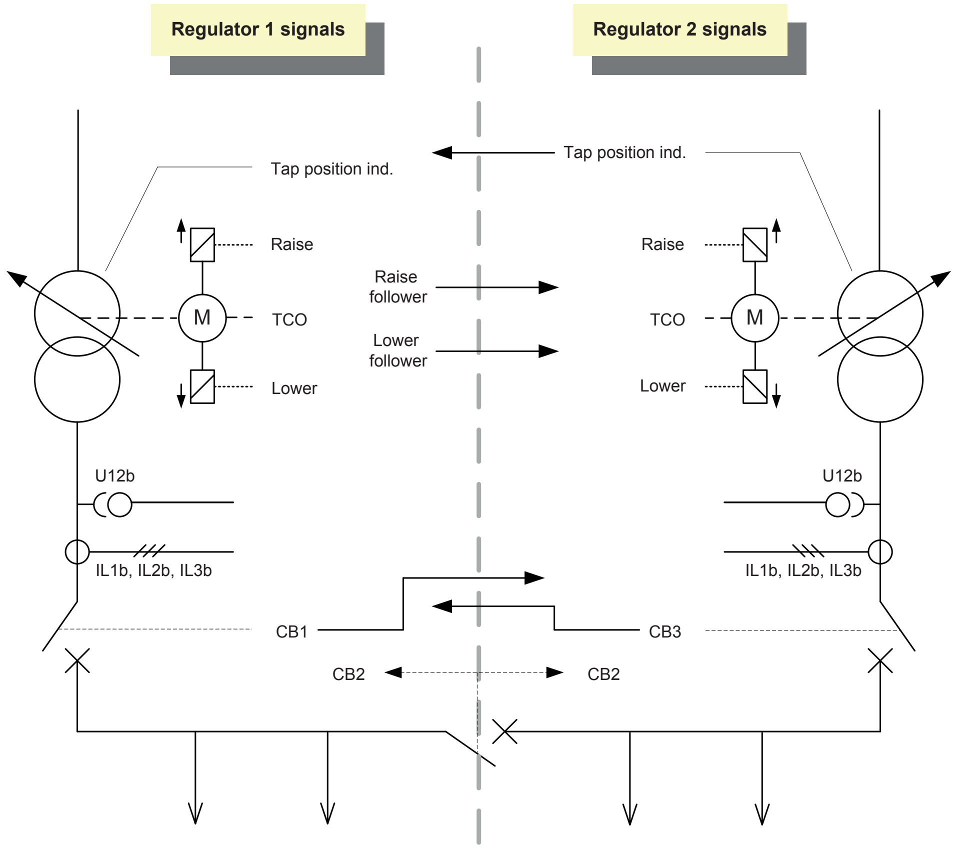


Figure 638: An example of the configuration for the Auto parallel (Master/ Follower) mode (the position of the follower known by the master)

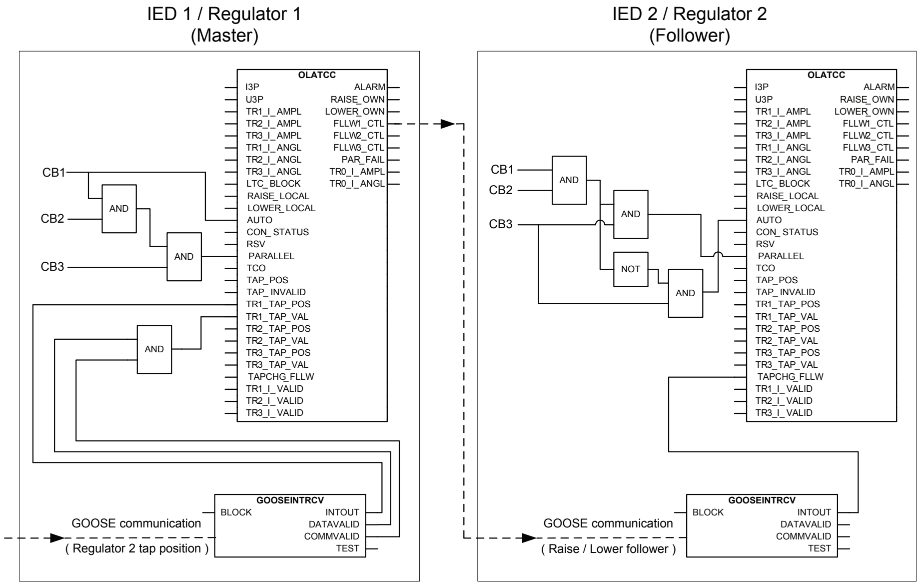


Figure 639: Simplified regulator 1&2 configurations of the Master/Follower example

Table 1175: The automatic selection of operation modes for regulators in the Master/Follower example

CB1	CB2	CB3	Regulator 1	Regulator 2
Open	Open	Open	Manual	Manual
Open	Open	Closed	Manual	Auto single
Open	Closed	Open	Manual	Manual
Open	Closed	Closed	Manual	Auto single
Closed	Open	Open	Auto single	Manual
Closed	Open	Closed	Auto single	Auto single
Closed	Closed	Open	Auto single	Manual
Closed	Closed	Closed	Auto parallel (Master) *Auto parallel mode* = "Auto master"	Auto parallel (Follower) *Auto parallel mode* = "Auto follower"

Configuration example for the Auto parallel (MCC) mode

The purpose of the Auto parallel (MCC) mode is to minimize the circulating current between the parallel transformers. The data exchange between the regulators can be done with the horizontal GOOSE communication.

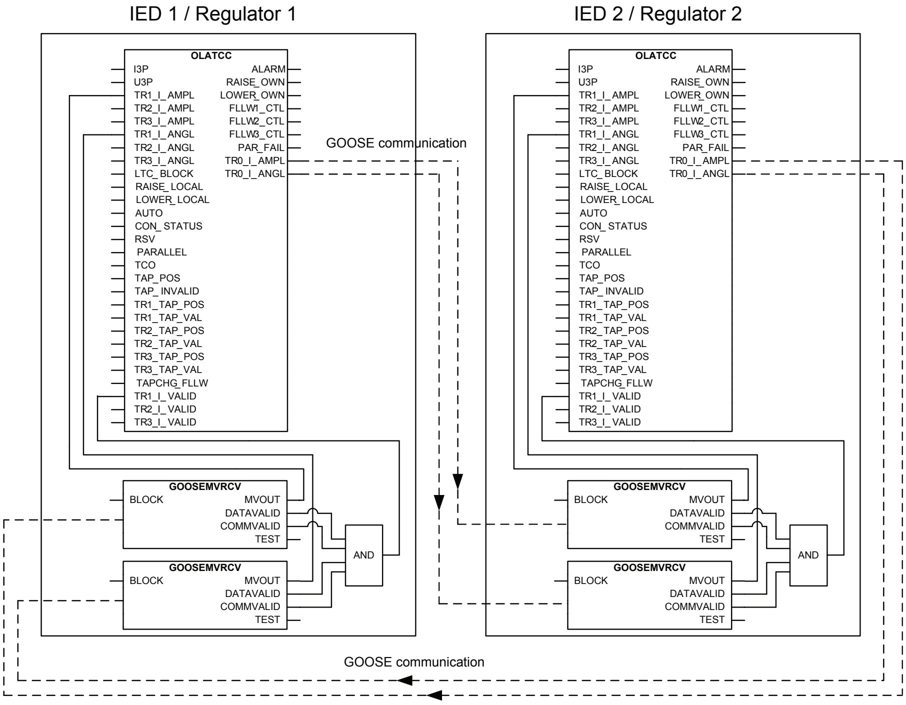


Figure 640: Two parallel transformers and horizontal connection via GOOSE to transfer current and phase angle information when MCC principle is used.

Configuration example for the Auto parallel (NRP) mode

The advantage of the Negative Reactance Principle (NRP) operation mode is that no wiring or communication is needed between the IEDs. The voltage regulators operate independently. However, for the cases where there is an occasional stepwise change in the phase angle of the load, the regulating error can be suppressed by an automatic setting group change or by changing the operation mode with the logic.

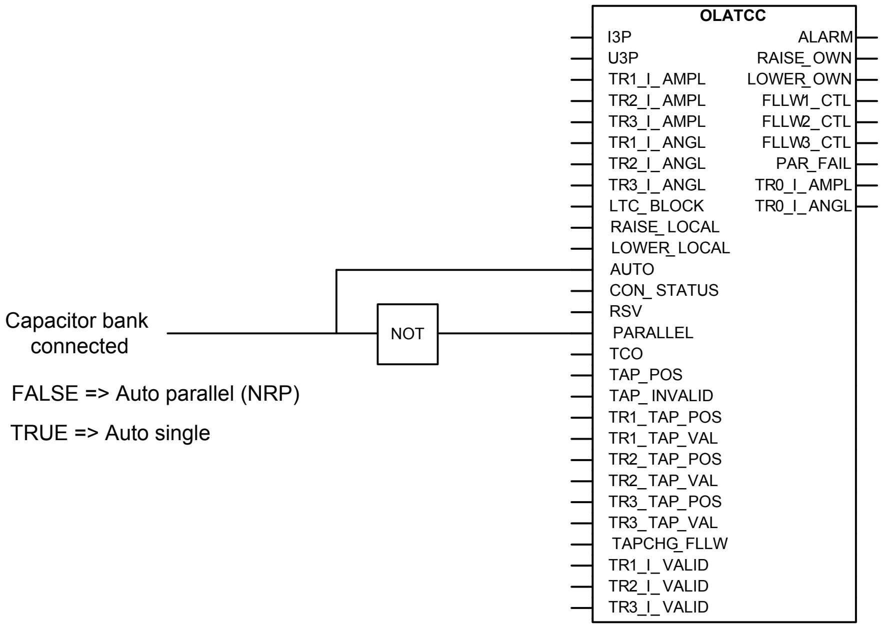


Figure 641: Changing the operation mode of OLATCC automatically when the capacitor bank is connected

Comparison summary between parallel operation modes

The parallel operation modes are needed because if the parallel regulators operated independently, at some point the transformers would become out of step with each other.

The circulating current would increase and the line drop compensation would thus increase for the transformer giving the highest voltage. Correspondingly, the increasing circulating current would cause the transformer giving the lowest voltage to decrease the voltage due to a decreased line drop compensation effect. In other words, the two transformers would run apart.

However, it is case-specific which parallel operation mode is the most suitable.

Table 1176: Different parallel operation modes

Parallel operation modes	Description
Master/Follower (follower positions not known by master)	Requires power transformers with identical ratings and step voltages - Extra wiring work: raising/lowering commands (input TAPCHG_FLLW connected from output FLLWx_CTL) from the master to the follower - Manual control needed in the beginning of operation - Blind control: follower positions after control cannot be supervised. It must be relied on that the followers are following the commands. + Parallel transformers are regulated as one unit + Supports an unlimited number of transformers in parallel
Master/Follower (follower positions known)	Requires power transformers with identical ratings and step voltages. - Extra wiring work: raising/lowering commands (the TAPCHG_FLLW input connected from the FLLWx_CTL output) from the master to the follower TAP_POS connections from the followers to the master - Supports not more than four transformers in parallel.
Negative reactance principle	The actual phase angle setting results in a regulating error. When the line drop compensation is used, the setting should be changed when the number of transformers in parallel operation is changed. + The step voltages and short circuit impedances of the transformers do not need to be identical. + No communication or wiring between regulators is needed, meaning that the principle can be applied even when the parallel transformers are located at different substations. + Supports an unlimited number of transformers in parallel
Minimizing circulating current	- Requires extra configuration efforts since this principle utilizes a horizontal communication between the regulators (the inputs TRx_I connected from parallel transformer controller's outputs TR0_I. + The step voltages and short circuit impedances of the transformers do not need to be identical. + The phase angle of the load current may vary without any impact on the regulation accuracy. + Automatic adjustment for the number of transformers (for an accurate calculation of line drop compensation term)

10.6.17 Signals

Table 1177: OLATCC Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	-	Three phase group signal for current inputs
U3P	GROUP SIGNAL	-	Three phase group signal for voltage inputs
TR1_I_AMPL	REAL	0.0	Received current magnitude from transformer 1
TR2_I_AMPL	REAL	0.0	Received current magnitude from transformer 2
TR3_I_AMPL	REAL	0.0	Received current magnitude from transformer 3
TR1_I_ANGL	REAL	0.0	Received current phase from transformer 1
TR2_I_ANGL	REAL	0.0	Received current phase from transformer 2
TR3_I_ANGL	REAL	0.0	Received current phase from transformer 3
LTC_BLOCK	BOOLEAN	0	External signal for blocking of automatic operation
RAISE_LOCAL	BOOLEAN	0	Raise command input from configuration
LOWER_LOCAL	BOOLEAN	0	Lower command input from configuration
AUTO	BOOLEAN	0	Selection of auto or manual operation in parallel mode
CON_STATUS	BOOLEAN	0	Network connection status of the (own) transformer
RSV	BOOLEAN	0	Reduce set voltage active
PARALLEL	BOOLEAN	0	Parallel (TRUE) or single (FALSE) operation
TCO	BOOLEAN	0	Tap changer operating input
TAP_POS	INTEGER	0	Integer representing tap changer position of own transformer
TAP_INVALID	BOOLEAN	0	Validity of tap changer position of own transformer
TR1_TAP_POS	INTEGER	0	Integer representing tap changer position for transformer 1
TR1_TAP_VAL	BOOLEAN	0	Validity of tap changer position of transformer 1
TR2_TAP_POS	INTEGER	0	Integer representing tap changer position for transformer 2
TR2_TAP_VAL	BOOLEAN	0	Validity of tap changer position of transformer 2
TR3_TAP_POS	INTEGER	0	Integer representing tap changer position for transformer 3
TR3_TAP_VAL	BOOLEAN	0	Validity of tap changer position of transformer 3
TAPCHG_FLLW	INTEGER	0	Raise/Lower command input from Master to control follower
TR1_I_VALID	BOOLEAN	0	Validity of received current from transformer 1
TR2_I_VALID	BOOLEAN	0	Validity of received current from transformer 2
TR3_I_VALID	BOOLEAN	0	Validity of received current from transformer 3

Table 1178: OLATCC Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm status
RAISE_OWN	BOOLEAN	Raise command for own transformer
LOWER_OWN	BOOLEAN	Lower command for own transformer
FLLW1_CTL	INTEGER	Lower/Raise for follower 1 in the Master/Follower mode
FLLW2_CTL	INTEGER	Lower/Raise for follower 2 in the Master/Follower mode
FLLW3_CTL	INTEGER	Lower/Raise for follower 3 in the Master/Follower mode
PAR_FAIL	BOOLEAN	Parallel failure detected
BLKD_I_LOD	BOOLEAN	Indication of load current blocking
BLKD_U_UN	BOOLEAN	Indication of under voltage blocking
RNBK_U_OV	BOOLEAN	Indication of runback raise voltage
BLKD_I_CIR	BOOLEAN	Indication of high circulating current blocking
BLKD_LTCBLK	BOOLEAN	Indication of external blocking
PARALLEL	BOOLEAN	Parallel mode or not
AUTO	BOOLEAN	Acting automatic/manual
TR0_I_AMPL	REAL	Current magnitude from own transformer
TR0_I_ANGL	REAL	Current phase angle from own transformer

10.6.18 Settings

Table 1179: OLATCC Group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Auto parallel mode	Master Follower NRP MCC	-	-	Master	Parallel mode selection
Band center voltage	0.000 - 2.000	pu	0.001	1.000	The band center voltage, Us
Line drop V Ris	0.0 - 25.0	%	0.1	0.0	Resistive line-drop compensation factor
Line drop V React	0.0 - 25.0	%	0.1	0.0	Reactive line-drop compensation factor
Band reduction	0.0 - 9.0	%	0.1	0.0	Step size for Reduce Set Voltage (RSV)
Stability factor	0.0 - 70.0	%	0.1	0.0	Stability factor in parallel operation
Load phase angle	-89 - 89	Deg	1	0	Load phase-shift, used with the Negative Reactance Principle
Control delay time 1	1.0 - 300.0	s	0.1	60.0	Control delay time 1
Control delay time 2	1.0 - 300.0	s	0.1	30.0	Control delay time 2

Table 1180: OLATCC Non group settings (basic)

Name	Values (Range)	Unit	Step	Default	Description
Operation	Off On	-	-	On	Operation Mode Off / On
Operation mode	Manual Auto single Auto parallel Input control	-	-	Manual	The operation mode
Custom Man blocking	Custom disabled OC UV OC, UV EXT OC, EXT UV, EXT OC, UV, EXT	-	-	OC	Customized manual blocking
Parallel trafos	0 - 10	-	1	0	Num of parallel transformers in addition to own transformer
Delay characteristic	Inverse time Definite time	-	-	Definite time	Selection of delay characteristic
Band width voltage	1.20 - 18.00	%	0.01	3.00	Band width voltage. Twice the allowed deviation
Load current limit	0.10 - 5.00	pu	0.01	2.00	Over current blocking limit
Block lower voltage	0.10 - 1.20	pu	0.01	0.70	Voltage limit, further voltage lowering commands are blocked
Runback raise V	0.80 - 1.60	pu	0.01	1.25	Voltage limit, where fast lower commands takes place
Cir current limit	0.10 - 5.00	pu	0.01	0.15	Blocking limit for high circulating current
LDC limit	0.00 - 2.00	pu	0.01	0.10	Maximum limit for line drop compensation term
Lower block tap	-36 - 36	-	1	0	Tap pos limit giving lowest voltage on the regulated side
Raise block tap	-36 - 36	-	1	17	Tap pos limit giving highest voltage on the regulated side
LTC pulse time	0.5 - 10.0	s	0.1	1.5	Output pulse duration, common for raise and lower pulses
LDC enable	FALSE TRUE	-	-	TRUE	Selection for line drop compensation

Table 1181: OLATCC Non group settings (advanced)

Name	Values (Range)	Unit	Step	Default	Description
Base value Sel phase	Phase Grp 1 Phase Grp 2 Phase Grp 3	-	-	Phase Grp 1	Base value selector, phase / phase-to-phase
Max operations in 1h	0 - 10000	-	1	100	Allowed number of controls per one hour sliding window
Cmd error delay time	10 - 50	s	1	20	Time delay before command error will be activated

Table continues on next page

Name	Values (Range)	Unit	Step	Default	Description
Follower delay time	6 - 20	s	1	6	Time delay between successive follower commands by a master
Alarms enabled	FALSE TRUE	-	-	TRUE	Alarm selection
Rv Pwr flow allowed	FALSE TRUE	-	-	FALSE	Reverse power flow allowed

10.6.19 Measured values

Table 1182: OLATCC Measured values

Name	Type	Default	Description
I_AMPL_A	REAL	0.0	Phase A current magnitude on the regulated side
I_AMPL_B	REAL	0.0	Phase B current magnitude on the regulated side
I_AMPL_C	REAL	0.0	Phase C current magnitude on the regulated side
I_ANGL_A	REAL	0.0	Phase A current phase angle on the regulated side
I_ANGL_B	REAL	0.0	Phase B current phase angle on the regulated side
I_ANGL_C	REAL	0.0	Phase C current phase angle on the regulated side
TR1_I_AMPL	REAL	0.0	Received current magnitude from transformer 1
TR2_I_AMPL	REAL	0.0	Received current magnitude from transformer 2
TR3_I_AMPL	REAL	0.0	Received current magnitude from transformer 3
TR1_I_ANGL	REAL	0.0	Received current phase from transformer 1
TR2_I_ANGL	REAL	0.0	Received current phase from transformer 2
TR3_I_ANGL	REAL	0.0	Received current phase from transformer 3
U_AMPL_AB	REAL	0.0	Magnitude of phase-to-phase voltage AB on the regulated side
U_ANGL_AB	REAL	0.0	Angle of phase-to-phase voltage AB on the regulated side
LTC_BLOCK	BOOLEAN	0	External signal for blocking of automatic operation
RAISE_LOCAL	BOOLEAN	0	Raise command input from configuration
LOWER_LOCAL	BOOLEAN	0	Lower command input from configuration
AUTO	BOOLEAN	0	Selection of auto or manual operation in parallel mode
CON_STATUS	BOOLEAN	0	Network connection status of the (own) transformer
RSV	BOOLEAN	0	Reduce set voltage active
PARALLEL	BOOLEAN	0	Parallel (TRUE) or single (FALSE) operation
TCO	BOOLEAN	0	Tap changer operating input
TAP_POS	INTEGER	0	Integer representing tap changer position of own transformer
Table continues on next page			

Name	Type	Default	Description
TAP_INVALID	BOOLEAN	0	Validity of tap changer position of own transformer
TR1_TAP_POS	INTEGER	0	Integer representing tap changer position for transformer 1
TR1_TAP_VAL	BOOLEAN	0	Validity of tap changer position of transformer 1
TR2_TAP_POS	INTEGER	0	Integer representing tap changer position for transformer 2
TR2_TAP_VAL	BOOLEAN	0	Validity of tap changer position of transformer 2
TR3_TAP_POS	INTEGER	0	Integer representing tap changer position for transformer 3
TR3_TAP_VAL	BOOLEAN	0	Validity of tap changer position of transformer 3
TAPCHG_FLLW	INTEGER	0	Raise/Lower command input from Master to control follower
TR1_I_VALID	BOOLEAN	0	Validity of received current from transformer 1
TR2_I_VALID	BOOLEAN	0	Validity of received current from transformer 2
TR3_I_VALID	BOOLEAN	0	Validity of received current from transformer 3

10.6.20 Monitored data

Table 1183: OLATCC Monitored data

Name	Type	Values (Range)	Unit	Description
ALARM	BOOLEAN	0=FALSE 1=TRUE	-	Alarm status
RAISE_OWN	BOOLEAN	0=FALSE 1=TRUE	-	Raise command for own transformer
LOWER_OWN	BOOLEAN	0=FALSE 1=TRUE	-	Lower command for own transformer
FLLW1_CTL	INTEGER	1=Lower 2=Raise 0=Stop	-	Lower/Raise for follower 1 in the Master/Follower mode
FLLW2_CTL	INTEGER	1=Lower 2=Raise 0=Stop	-	Lower/Raise for follower 2 in the Master/Follower mode
FLLW3_CTL	INTEGER	1=Lower 2=Raise 0=Stop	-	Lower/Raise for follower 3 in the Master/Follower mode
PAR_FAIL	BOOLEAN	0=FALSE 1=TRUE	-	Parallel failure detected
TIMER_STS	INTEGER	0=Timer off 1=Lower timer1 on 2=Raise timer1 on 3=Lower timer2 on 4=Raise timer2 on 5=Fast lower T on	-	Timer T1, T2 or fast lower timer active

Table continues on next page

Name	Type	Values (Range)	Unit	Description
OPR_MODE_STS	INTEGER	0=Not in use 1=Manual 2=Auto single 3=Auto master 4=Auto follower 5=MCC 6=NRP	-	The acting operation mode of the function block
BLK_STATUS	INTEGER	-	-	Bit-coded output showing the blocking status for the next operation
BLKD_I_LOD	BOOLEAN	0=FALSE 1=TRUE	-	Indication of load current blocking
BLKD_U_UN	BOOLEAN	0=FALSE 1=TRUE	-	Indication of under voltage blocking
RNBK_U_OV	BOOLEAN	0=FALSE 1=TRUE	-	Indication of runback raise voltage
BLKD_I_CIR	BOOLEAN	0=FALSE 1=TRUE	-	Indication of high circulating current blocking
BLKD_LTCBLK	BOOLEAN	0=FALSE 1=TRUE	-	Indication of external blocking
PARALLEL	BOOLEAN	0=FALSE 1=TRUE	-	Parallel mode or not
AUTO	BOOLEAN	0=FALSE 1=TRUE	-	Acting automatic/manual
ALARM_REAS	INTEGER	0=No alarm 1=Cmd error 2=TCO error 3=Cmd + TCO err 4=Pump error 5=Pump + cmd err 6=Pump + TCO err 7=Pmp+TCO +cmd err	-	Status and reason for alarm
FAIL_FLLW	INTEGER	0=No failed fllws 1=Follower 1 2=Follower 2 4=Follower 3 3=Followers 1+2 5=Followers 1+3 6=Followers 2+3 7=Followers 1+2+3	-	Failed followers

Table continues on next page

Name	Type	Values (Range)	Unit	Description
PAR_UNIT_MCC	INTEGER	0=No parall units 1=Trafo 1 2=Trafo 2 3=Trafos 1 and 2 4=Trafo 3 5=Trafos 1 and 3 6=Trafos 2 and 3 7=Trafos 1+2+3	-	Parallel units included in MCC calculation
OPR_CNT	INTEGER	-	-	Total number of commands given, manual and automatic
OP_TM_NUM_H	INTEGER	-	-	Number of controls for own tap changer during last hour
TR0_I_AMPL	REAL	-	A	Current magnitude from own transformer
TR0_I_ANGL	REAL	-	deg	Current phase angle from own transformer
U_MEAS	REAL	-	kV	Phase-to-phase voltage , average filtered
ANGL_UA_IA	REAL	-	deg	Measured angle value between phase A voltage and current
U_CTL	REAL	-	kV	Control voltage, Up, target voltage level
UD_CTL	REAL	-	kV	Voltage difference between measured and control Voltage
I_CIR	REAL	-	A	Calculated circulating current - calculated in operation modes NRP and MCC
LDC	REAL	-	kV	Calculated line drop compensation

10.6.21 Technical data

Table 1184: OLATCC Technical data

Characteristic	Value
Operation accuracy 1)	At the frequency $f = f_n$
	Differential voltage Ud: ±1.0% of the measured value or $\pm 0.004 \times U_n$ (in measured voltages $<2.0 \times U_n$)
	Operation value: ±1.0% of the U_d or $\pm 0.004 \times U_n$ for $U_s = 1.0 \times U_n$
Operate time accuracy in definite time mode 1)	±1.0% of the set value or 0.11 s
Table continues on next page	

Characteristic	Value
Operate time accuracy in inverse time mode [1)]	±15.0% of the set value or 0.15 s (at theoretical B in range of 1.1…5.0) Also note fixed minimum operate time (IDMT) 1 s
Reset ratio for control operation	Typically 0.80 (1.20)
Reset ratio for analog based blockings (except run back raise voltage blocking)	Typically 0.96 (1.04)

1) Default setting values used

Section 11 General function block features

11.1 Definite time characteristics

11.1.1 Definite time operation

The DT mode is enabled when the *Operating curve type* setting is selected either as "ANSI Def. Time" or "IEC Def. Time". In the DT mode, the OPERATE output of the function is activated when the time calculation exceeds the set *Operate delay time*.

The user can determine the reset in the DT mode with the *Reset delay time* setting, which provides the delayed reset property when needed.

The *Type of reset curve* setting has no effect on the reset method when the DT mode is selected, but the reset is determined solely with the *Reset delay time* setting.

The purpose of the delayed reset is to enable fast clearance of intermittent faults, for example self-sealing insulation faults, and severe faults which may produce high asymmetrical fault currents that partially saturate the current transformers. It is typical for an intermittent fault that the fault current contains so called drop-off periods, during which the fault current falls below the set start current, including hysteresis. Without the delayed reset function, the operate timer would reset when the current drops off. In the same way, an apparent drop-off period of the secondary current of the saturated current transformer can also reset the operate timer.

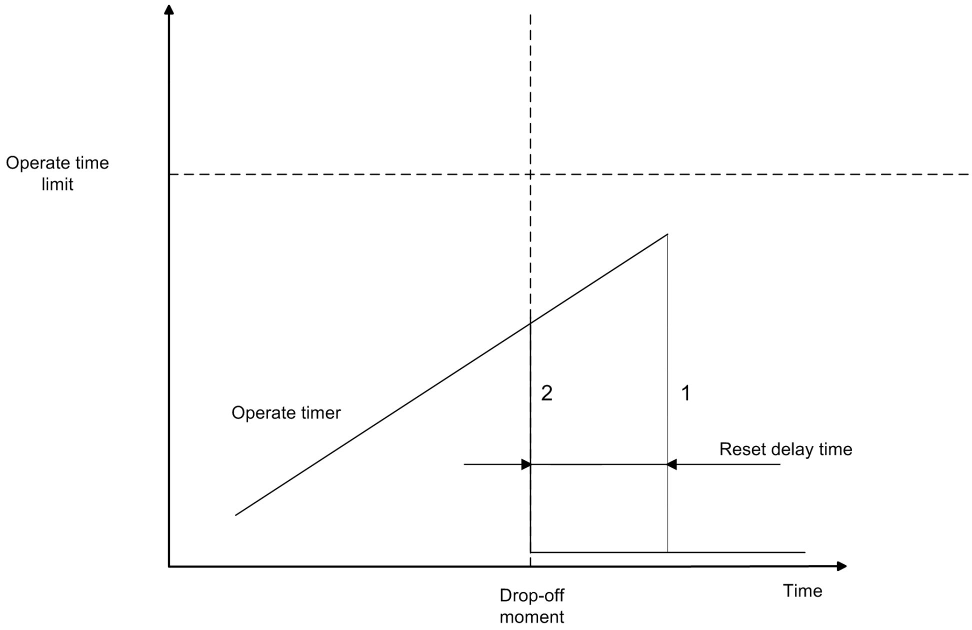


Figure 642: Operation of the counter in drop-off

In case 1, the reset is delayed with the *Reset delay time* setting and in case 2, the counter is reset immediately, because the *Reset delay time* setting is set to zero.

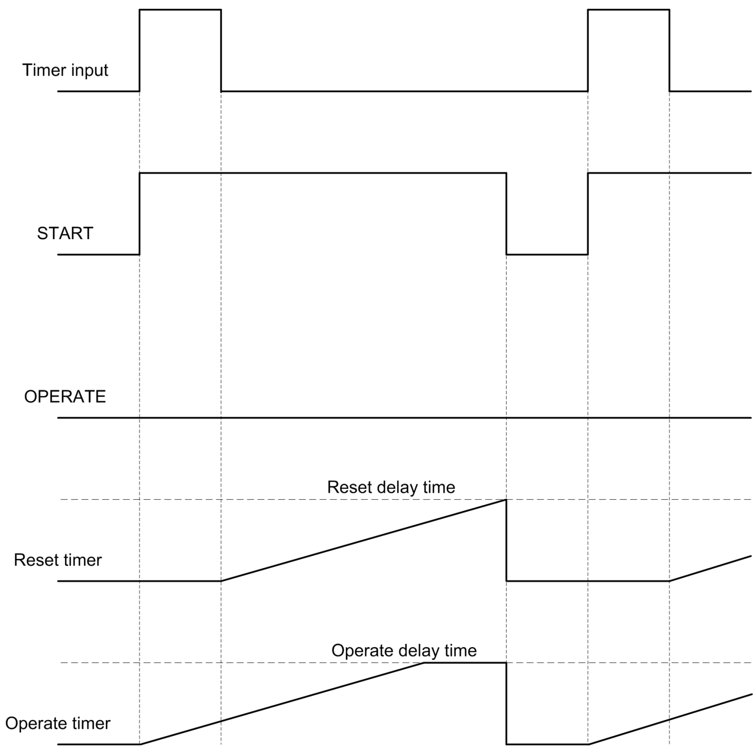


Figure 643: Drop-off period is longer than the set Reset delay time

When the drop-off period is longer than the set *Reset delay time*, as described in Figure 643, the input signal for the definite timer (here: timer input) is active, provided that the current is above the set *Start value*. The input signal is inactive when the current is below the set *Start value* and the set hysteresis region. The timer input rises when a fault current is detected. The definite timer activates the `START` output and the operate timer starts elapsing. The reset (drop-off) timer starts when the timer input falls, that is, the fault disappears. When the reset (drop-off) timer elapses, the operate timer is reset. Since this happens before another start occurs, the `OPERATE` output is not activated.

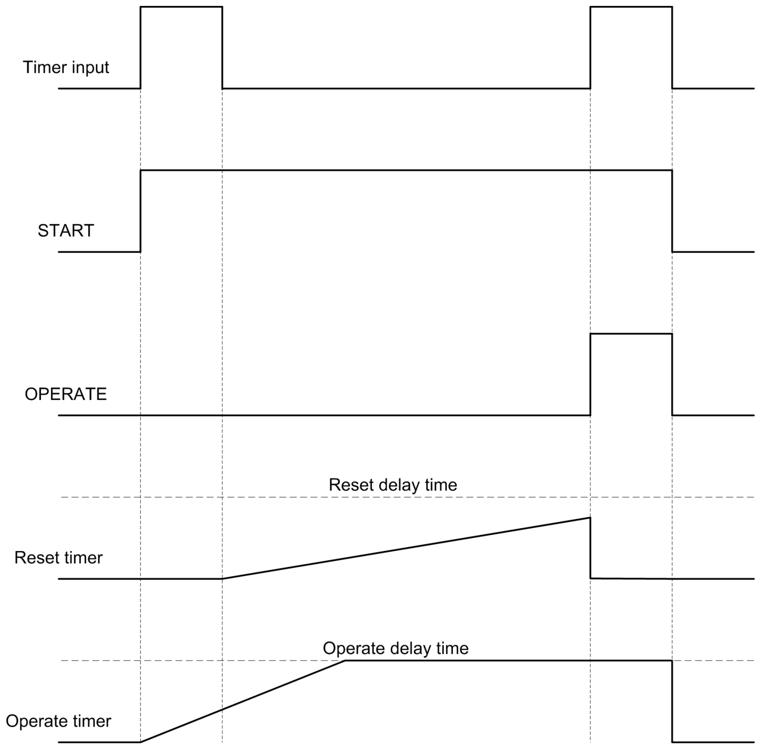


Figure 644: Drop-off period is shorter than the set Reset delay time

When the drop-off period is shorter than the set *Reset delay time*, as described in Figure 644, the input signal for the definite timer (here: timer input) is active, provided that the current is above the set *Start value*. The input signal is inactive when the current is below the set *Start value* and the set hysteresis region. The timer input rises when a fault current is detected. The definite timer activates the `START` output and the operate timer starts elapsing. The Reset (drop-off) timer starts when the timer input falls, that is, the fault disappears. Another fault situation occurs before the reset (drop-off) timer has elapsed. This causes the activation of the `OPERATE` output, since the operate timer already has elapsed.

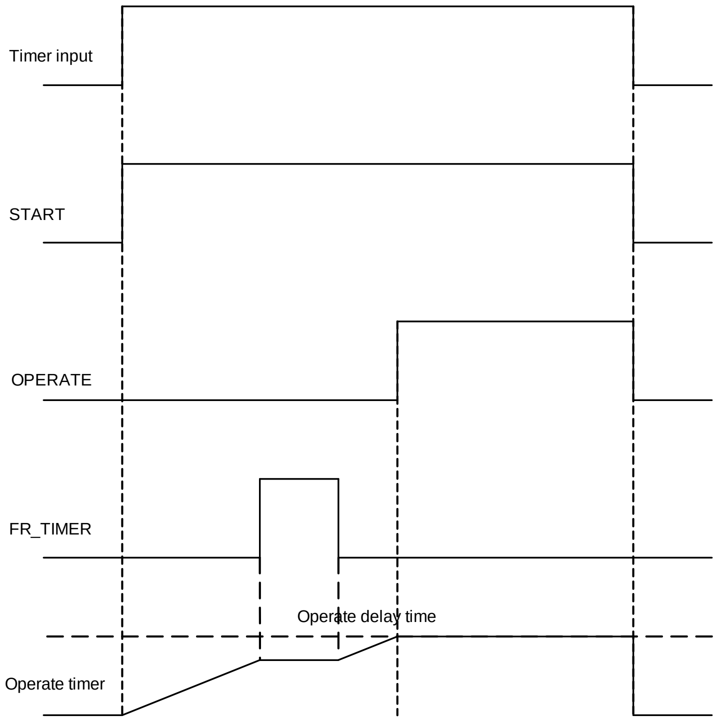


Figure 645: Operating effect of the `FR_TIMER` *input*

If the FR_TIMER input is activated when the operate timer is running, as described in Figure 645, the timer is frozen during the timer FR_TIMER remains active. If the timer input is not active longer than specified by the *Reset delay time* setting, the operate timer is reset in the way described in Figure 643, regardless of the FR_TIMER input.

If the BLOCK input is activated when the operate timer is running, as described in Figure 646, the operate timer and the reset timer reset. It also resets the START and OPERATE outputs.

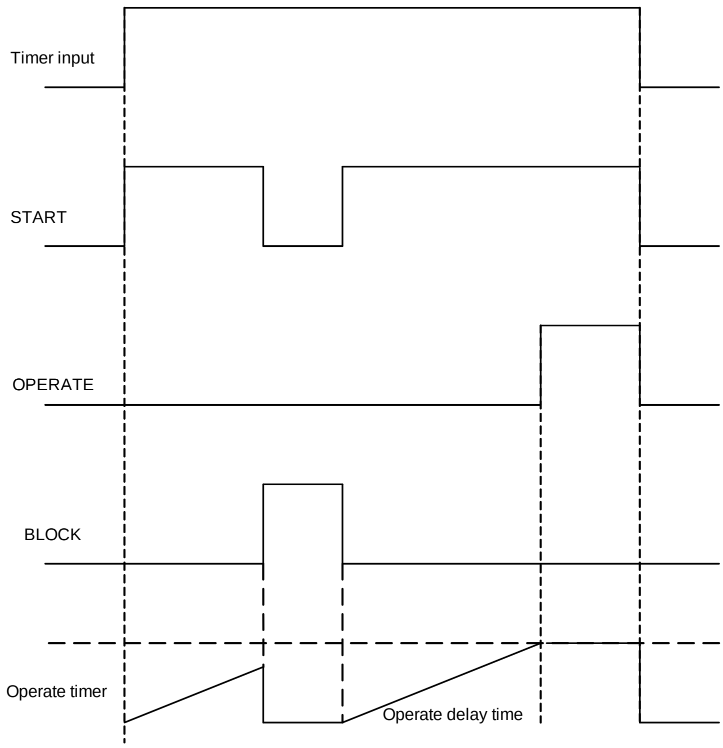


Figure 646: Operating effect of the `BLOCK` *input*

`BLK_ST` and `BLK_OPR` can be used to individually block the `START` and `OPERATE` signal respectively.

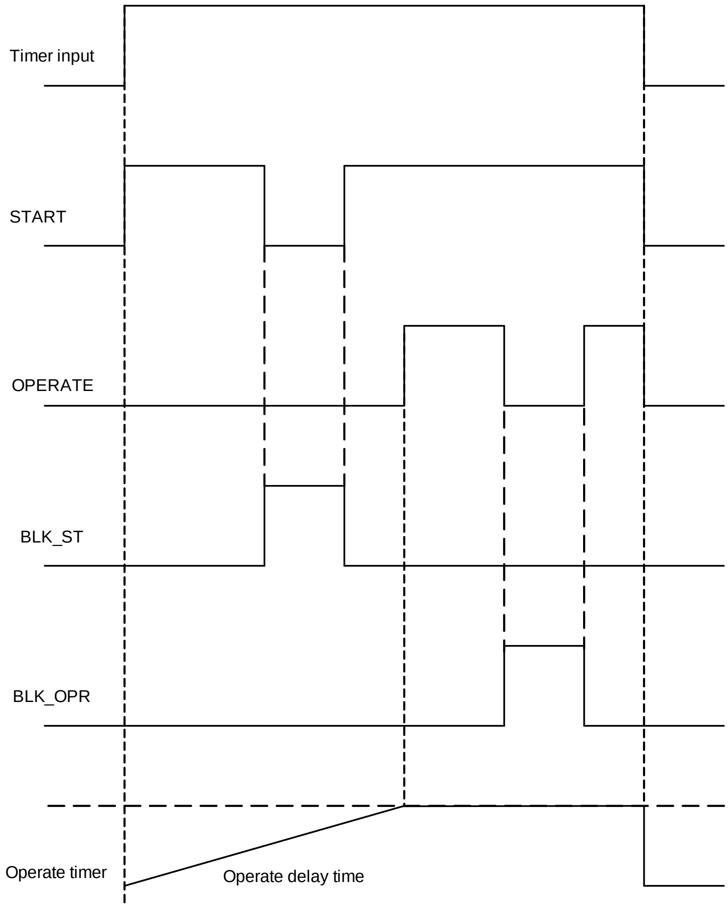


Figure 647: Operating effect of the `BLK_ST` *and* `BLK_OPR` *input*

Activation of `BLK_ST` or `BLK_OPR` does not reset the timer.

11.2 Current based inverse definite minimum time (IDMT) characteristics

11.2.1 IDMT curves for overcurrent protection

In inverse-time modes, the operation time depends on the momentary value of the current: the higher the current, the faster the operation time. The operation time calculation or integration starts immediately when the current exceeds the set *Start value* and the `START` output is activated.

The `OPERATE` output of the component is activated when the cumulative sum of the integrator calculating the overcurrent situation exceeds the value set by the inverse-time mode. The set value depends on the selected curve type and the setting values used. The curve scaling is determined with the *Time multiplier* setting.

The *Minimum operate time* setting defines the minimum operate time for the IDMT mode, that is, it is possible to limit the IDMT based operate time for not becoming too short.

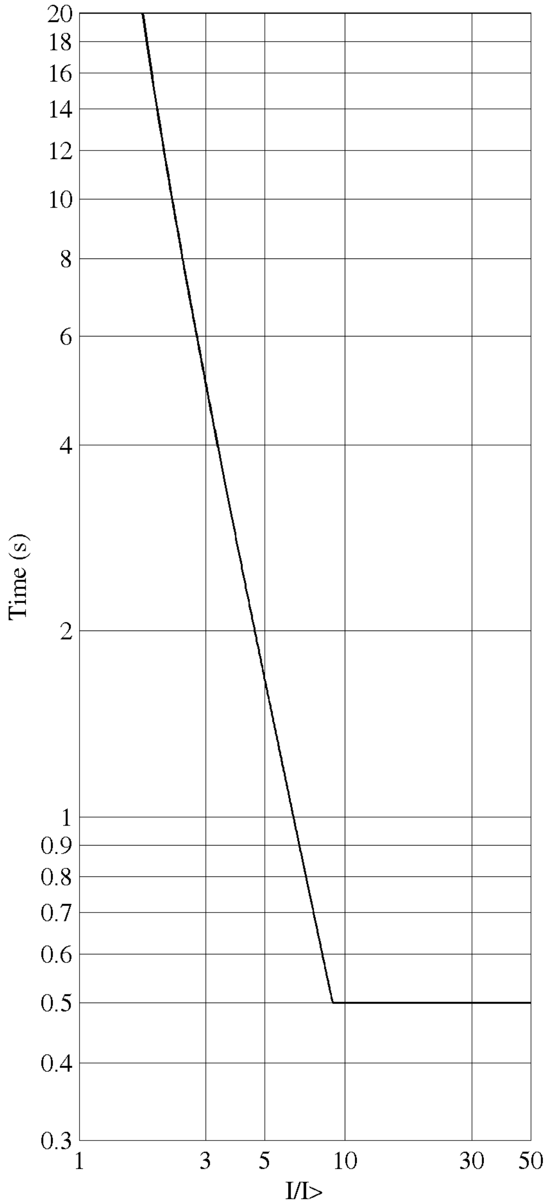


Figure 648: Operate time curves based on IDMT characteristic with the value of the Minimum operate time setting = 0.5 second

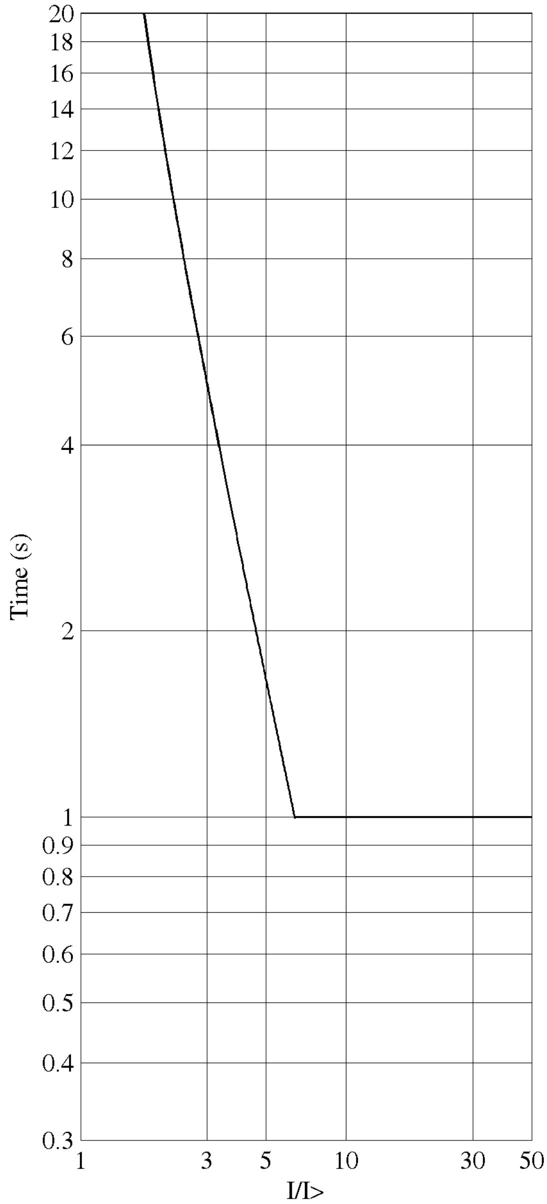


Figure 649: Operate time curves based on IDMT characteristic with the value of the Minimum operate time setting = 1 second

11.2.1.1 Standard inverse-time characteristics

For inverse-time operation, both IEC and ANSI/IEEE standardized inverse-time characteristics are supported.

The operate times for the ANSI and IEC IDMT curves are defined with the coefficients A, B and C.

The values of the coefficients can be calculated according to the formula:

$$t[s] = \left(\frac{A}{\left(\frac{I}{I>} \right)^{C} - 1} + B \right) \cdot k$$

(Equation 190)

t[s] Operate time in seconds

I measured current

I> set *Start value*

k set *Time multiplier*

Table 1185: Curve parameters for ANSI and IEC IDMT curves

Curve name	A	B	C
(1) ANSI Extremely Inverse	28.2	0.1217	2.0
(2) ANSI Very Inverse	19.61	0.491	2.0
(3) ANSI Normal Inverse	0.0086	0.0185	0.02
(4) ANSI Moderately Inverse	0.0515	0.1140	0.02
(6) Long Time Extremely Inverse	64.07	0.250	2.0
(7) Long Time Very Inverse	28.55	0.712	2.0
(8) Long Time Inverse	0.086	0.185	0.02
(9) IEC Normal Inverse	0.14	0.0	0.02
(10) IEC Very Inverse	13.5	0.0	1.0
(11) IEC Inverse	0.14	0.0	0.02
(12) IEC Extremely Inverse	80.0	0.0	2.0
(13) IEC Short Time Inverse	0.05	0.0	0.04
(14) IEC Long Time Inverse	120	0.0	1.0

The maximum guaranteed measured current is 50 x In for the current protection. When the set *Start value* exceeds 1.00 x In, the turn point where the theoretical IDMT characteristics are leveling out to the definite time can be calculated with the formula:

$$Turn\ point = \frac{50 \times In}{Start\ value}$$

(Equation 191)

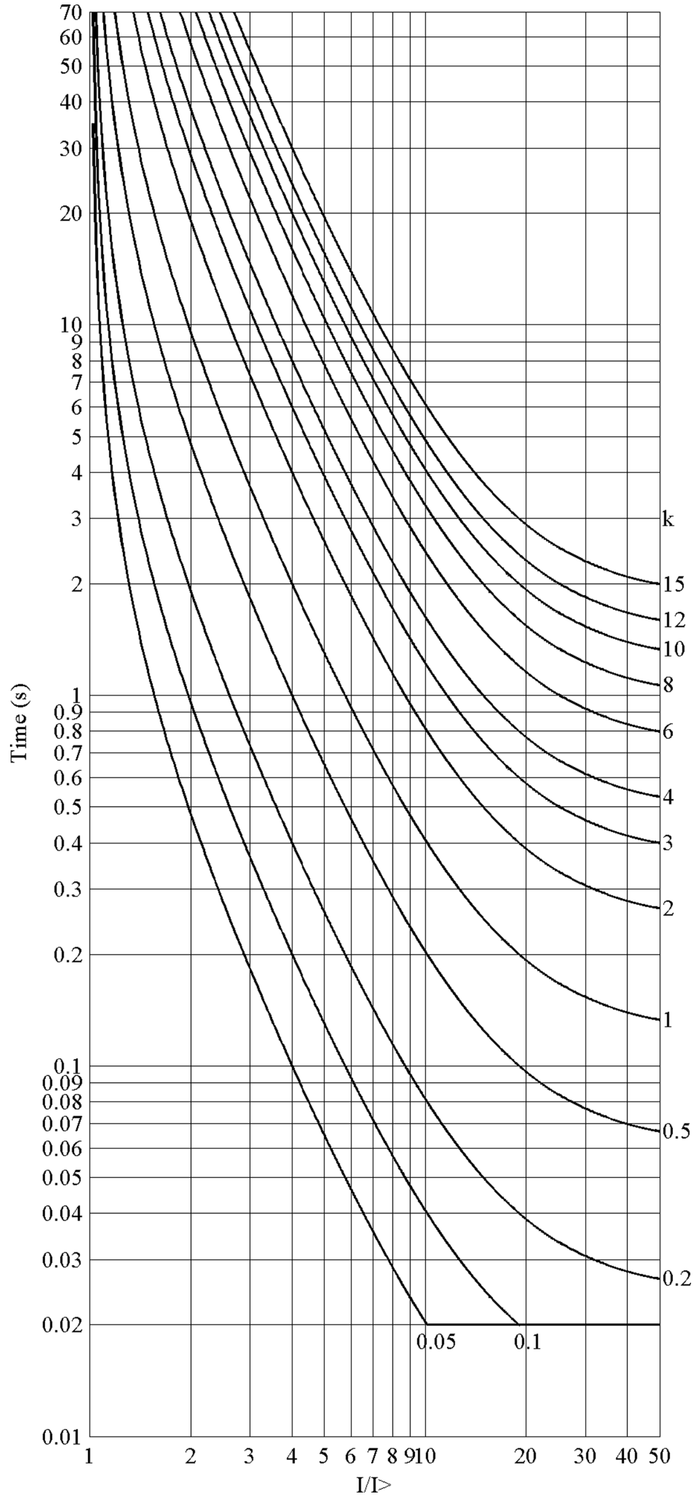


Figure 650: ANSI extremely inverse-time characteristics

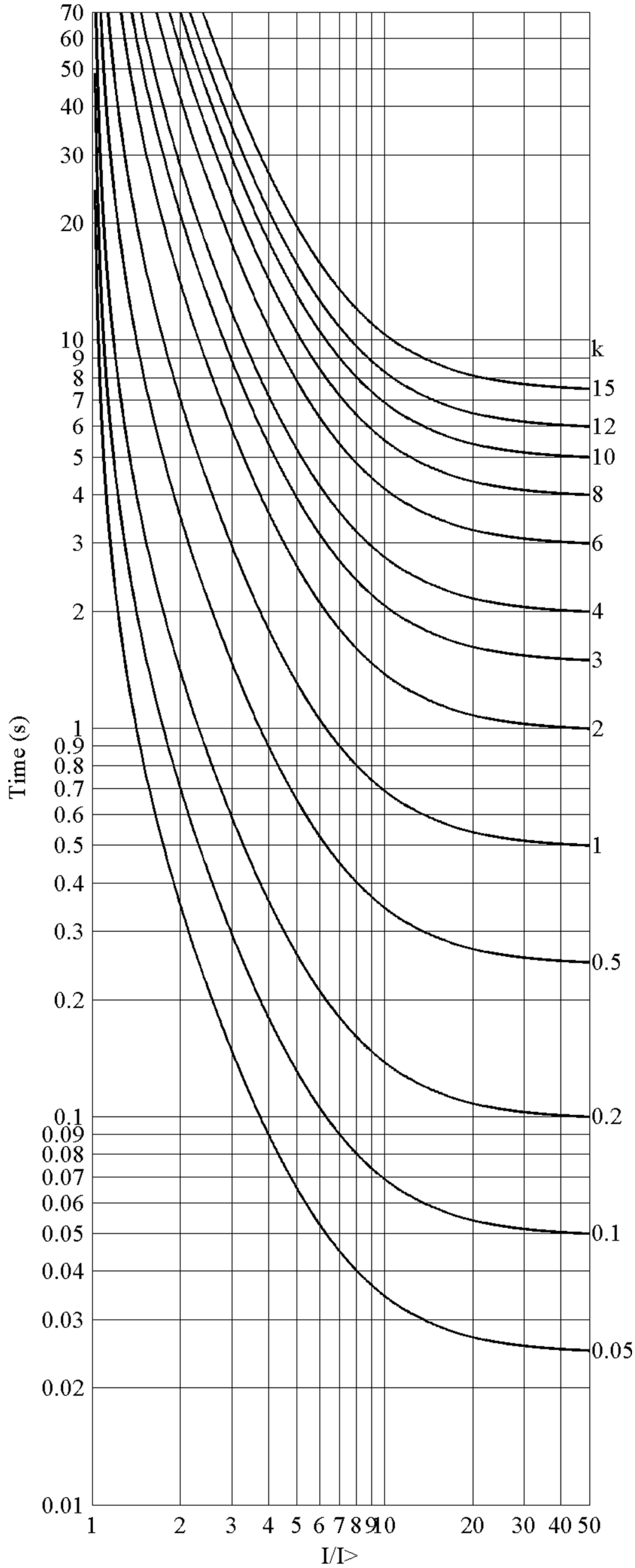


Figure 651: ANSI very inverse-time characteristics

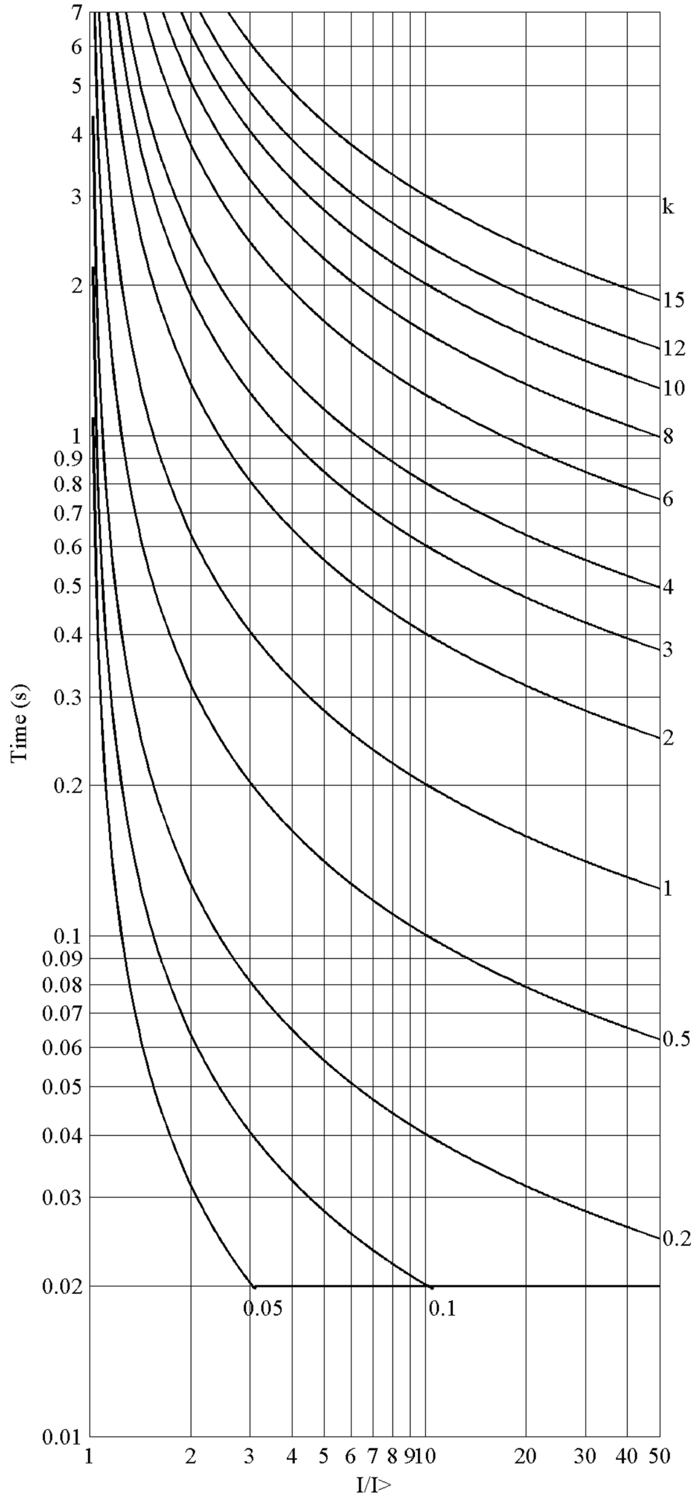


Figure 652: ANSI normal inverse-time characteristics

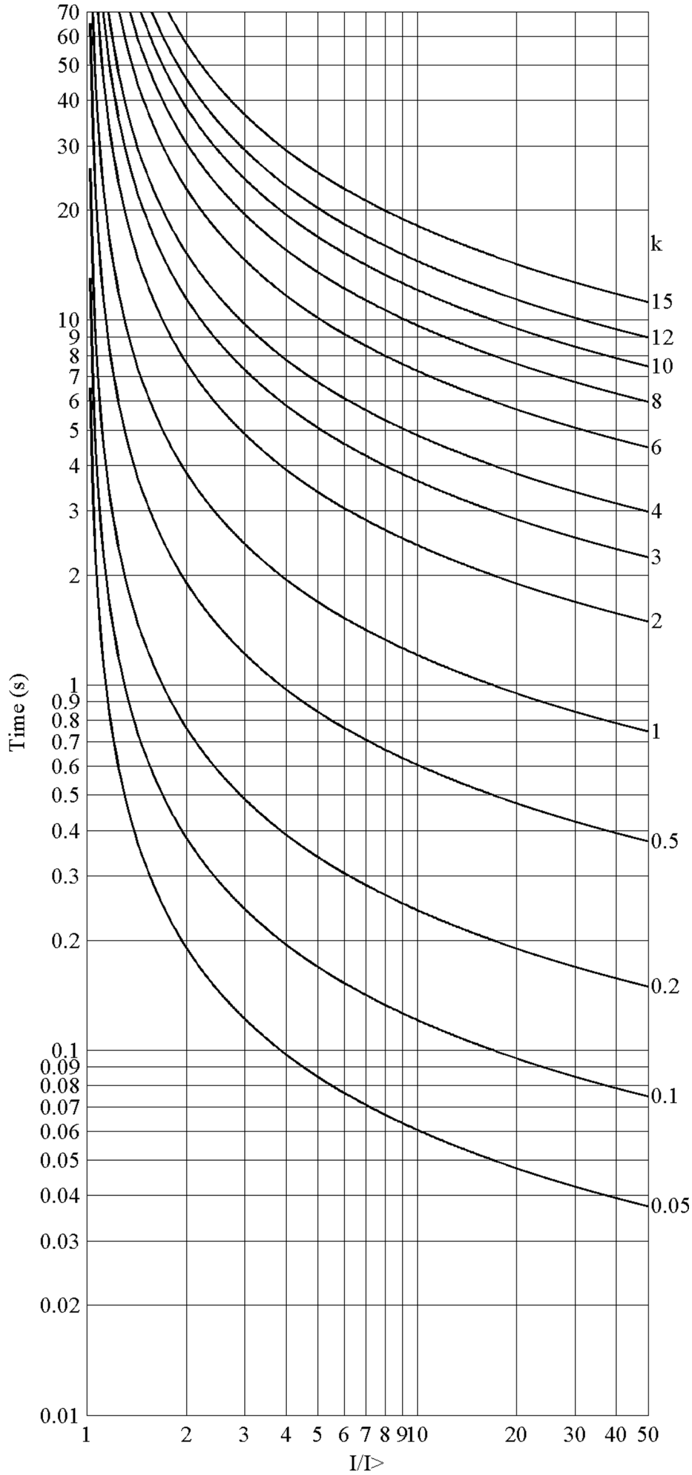


Figure 653: ANSI moderately inverse-time characteristics

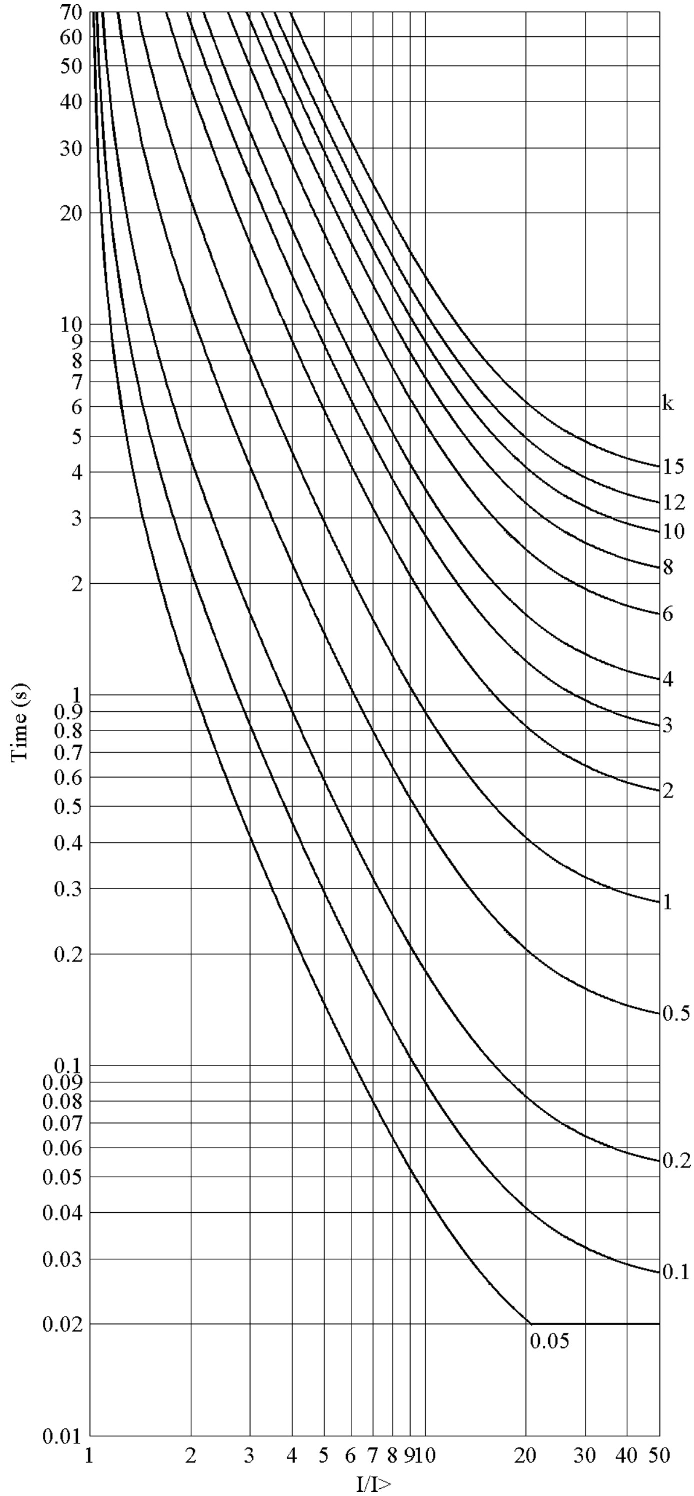


Figure 654: ANSI long-time extremely inverse-time characteristics

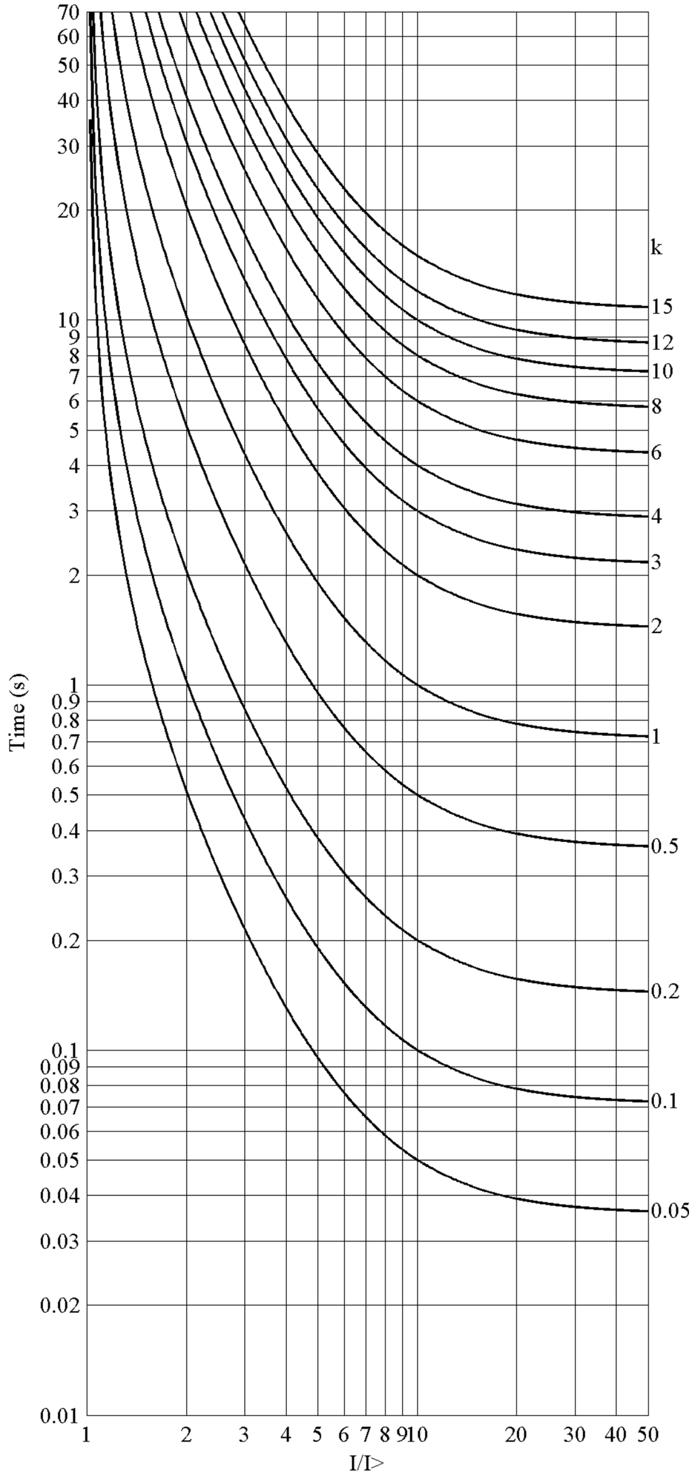


Figure 655: ANSI long-time very inverse-time characteristics

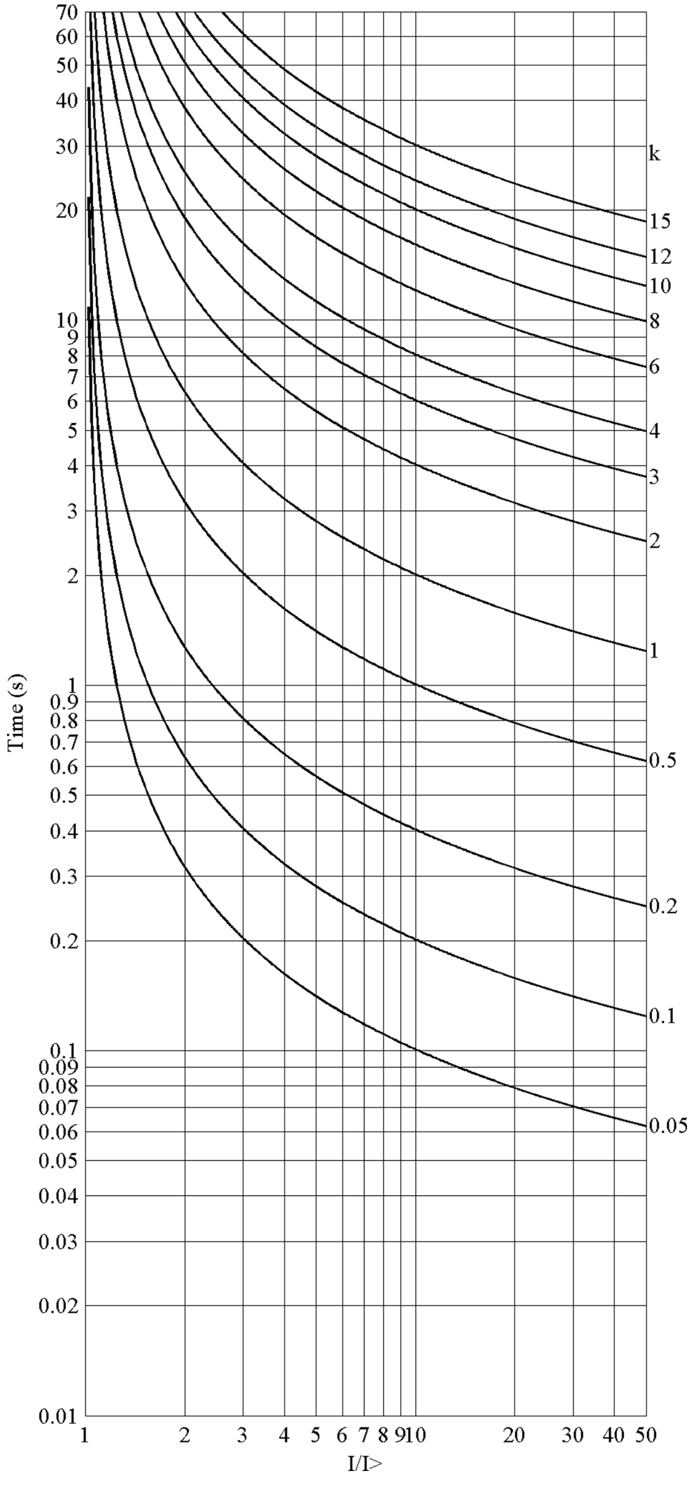


Figure 656: ANSI long-time inverse-time characteristics

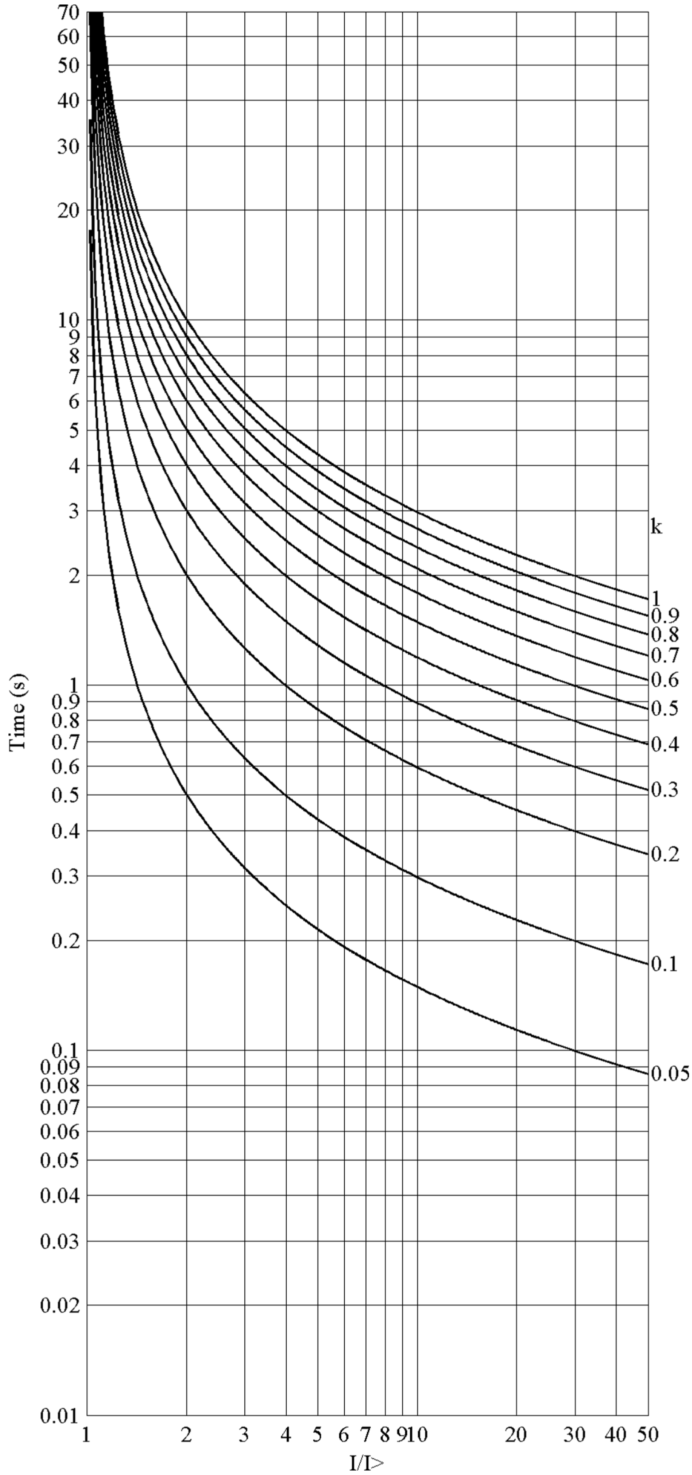


Figure 657: IEC normal inverse-time characteristics

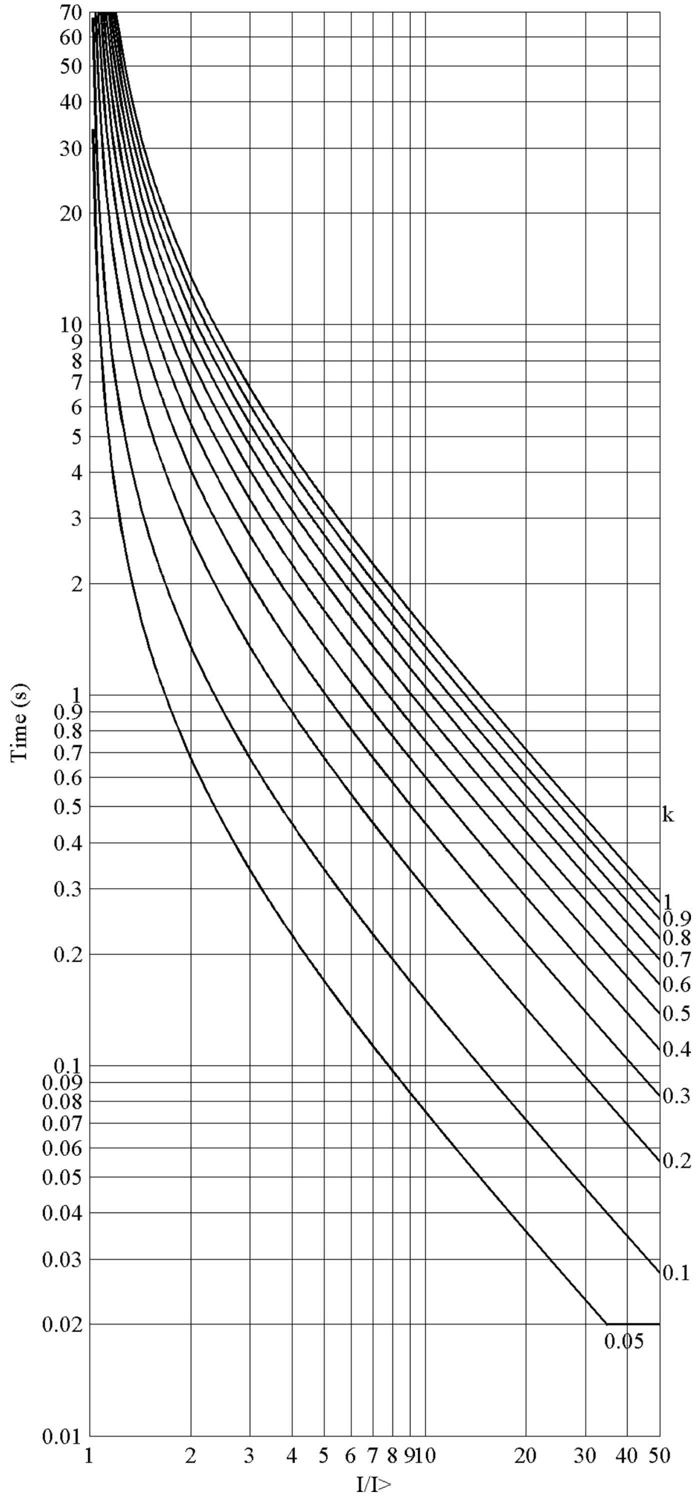


Figure 658: IEC very inverse-time characteristics

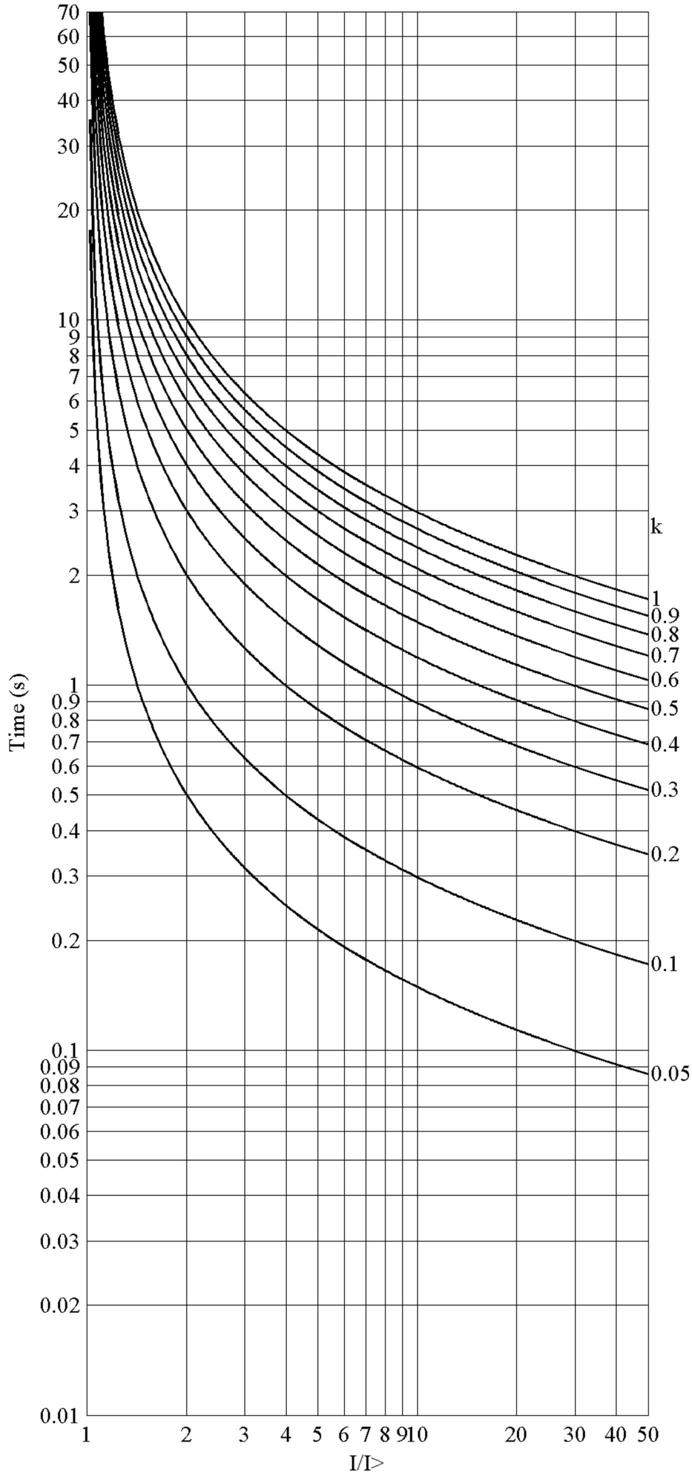


Figure 659: IEC inverse-time characteristics

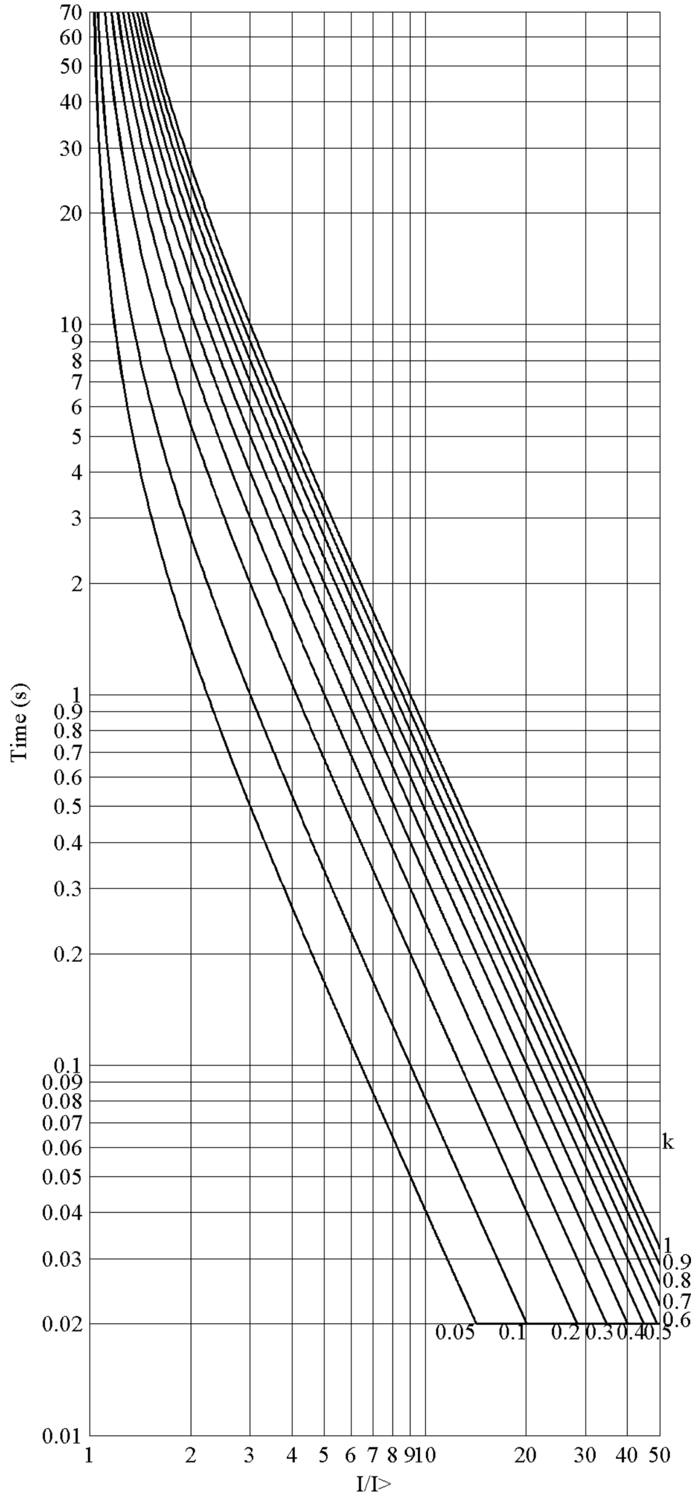


Figure 660: IEC extremely inverse-time characteristics

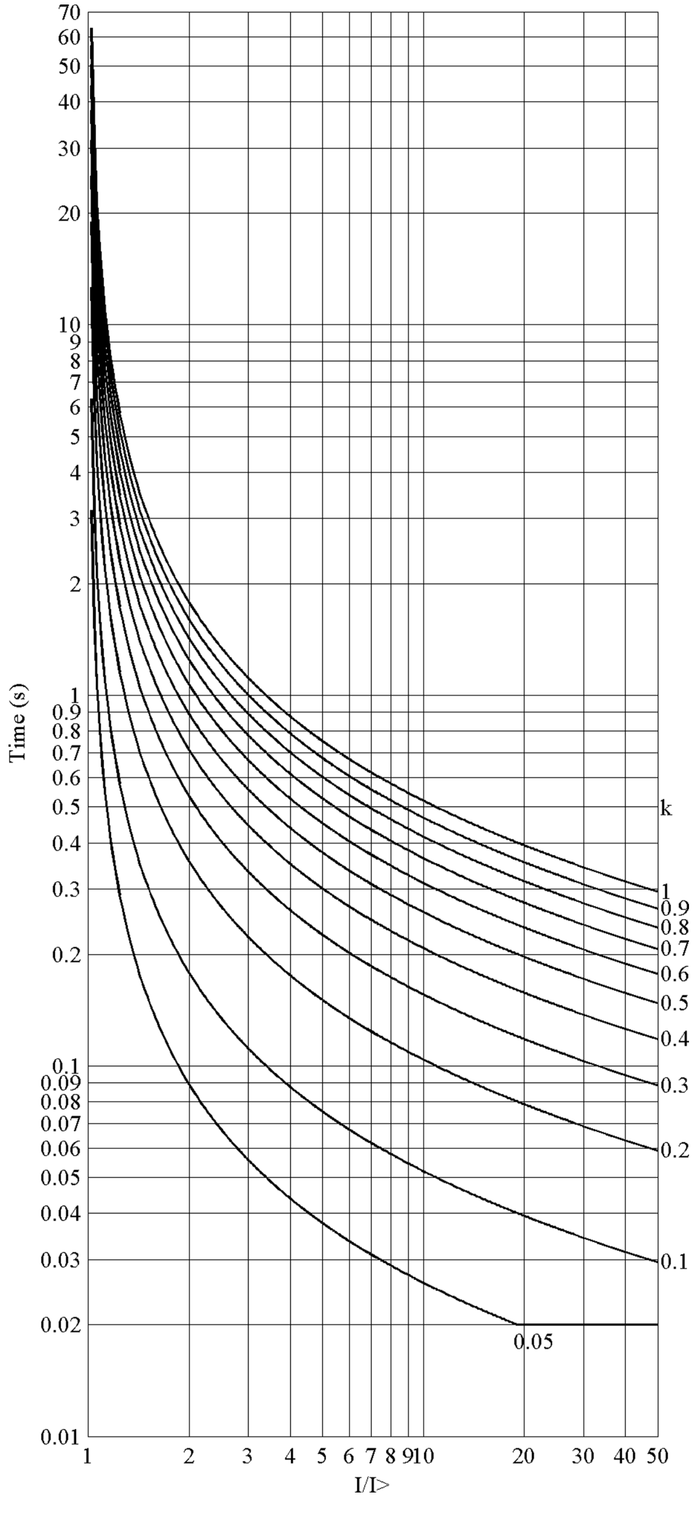


Figure 661: IEC short-time inverse-time characteristics

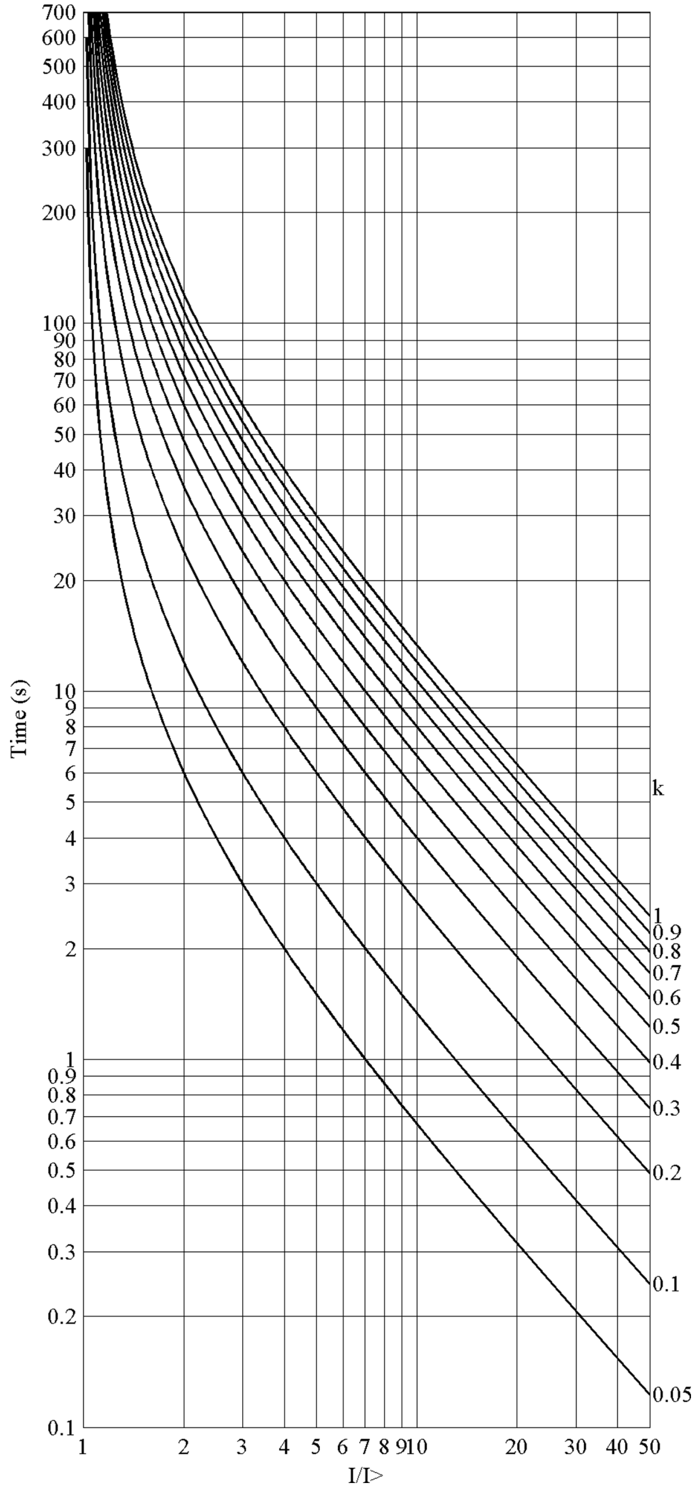


Figure 662: IEC long-time inverse-time characteristics

11.2.1.2 User-programmable inverse-time characteristics

The user can define curves by entering parameters into the following standard formula:

$$t[s] = \left(\frac{A}{\left(\frac{I}{I>}\right)^{c} - E} + B \right) \cdot k$$

(Equation 192)

t[s]	Operate time (in seconds)
A	set *Curve parameter A*
B	set *Curve parameter B*
C	set *Curve parameter C*
E	set *Curve parameter E*
I	Measured current
I>	set *Start value*
k	set *Time multiplier*

11.2.1.3 RI and RD-type inverse-time characteristics

The RI-type simulates the behavior of electromechanical relays. The RD-type is an earth-fault specific characteristic.

The RI-type is calculated using the formula

$$t[s] = \left(\frac{k}{0.339 - 0.236 \times \frac{I>}{I}} \right)$$

(Equation 193)

The RD-type is calculated using the formula

$$t[s] = 5.8 - 1.35 \times \mathrm{In}\left(\frac{I}{k \times I>} \right)$$

(Equation 194)

t[s]	Operate time (in seconds)
k	set *Time multiplier*
I	Measured current
I>	set *Start value*

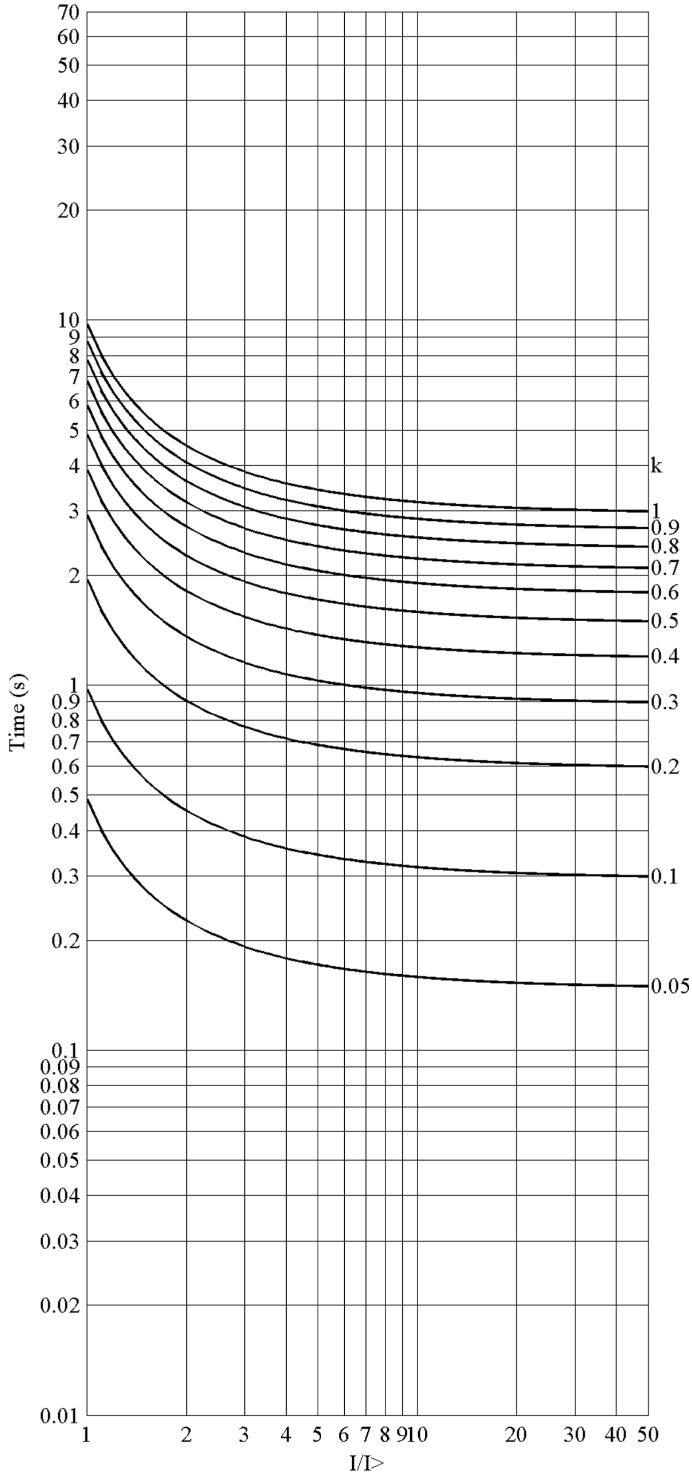


Figure 663: RI-type inverse-time characteristics

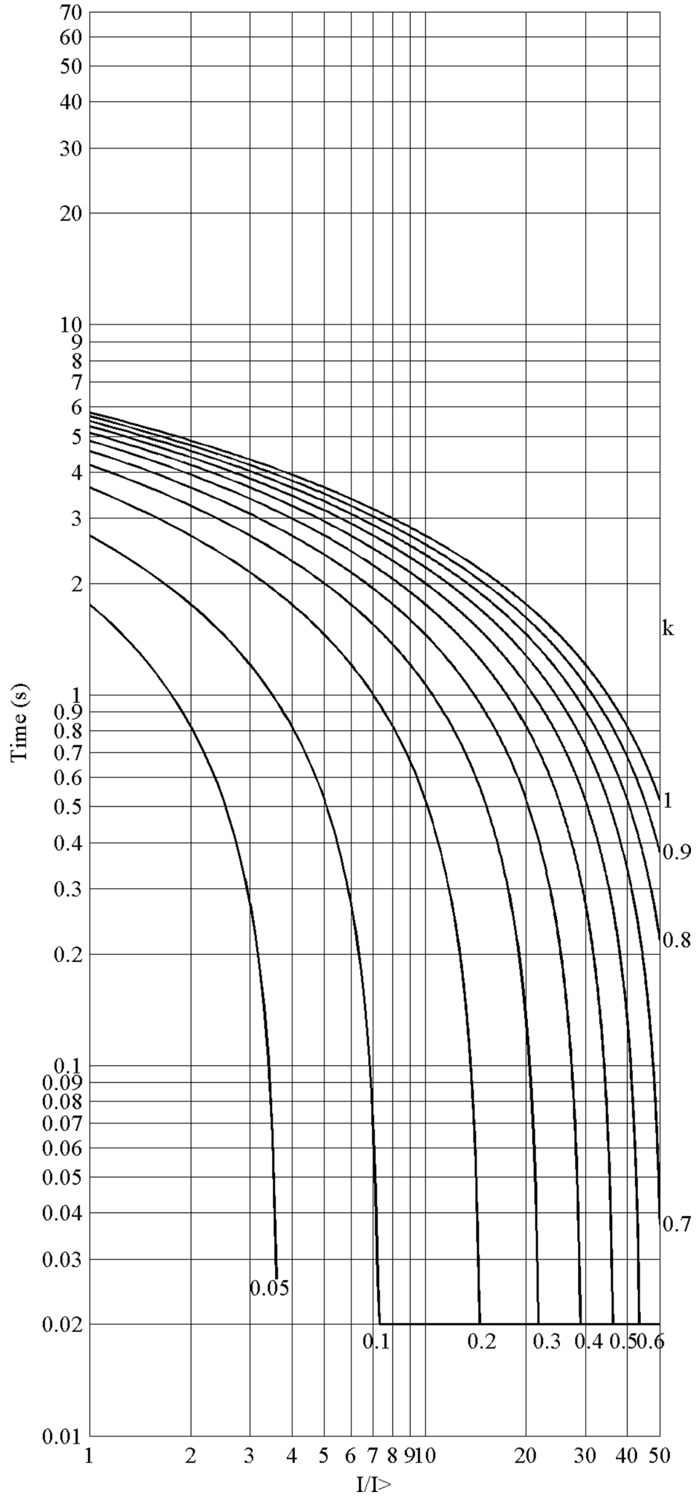


Figure 664: RD-type inverse-time characteristics

11.2.2 Reset in inverse-time modes

The user can select the reset characteristics by using the *Type of reset curve* setting.

Table 1186: Values for reset mode

Setting name	Possible values
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset

Immediate reset

If the *Type of reset curve* setting in a drop-off case is selected as "Immediate", the inverse timer resets immediately.

Definite time reset

The definite type of reset in the inverse-time mode can be achieved by setting the *Type of reset curve* parameter to “Def time reset”. As a result, the operate inverse-time counter is frozen for the time determined with the *Reset delay time* setting after the current drops below the set *Start value*, including hysteresis.The integral sum of the inverse-time counter is reset, if another start does not occur during the reset delay.

If the *Type of reset curve* setting is selected as “Def time reset”, the current level has no influence on the reset characteristic.

Inverse reset

Inverse reset curves are available only for ANSI and user-programmable curves. If you use other curve types, immediate reset occurs.

Standard delayed inverse reset

The reset characteristic required in ANSI (IEEE) inverse-time modes is provided by setting the *Type of reset curve* parameter to “Inverse reset”. In this mode, the time delay for reset is given with the following formula using the coefficient D, which has its values defined in the table below.

$$t[s] = \left(\frac{D}{\left(\frac{I}{I>} \right)^2 - 1} \right) \cdot k$$

(Equation 195)

t[s] Reset time (in seconds)

k set *Time multiplier*

I Measured current

I> set *Start value*

Table 1187: Coefficients for ANSI delayed inverse reset curves

Curve name	D
(1) ANSI Extremely Inverse	29.1
(2) ANSI Very Inverse	21.6
(3) ANSI Normal Inverse	0.46
(4) ANSI Moderately Inverse	4.85
(6) Long Time Extremely Inverse	30
(7) Long Time Very Inverse	13.46
(8) Long Time Inverse	4.6

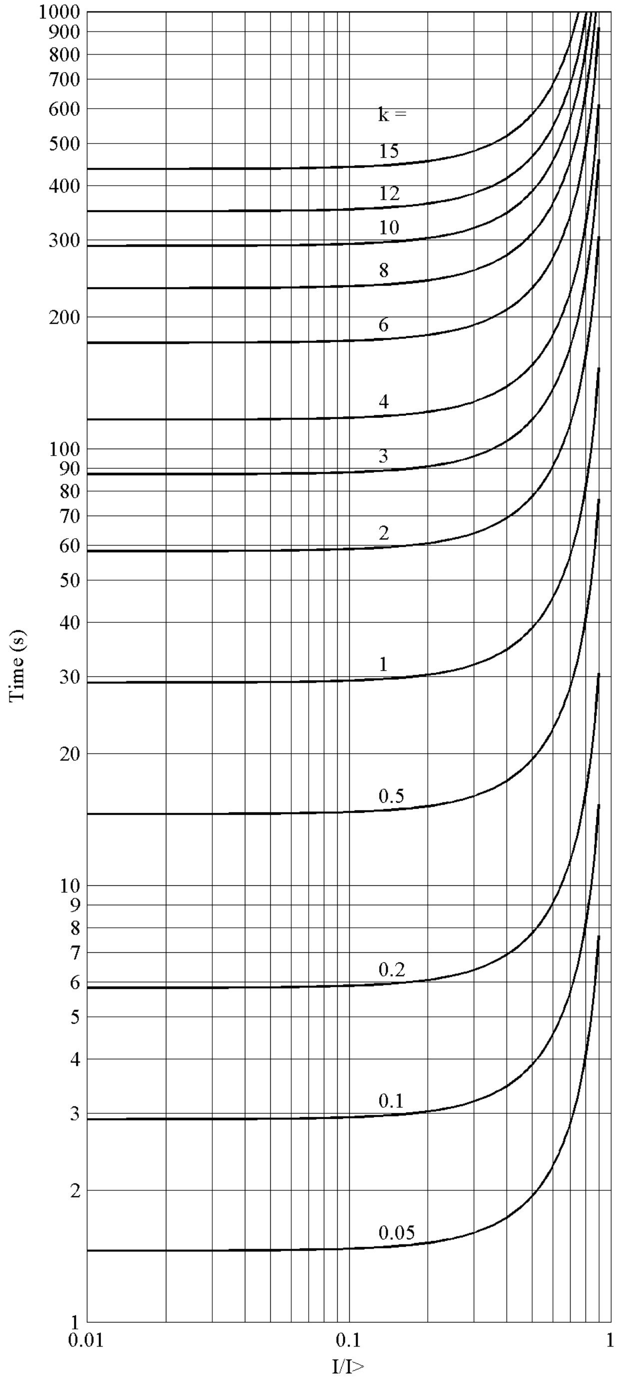


Figure 665: ANSI extremely inverse reset time characteristics

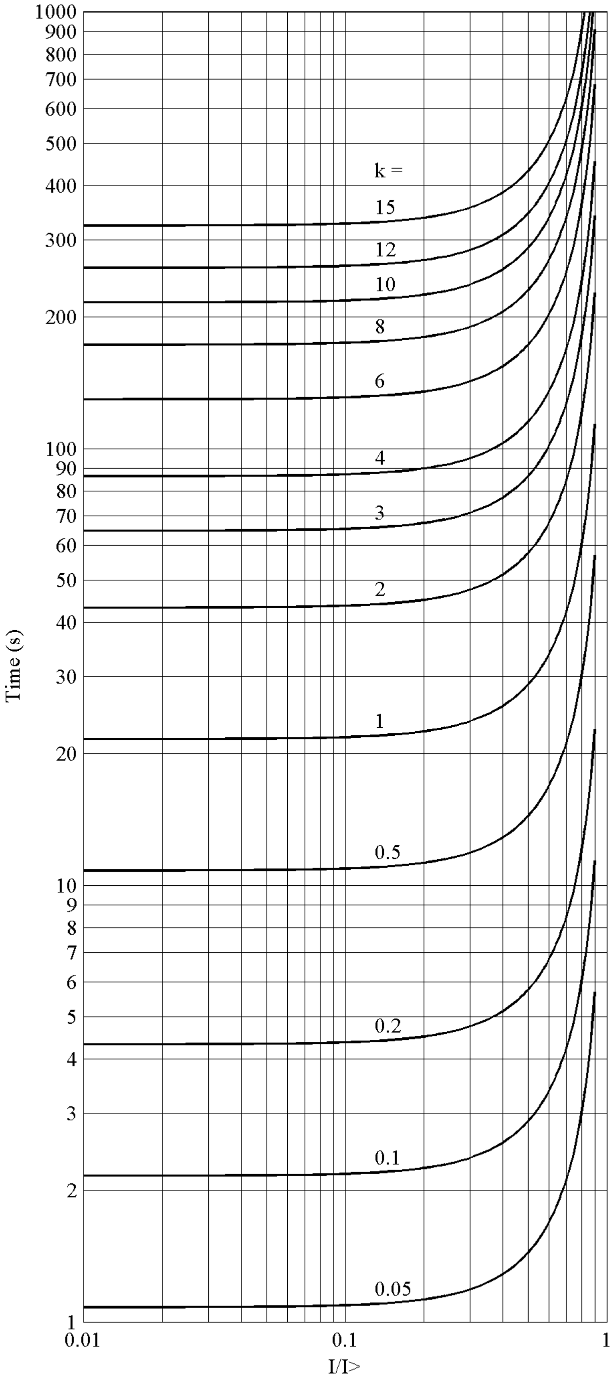


Figure 666: ANSI very inverse reset time characteristics

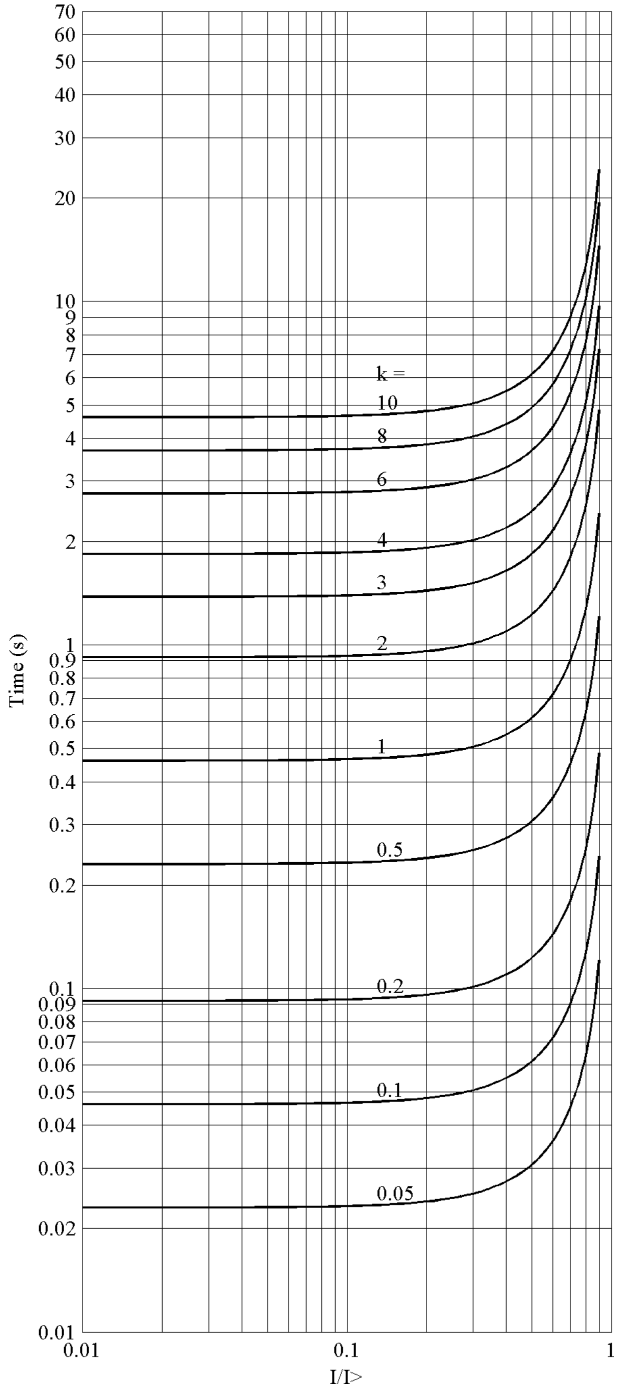


Figure 667: ANSI normal inverse reset time characteristics

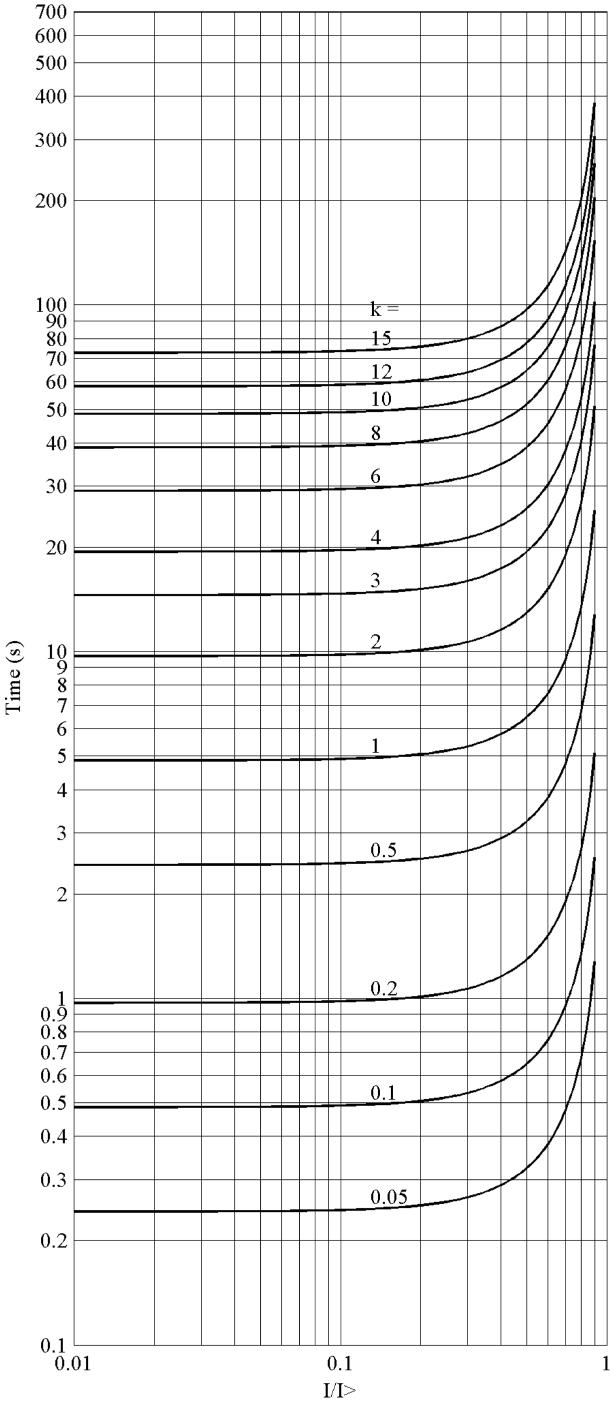


Figure 668: ANSI moderately inverse reset time characteristics

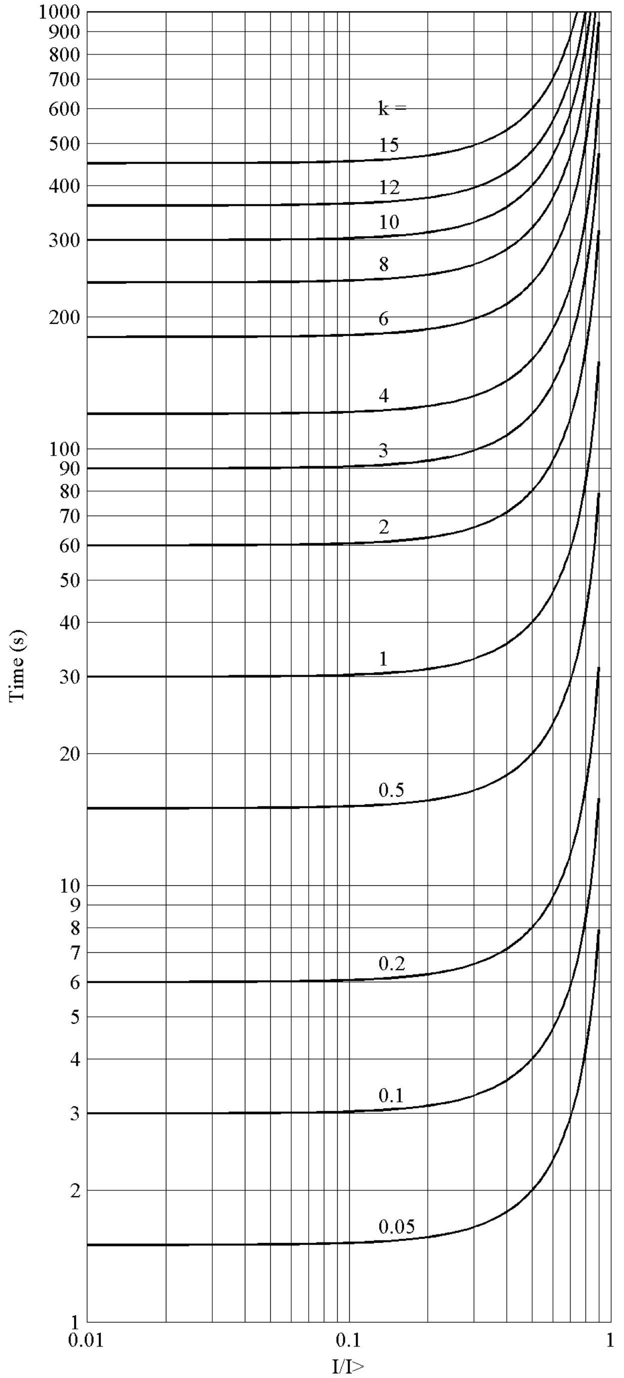


Figure 669: ANSI long-time extremely inverse reset time characteristics

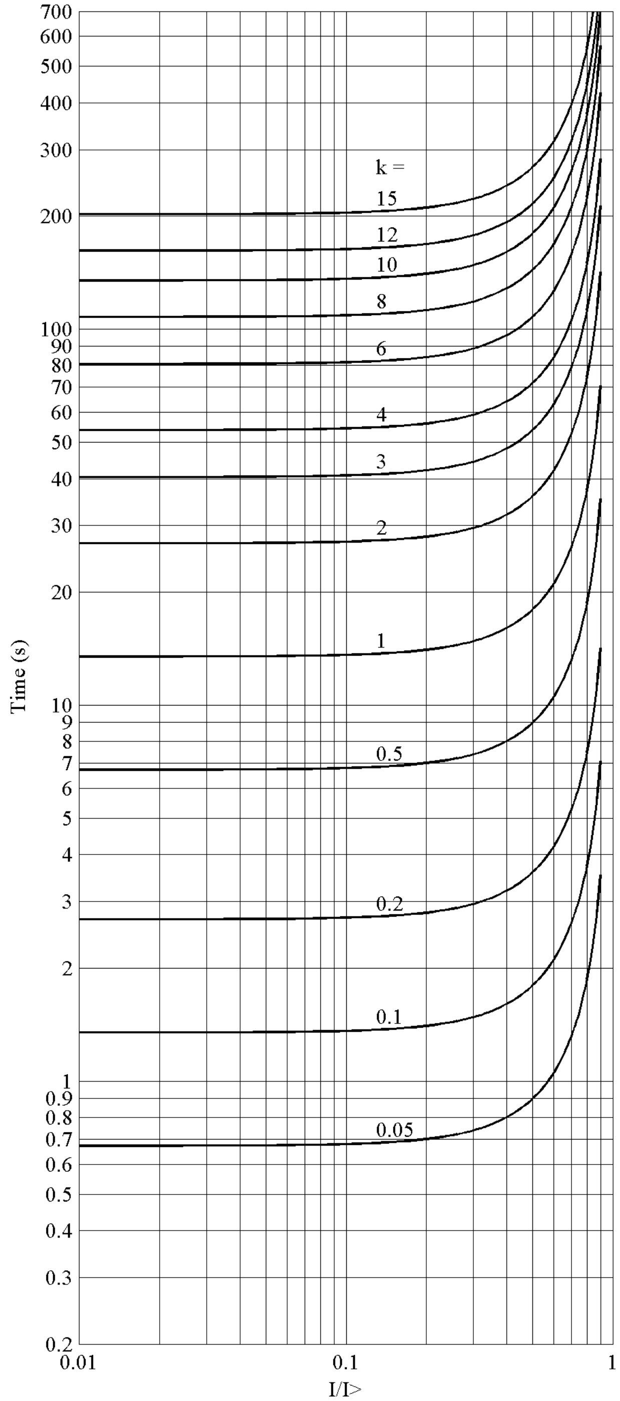


Figure 670: ANSI long-time very inverse reset time characteristics

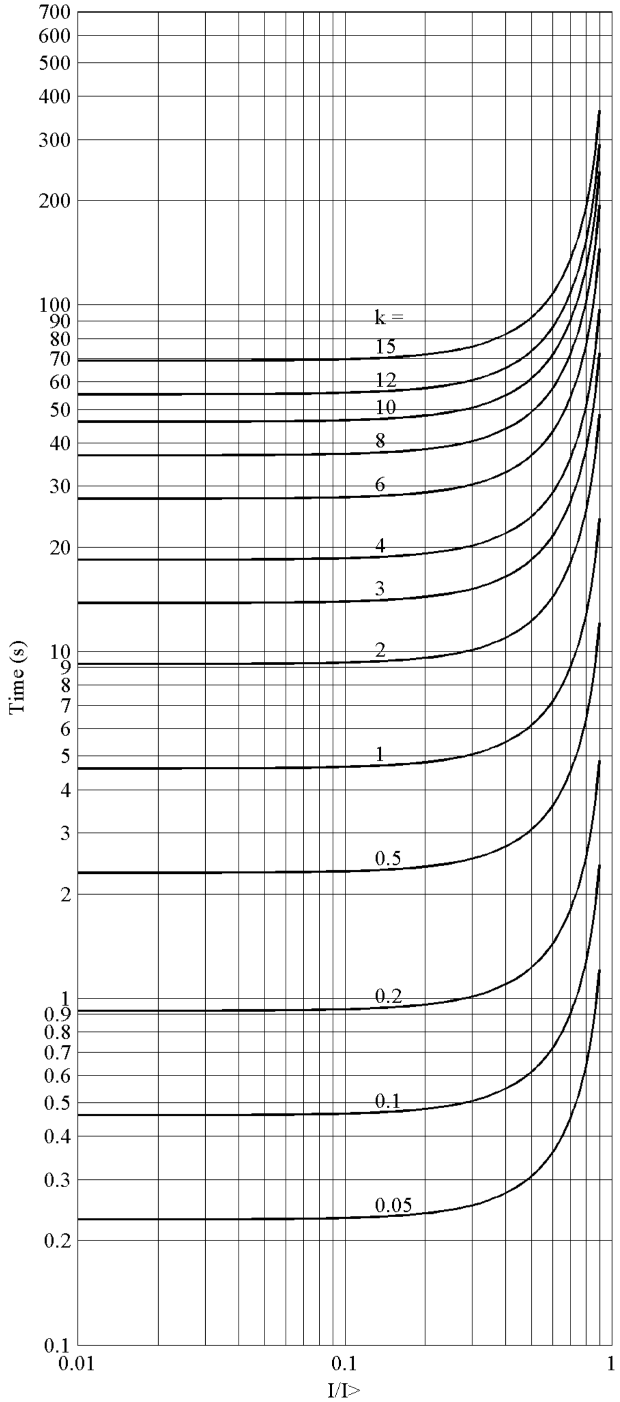


Figure 671: ANSI long-time inverse reset time characteristics

The delayed inverse-time reset is not available for IEC-type inverse time curves.

User-programmable delayed inverse reset

The user can define the delayed inverse reset time characteristics with the following formula using the set *Curve parameter D*.

$$t[s] = \left(\frac{D}{\left(\frac{I}{I>} \right)^2 - 1} \right) \cdot k$$

(Equation 196)

t[s]	Reset time (in seconds)
k	set *Time multiplier*
D	set *Curve parameter D*
I	Measured current
I>	set *Start value*

11.2.3 Inverse-timer freezing

When the FR_TIMER input is active, the internal value of the time counter is frozen at the value of the moment just before the freezing. Freezing of the counter value is chosen when the user does not wish the counter value to count upwards or to be reset. This may be the case, for example, when the inverse-time function of a protection relay needs to be blocked to enable the definite-time operation of another protection relay for selectivity reasons, especially if different relaying techniques (old and modern relays) are applied.

The activation of the BLOCK input also lengthens the minimum delay value of the timer.

Activating the BLOCK input alone does not affect the operation of the START output. It still becomes active when the current exceeds the set *Start value*, and inactive when the current falls below the set *Start value* and the set *Reset delay time* has expired.

11.3 Voltage based inverse definite minimum time characteristics

11.3.1 IDMT curves for overvoltage protection

In inverse-time modes, the operate time depends on the momentary value of the voltage, the higher the voltage, the faster the operate time. The operate time calculation or integration starts immediately when the voltage exceeds the set value of the *Start value* setting and the START output is activated.

The OPERATE output of the component is activated when the cumulative sum of the integrator calculating the overvoltage situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used. The user determines the curve scaling with the *Time multiplier* setting.

The *Minimum operate time* setting defines the minimum operate time for the IDMT mode, that is, it is possible to limit the IDMT based operate time for not becoming too short. For example:

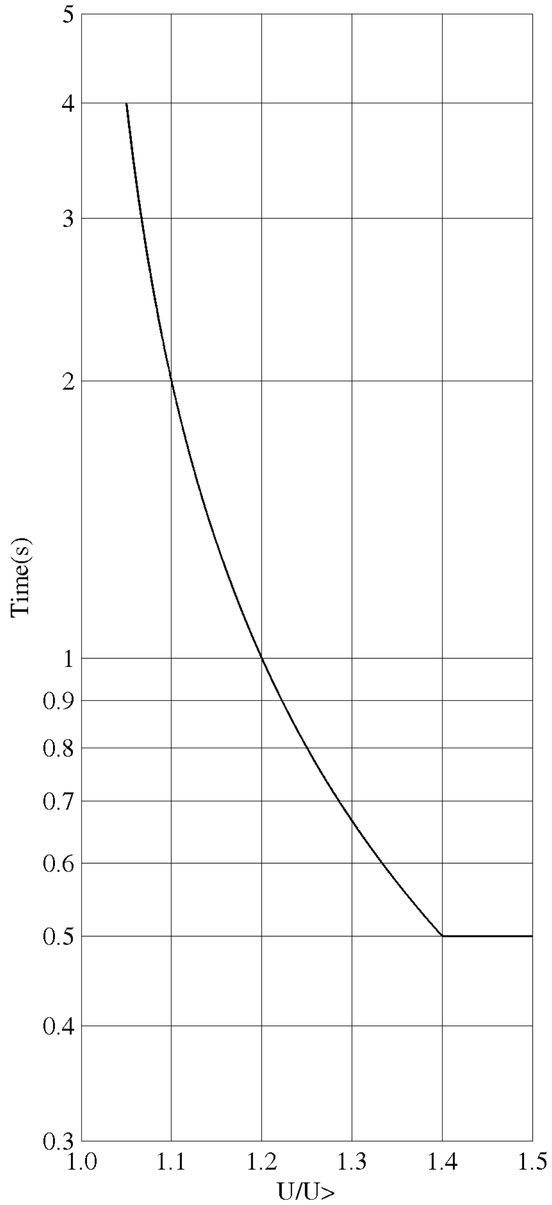


Figure 672: Operate time curve based on IDMT characteristic with Minimum operate time set to 0.5 second

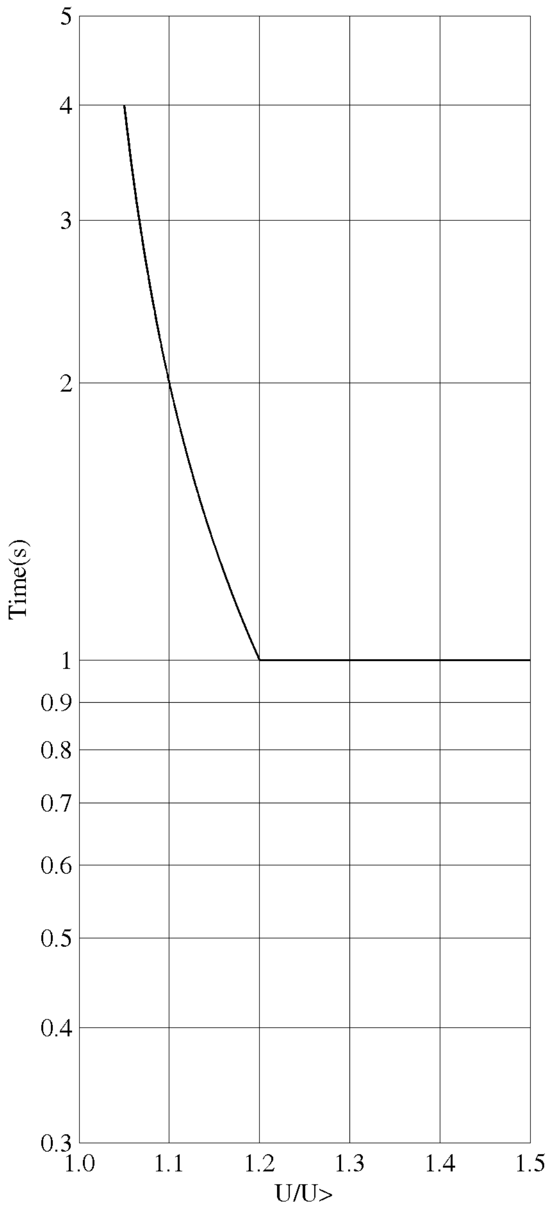


Figure 673: Operate time curve based on IDMT characteristic with Minimum operate time set to 1 second

11.3.1.1 Standard inverse-time characteristics for overvoltage protection

The operate times for the standard overvoltage IDMT curves are defined with the coefficients A, B, C, D and E.

The inverse operate time can be calculated with the formula:

$$t\left[s\right]=\frac{k\cdot A}{\left(B\times\frac{U-U>}{U>}-C\right)^{E}}+D$$

(Equation 197)

t [s] operate time in seconds

U measured voltage

U> the set value of *Start value*

k the set value of *Time multiplier*

Table 1188: Curve coefficients for the standard overvoltage IDMT curves

Curve name	A	B	C	D	E
(17) Inverse Curve A	1	1	0	0	1
(18) Inverse Curve B	480	32	0.5	0.035	2
(19) Inverse Curve C	480	32	0.5	0.035	3

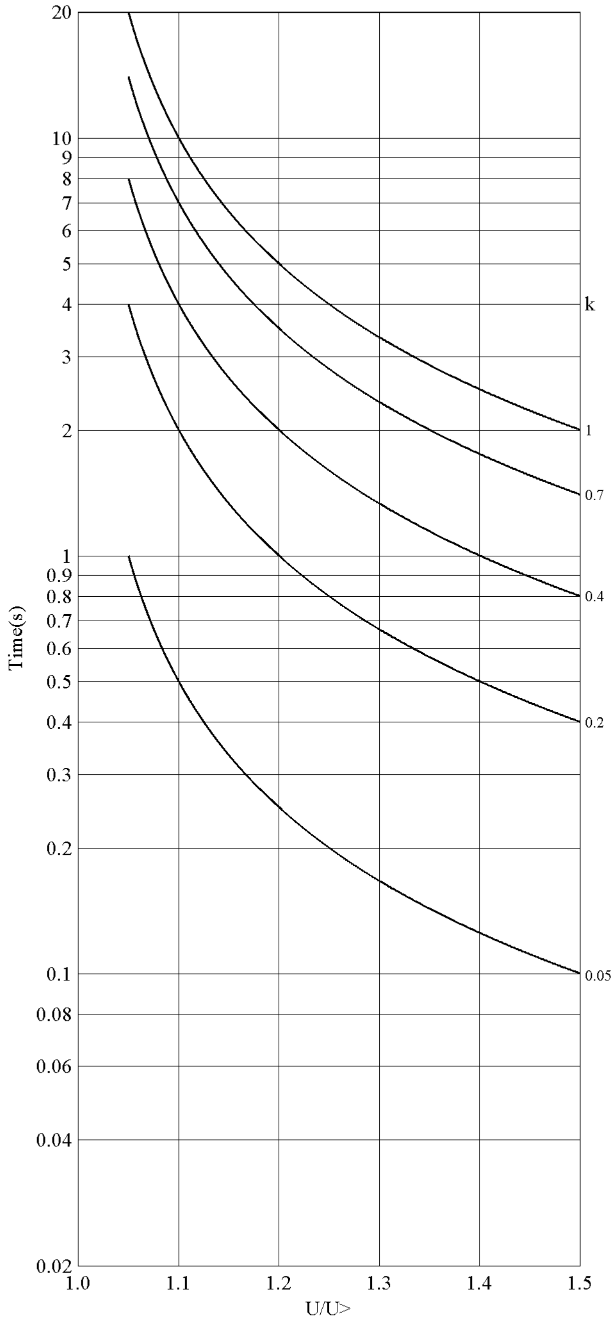


Figure 674: Inverse curve A characteristic of overvoltage protection

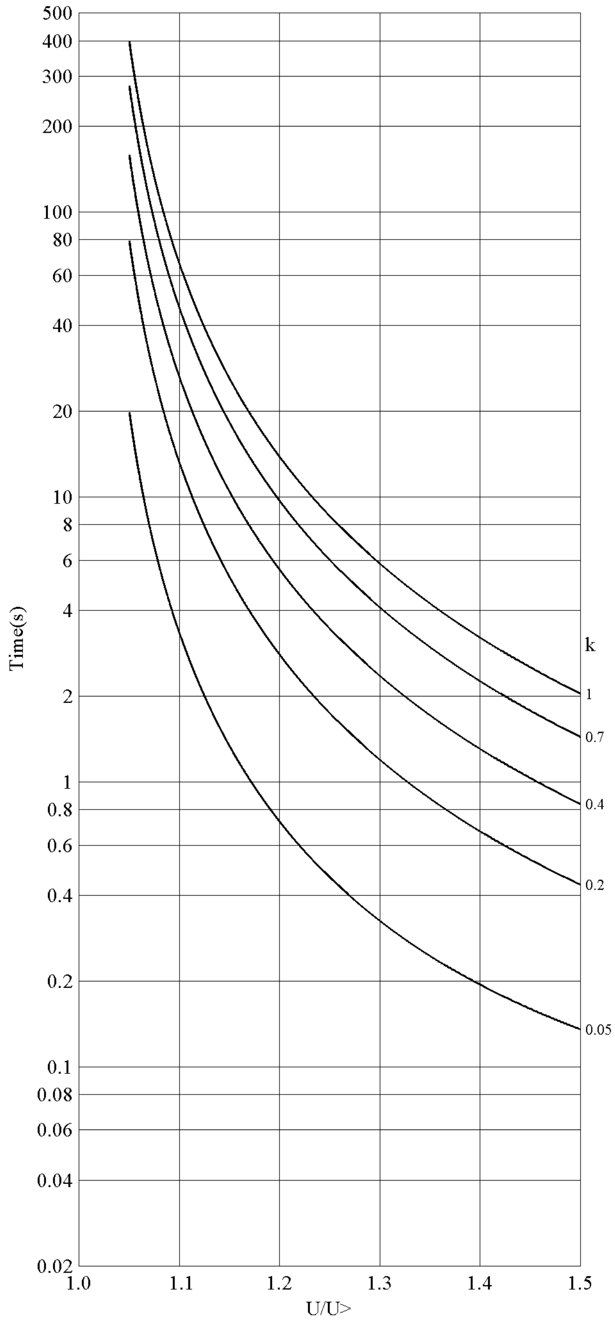


Figure 675: Inverse curve B characteristic of overvoltage protection

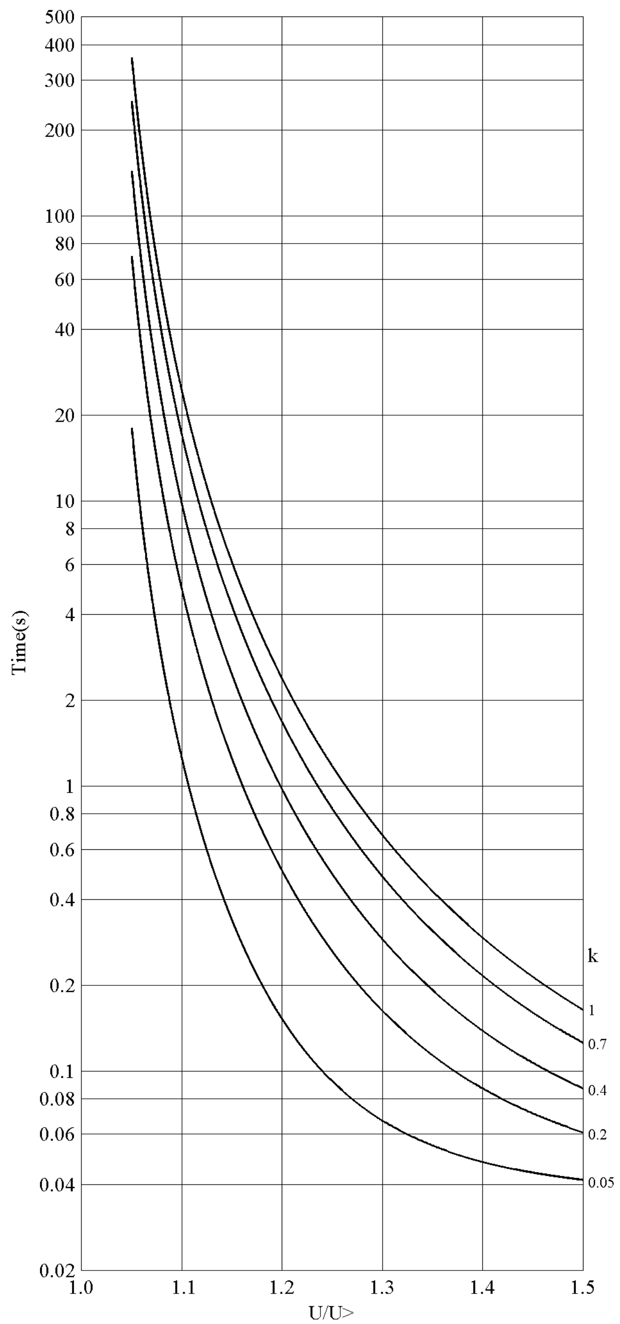


Figure 676: Inverse curve C characteristic of overvoltage protection

11.3.1.2 User programmable inverse-time characteristics for overvoltage protection

The user can define the curves by entering the parameters using the standard formula:

$$t\left[s\right]=\frac{k\cdot A}{\left(B\times\frac{U-U>}{U>}-C\right)^{E}}+D$$

(Equation 198)

t[s]	operate time in seconds
A	the set value of *Curve parameter A*
B	the set value of *Curve parameter B*
C	the set value of *Curve parameter C*
D	the set value of *Curve parameter D*
E	the set value of *Curve parameter E*
U	measured voltage
U>	the set value of *Start value*
k	the set value of *Time multiplier*

11.3.1.3 IDMT curve saturation of overvoltage protection

For the overvoltage IDMT mode of operation, the integration of the operate time does not start until the voltage exceeds the value of *Start value*. To cope with discontinuity characteristics of the curve, a specific parameter for saturating the equation to a fixed value is created. The *Curve Sat Relative* setting is the parameter and it is given in percents compared to *Start value*. For example, due to the curve equation B and C, the characteristics equation output is saturated in such a way that when the input voltages are in the range of *Start value* to *Curve Sat Relative* in percent over *Start value*, the equation uses *Start value* * (1.0 + *Curve Sat Relative* / 100) for the measured voltage. Although, the curve A has no discontinuities when the ratio U/U> exceeds the unity, *Curve Sat Relative* is also set for it. The *Curve Sat Relative* setting for curves A, B and C is 2.0 percent. However, it should be noted that the user must carefully calculate the curve characteristics concerning the discontinuities in the curve when the programmable curve equation is used. Thus, the *Curve Sat Relative* parameter gives another degree of freedom to move the inverse curve on the voltage ratio axis and it effectively sets the maximum operate time for the IDMT curve because for the voltage ratio values affecting by this setting, the operation time is fixed, that is, the definite time, depending on the parameters but no longer the voltage.

11.3.2 IDMT curves for undervoltage protection

In the inverse-time modes, the operate time depends on the momentary value of the voltage, the lower the voltage, the faster the operate time. The operate time calculation or integration starts immediately when the voltage goes below the set value of the *Start value* setting and the `START` output is activated.

The `OPERATE` output of the component is activated when the cumulative sum of the integrator calculating the undervoltage situation exceeds the value set by the inverse-time mode. The set value depends on the selected curve type and the setting values used. The user determines the curve scaling with the *Time multiplier* setting.

The *Minimum operate time* setting defines the minimum operate time possible for the IDMT mode. For setting a value for this parameter, the user should carefully study the particular IDMT curve.

11.3.2.1 Standard inverse-time characteristics for undervoltage protection

The operate times for the standard undervoltage IDMT curves are defined with the coefficients A, B, C, D and E.

The inverse operate time can be calculated with the formula:

$$t\left[s\right] = \frac{k \cdot A}{\left(B \times \frac{U < -U}{U <} - C\right)^{E}} + D$$

(Equation 199)

t [s]	operate time in seconds
U	measured voltage
U<	the set value of the *Start value* setting
k	the set value of the *Time multiplier* setting

Table 1189: Curve coefficients for standard undervoltage IDMT curves

Curve name	A	B	C	D	E
(21) Inverse Curve A	1	1	0	0	1
(22) Inverse Curve B	480	32	0.5	0.055	2

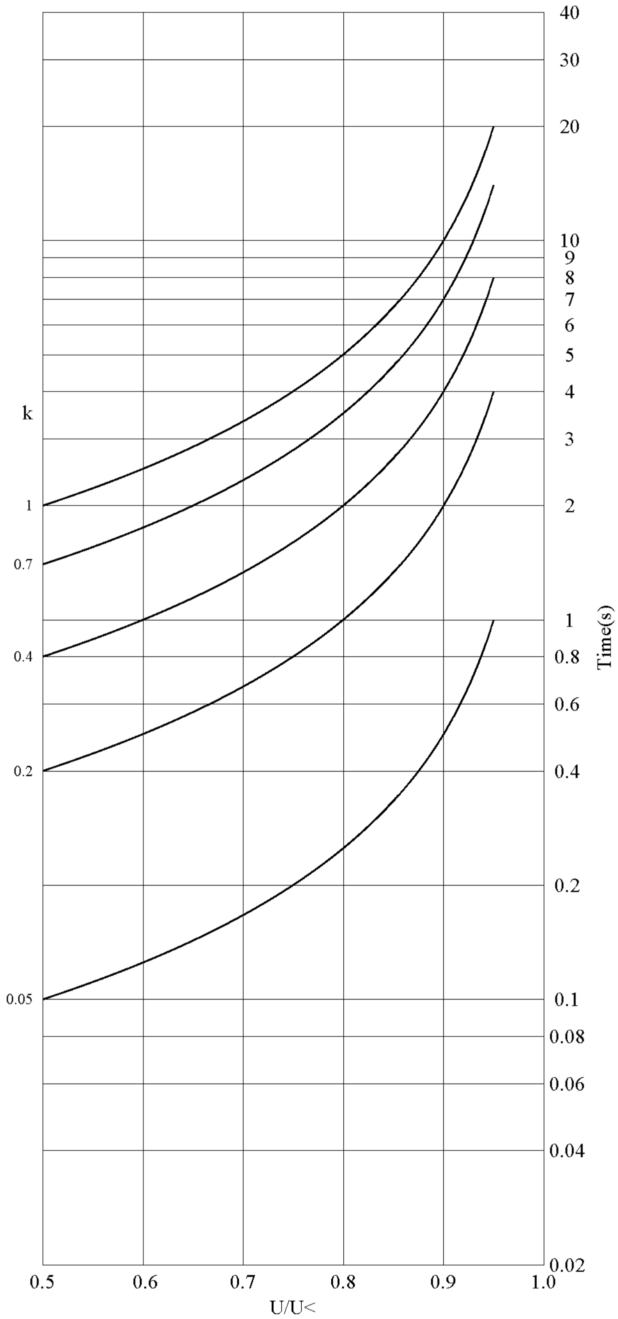


Figure 677: : Inverse curve A characteristic of undervoltage protection

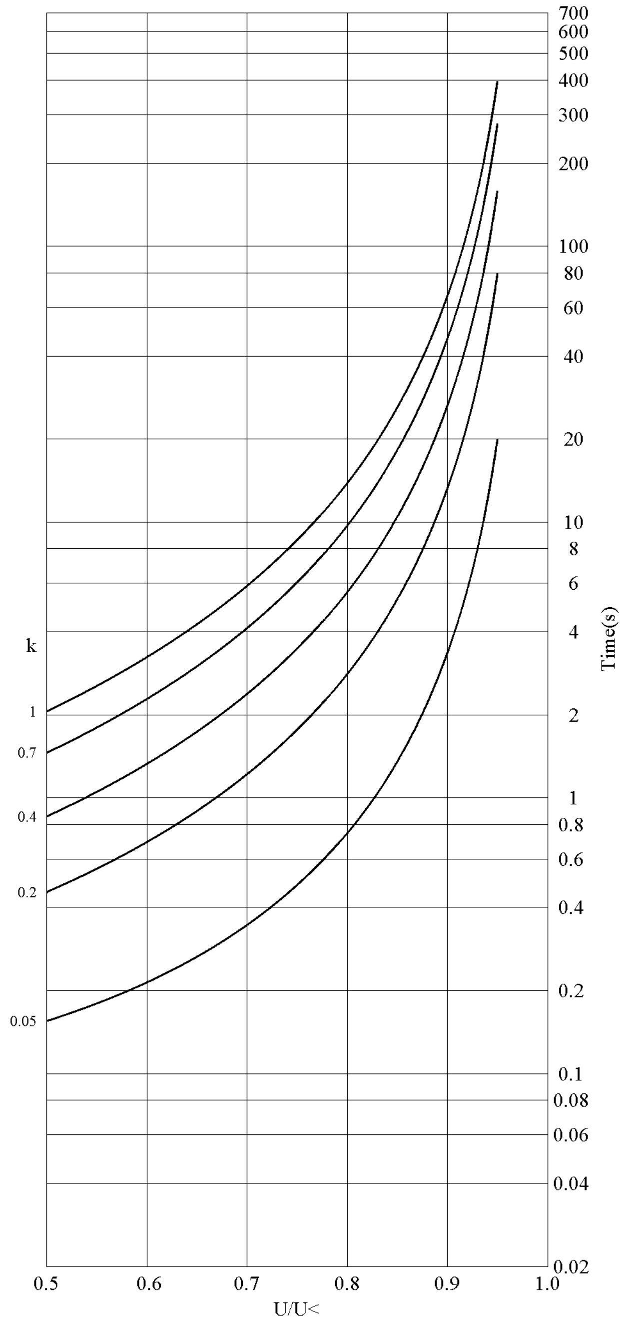


Figure 678: Inverse curve B characteristic of undervoltage protection

11.3.2.2 User-programmable inverse-time characteristics for undervoltage protection

The user can define curves by entering parameters into the standard formula:

$$t\left[s\right] = \frac{k \cdot A}{\left(B \times \frac{U < -U}{U <} - C\right)^{E}} + D$$

(Equation 200)

t[s]	operate time in seconds
A	the set value of *Curve parameter A*
B	the set value of *Curve parameter B*
C	the set value of *Curve parameter C*
D	the set value of *Curve parameter D*
E	the set value of *Curve parameter E*
U	measured voltage
U<	the set value of *Start value*
k	the set value of *Time multiplier*

11.3.2.3 IDMT curve saturation of undervoltage protection

For the undervoltage IDMT mode of operation, the integration of the operate time does not start until the voltage falls below the value of *Start value*. To cope with discontinuity characteristics of the curve, a specific parameter for saturating the equation to a fixed value is created. The *Curve Sat Relative* setting is the parameter and it is given in percents compared with *Start value*. For example, due to the curve equation B, the characteristics equation output is saturated in such a way that when input voltages are in the range from *Start value* to *Curve Sat Relative* in percents under *Start value*, the equation uses *Start value* * (1.0 - *Curve Sat Relative* / 100) for the measured voltage. Although, the curve A has no discontinuities when the ratio U/U> exceeds the unity, *Curve Sat Relative* is set for it as well. The *Curve Sat Relative* setting for curves A, B and C is 2.0 percent. However, it should be noted that the user must carefully calculate the curve characteristics concerning also discontinuities in the curve when the programmable curve equation is used. Thus, the *Curve Sat Relative* parameter gives another degree of freedom to move the inverse curve on the voltage ratio axis and it effectively sets the maximum operate time for the IDMT curve because for the voltage ratio values affecting by this setting, the operation time is fixed, that is, the definite time, depending on the parameters but no longer the voltage.

11.4 Measurement modes

In many current or voltage dependent function blocks, there are various alternative measuring principles.

- RMS
- DFT which is a numerically calculated fundamental component of the signal
- Peak-to-peak
- Peak-to-peak with peak backup

Consequently, the measurement mode can be selected according to the application.

In extreme cases, for example with high overcurrent or harmonic content, the measurement modes function in a slightly different way. The operation accuracy is defined with the frequency range of f/fn=0.95...1.05. In peak-to-peak and RMS measurement modes, the harmonics of the phase currents are not suppressed, whereas in the fundamental frequency measurement the suppression of harmonics is at least -50 dB at the frequency range of f= n x fn, where n = 2, 3, 4, 5,...

RMS

The RMS measurement principle is selected with the *Measurement mode* setting using the value "RMS". RMS consists of both AC and DC components. The AC component is the effective mean value of the positive and negative peak values. RMS is used in applications where the effect of the DC component must be taken into account.

RMS is calculated according to the formula:

$$I_{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} I_i^2}$$

(Equation 201)

n The number of samples in a calculation cycle

I_i The current sample value

DFT

The DFT measurement principle is selected with the *Measurement mode* setting using the value "DFT". In the DFT mode, the fundamental frequency component of the measured signal is numerically calculated from the samples. In some applications, for example, it can be difficult to accomplish sufficiently sensitive settings and accurate operation of the low stage, which may be due to a considerable amount of harmonics on the primary side currents. In such a case, the operation can be based solely on the fundamental frequency component of the current. In addition, the DFT mode has slightly higher CT requirements than the peak-to-peak mode, if used with high and instantaneous stages.

Peak-to-peak

The peak-to-peak measurement principle is selected with the *Measurement mode* setting using the value "Peak-to-Peak". It is the fastest measurement mode, in which the measurement quantity is made by calculating the average from the positive and negative peak values. The DC component is not included. The retardation time is short. The damping of the harmonics is quite low and practically determined by the characteristics of the anti-aliasing filter of the protection relay inputs. Consequently, this mode is usually used in conjunction with high and instantaneous stages, where the suppression of harmonics is not so important. In addition, the peak-to-peak mode allows considerable CT saturation without impairing the performance of the operation.

Peak-to-peak with peak backup

The peak-to-peak with peak backup measurement principle is selected with the *Measurement mode* setting using the value "P-to-P+backup". It is similar to the peak-to-peak mode, with the exception that it has been enhanced with the peak backup. In the peak-to-peak with peak backup mode, the function starts with two conditions: the peak-to-peak value is above the set start current or the peak value is above two times the set *Start value*. The peak backup is enabled only when the function is used in the DT mode in high and instantaneous stages for faster operation.

11.5 Generator startup and shutdown protection

For a protection function to operate over a wide range of frequency, it is necessary that the configuration of the IED is such that the preprocessor function (SMAI) processes the analog signal using frequency adaptive approach. The measurement mode, when selectable, has to be set to DFT.

Table 1190: Protection functions that can be used during the generator startup or shutdown phase

Function/Freq.	10-20 Hz	20-40 Hz	40-70 Hz
MPDIF	Operational	Operational	Operational
DAPTOF	Not operational	Operational 1)	Operational 1)
DEFLPDEF	Operational	Operational	Operational
DEFHPDEF	Operational	Operational	Operational
EFLPTOC	Operational	Operational	Operational
EFHPTOC	Operational	Operational	Operational
EFIPTOC	Not operational 2)	Not operational 2)	Operational
HREFPDIF	Not operational 2)	Not operational 2)	Operational
MREFPTOC	Operational	Operational	Operational
OEPVPH	Not operational 2)	Not operational 2)	Operational
PHLPTOC	Operational	Operational	Operational
PHHPTOC	Operational	Operational	Operational
PHIPTOC	Not operational 2)	Not operational 2)	Operational
Table continues on next page			

Function/Freq.	10-20 Hz	20-40 Hz	40-70 Hz
PHPTOV	Operational 3)	Operational	Operational
ROVPTOV	Operational 4)	Operational	Operational
TR2PTDF	Operational	Operational	Operational

1) Start value setting range 35 - 64 Hz
2) Function has to be blocked
3) Start value setting must be higher than 1.0 x Un
4) Measured Uo must be used

Section 12 Requirements for measurement transformers

12.1 Current transformers

12.1.1 Current transformer requirements for overcurrent protection

For reliable and correct operation of the overcurrent protection, the CT has to be chosen carefully. The distortion of the secondary current of a saturated CT may endanger the operation, selectivity, and co-ordination of protection. However, when the CT is correctly selected, a fast and reliable short circuit protection can be enabled.

The selection of a CT depends not only on the CT specifications but also on the network fault current magnitude, desired protection objectives, and the actual CT burden. The protection settings of the protection relay should be defined in accordance with the CT performance as well as other factors.

12.1.1.1 Current transformer accuracy class and accuracy limit factor

The rated accuracy limit factor (F_n) is the ratio of the rated accuracy limit primary current to the rated primary current. For example, a protective current transformer of type 5P10 has the accuracy class 5P and the accuracy limit factor 10. For protective current transformers, the accuracy class is designed by the highest permissible percentage composite error at the rated accuracy limit primary current prescribed for the accuracy class concerned, followed by the letter "P" (meaning protection).

Table 1191: Limits of errors according to IEC 60044-1 for protective current transformers

Accuracy class	Current error at rated primary current (%)	Phase displacement at rated primary current		Composite error at rated accuracy limit primary current (%)
		minutes	centiradians	
5P	±1	±60	±1.8	5
10P	±3	-	-	10

The accuracy classes 5P and 10P are both suitable for non-directional overcurrent protection. The 5P class provides a better accuracy. This should be noted also if there are accuracy requirements for the metering functions (current metering, power metering, and so on) of the protection relay.

The CT accuracy primary limit current describes the highest fault current magnitude at which the CT fulfils the specified accuracy. Beyond this level, the secondary current of the CT is distorted and it might have severe effects on the performance of the protection relay.

In practise, the actual accuracy limit factor (F_a) differs from the rated accuracy limit factor (F_n) and is proportional to the ratio of the rated CT burden and the actual CT burden.

The actual accuracy limit factor is calculated using the formula:

$$F_a \approx F_n \times \frac{|S_{in} + S_n|}{|S_{in} + S|}$$

F_n	the accuracy limit factor with the nominal external burden S_n
S_{in}	the internal secondary burden of the CT
S	the actual external burden

12.1.1.2 Non-directional overcurrent protection

The current transformer selection

Non-directional overcurrent protection does not set high requirements on the accuracy class or on the actual accuracy limit factor (F_a) of the CTs. It is, however, recommended to select a CT with F_a of at least 20.

The nominal primary current I_{1n} should be chosen in such a way that the thermal and dynamic strength of the current measuring input of the protection relay is not exceeded. This is always fulfilled when

$I_{1n} > I_{kmax} / 100$,

I_{kmax} is the highest fault current.

The saturation of the CT protects the measuring circuit and the current input of the protection relay. For that reason, in practice, even a few times smaller nominal primary current can be used than given by the formula.

Recommended start current settings

If I_{kmin} is the lowest primary current at which the highest set overcurrent stage is to operate, the start current should be set using the formula:

Current start value $< 0.7 \times (I_{kmin} / I_{1n})$

I_{1n} is the nominal primary current of the CT.

The factor 0.7 takes into account the protection relay inaccuracy, current transformer errors, and imperfections of the short circuit calculations.

The adequate performance of the CT should be checked when the setting of the high set stage overcurrent protection is defined. The operate time delay caused by the CT saturation is typically small enough when the overcurrent setting is noticeably lower than F_a.

When defining the setting values for the low set stages, the saturation of the CT does not need to be taken into account and the start current setting is simply according to the formula.

Delay in operation caused by saturation of current transformers

The saturation of CT may cause a delayed protection relay operation. To ensure the time selectivity, the delay must be taken into account when setting the operate times of successive protection relays.

With definite time mode of operation, the saturation of CT may cause a delay that is as long as the time constant of the DC component of the fault current, when the current is only slightly higher than the starting current. This depends on the accuracy limit factor of the CT, on the remanence flux of the core of the CT, and on the operate time setting.

With inverse time mode of operation, the delay should always be considered as being as long as the time constant of the DC component.

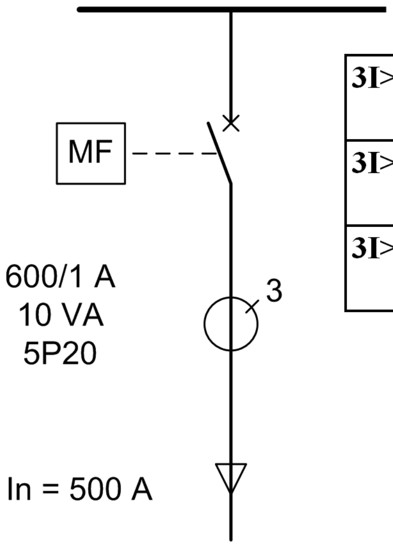
With inverse time mode of operation and when the high-set stages are not used, the AC component of the fault current should not saturate the CT less than 20 times the starting current. Otherwise, the inverse operation time can be further prolonged. Therefore, the accuracy limit factor F_a should be chosen using the formula:

$F_a > 20 \times \textit{Current start value} / I_{1n}$

The *Current start value* is the primary start current setting of the protection relay.

12.1.1.3 Example for non-directional overcurrent protection

The following figure describes a typical medium voltage feeder. The protection is implemented as three-stage definite time non-directional overcurrent protection.



3I>	**1200 A** **0.75 s**	**2.00 x I_{2n}** **0.75 s**
3I>>	**1800A** **0.50 s**	**3.00 x I_{2n}** **0.50 s**
3I>>>	**3500 A** **0.20 s**	**5.83 x I_{2n}** **0.20 s**

Figure 679: Example of three-stage overcurrent protection

The maximum three-phase fault current is 41.7 kA and the minimum three-phase short circuit current is 22.8 kA. The actual accuracy limit factor of the CT is calculated to be 59.

The start current setting for low-set stage (3I>) is selected to be about twice the nominal current of the cable. The operate time is selected so that it is selective with the next protection relay (not visible in Figure 679). The settings for the high-set stage and instantaneous stage are defined also so that grading is ensured with the downstream protection. In addition, the start current settings have to be defined so that the protection relay operates with the minimum fault current and it does not operate with the maximum load current. The settings for all three stages are as in Figure 679.

For the application point of view, the suitable setting for instantaneous stage (I>>>) in this example is 3 500 A (5.83 × I_{2n}). I_{2n} is the 1.2 multiple with nominal primary current of the CT. For the CT characteristics point of view, the criteria given by the current transformer selection formula is fulfilled and also the protection relay setting is considerably below the F_a. In this application, the CT rated burden could have been selected much lower than 10 VA for economical reasons.

Section 13 IED physical connections

13.1 Protective earth connections

The IED shall be earthed with a 16.0 mm^2 flat copper cable.

The earth lead should be as short as possible, distance to nearest eartning point shall be less than 1500 mm.

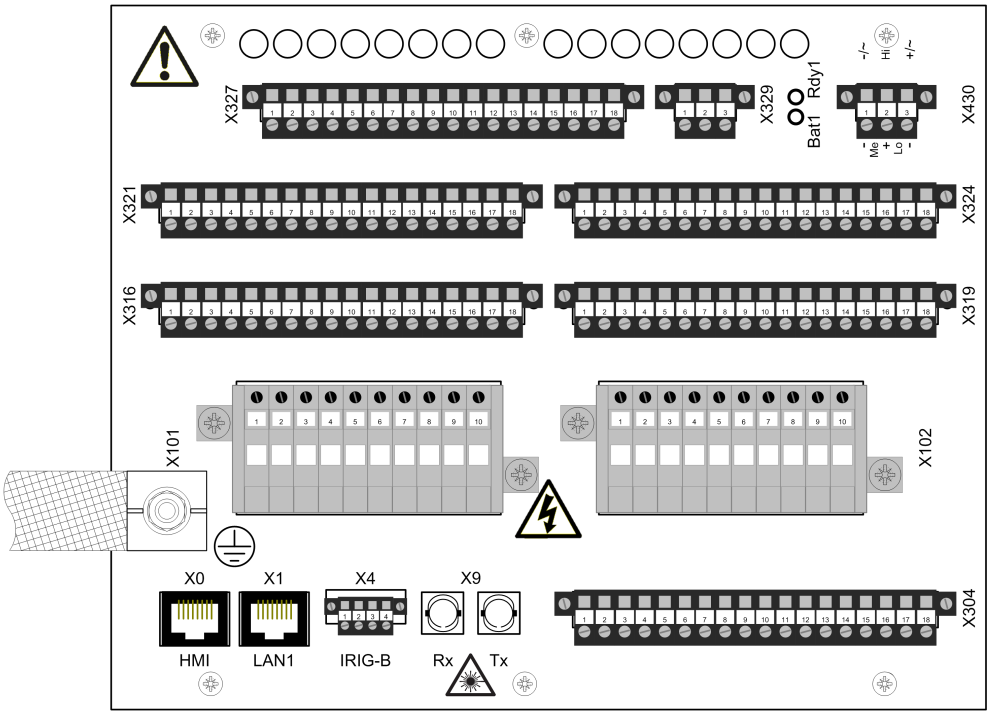


Figure 680: Protective earth pin is located to the left of connector X101 on the 4U half 19” case

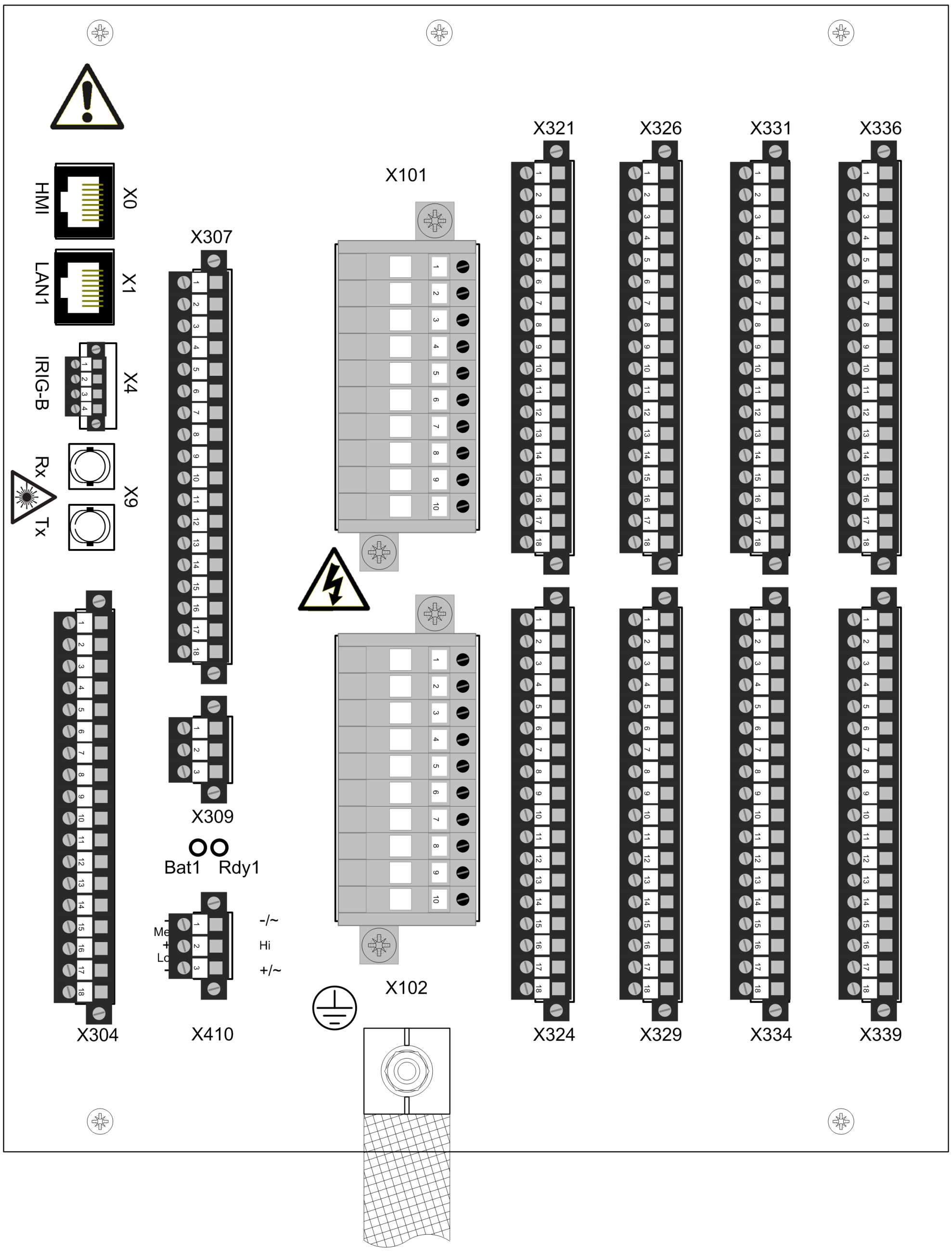


Figure 681: Protective earth pin is located below connector X102 on the 6U half 19" case

13.2 Inputs

13.2.1 Measuring inputs

Each terminal for CTs/VTs is dimensioned for one 0.5...6.0 mm^2 wire or for two wires of maximum 2.5 mm^2.

Table 1192: REF630 modules

Terminal	AIMA01A 1KHL178012R0008	AIMA03A 1KHL178012R0009	AIMA02A 1KHL178012R0010
X101-1, 2	CT	CT	CT
X101-3, 4	CT	CT	CT
X101-5, 6	CT	CT	CT
X101-7, 8	CT	None	CT
X101-9, 10	None	CT_S 1)	CT_S 1)
X102-1, 2	VT	VT	None
X102-3, 4	VT	VT	VT
X102-5, 6	VT	VT	VT
X102-7, 8	VT	VT	VT
X102-9, 10	VT	VT	VT

1) Current Transducer for 0.1 A / 0.5 A

Table 1193: REG630 and REM630 modules

Terminal	AIMA02A 1KHL178012R0010	AIMA04A 1KHL178012R0005	AIMA05A 1KHL178012R0013
X101-1, 2	CT	CT	CT
X101-3, 4	CT	CT	CT
X101-5, 6	CT	CT	CT
X101-7, 8	CT	CT	CT
X101-9, 10	CT_S 1)	CT	CT
X102-1, 2	None	CT	CT
X102-3, 4	VT	CT	CT
X102-5, 6	VT	VT	CT
X102-7, 8	VT	VT	VT
X102-9, 10	VT	VT	VT

1) Current Transducer for 0.1 A / 0.5 A

Table 1194: RET630 modules

Terminal	AIMA04A 1KHL178012R0005	AIMA06A 1KHL178012R0012	AIMA05A 1KHL178012R0013
X101-1, 2	CT	CT	CT
X101-3, 4	CT	CT	CT
X101-5, 6	CT	CT	CT
X101-7, 8	CT	CT	CT
X101-9, 10	CT	CT	CT
X102-1, 2	CT	CT	CT
X102-3, 4	CT	CT	CT
X102-5, 6	VT	CT_S 1)	CT
X102-7, 8	VT	VT	VT
X102-9, 10	VT	VT	VT

1) Current Transducer for 0.1 A / 0.5 A

13.2.2 Auxiliary supply voltage input

The auxiliary voltage of the IED is connected to terminals X430-1 and X430-2/3 or X410-1 and X410-2/3. The terminals used depend on the power supply and the IED case size.

The permitted auxiliary voltage range of the IED is marked on the device label on the side of the IED.

Table 1195: Auxiliary voltage supply of 110...250 V DC or 100...240 V AC

Case	Terminal	Description
4U half 19”	X430-1	- Input
	X430-3	+ Input
6U half 19”	X410-1	- Input
	X410-3	+ Input

Table 1196: Auxiliary voltage supply of 48-125 V DC

Case	Terminal	Description
4U half 19”	X430-1	- Input
	X430-2	+ Input
6U half 19”	X410-1	- Input
	X410-2	+ Input

13.2.3 Binary inputs

The binary inputs can be used, for example, for status indications, to generate a blocking signal, to unlatch output contacts, to trigger the disturbance recorder or for remote control of IED settings.

Each signal connector terminal is dimensioned for one 0.5...2.5 mm^2 wire or for two 0.5...1.0 mm^2 wires.

Use only DC power for the binary inputs. Use of AC power, including full- or half-wave rectified AC power, may cause damage to the binary input modules.

Table 1197: Binary inputs X304, 4U half 19” and 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X304-1	Common - for inputs 1-4		
X304-2	Binary input 1 +	COM_101	BI1
X304-3	Binary input 2 +	COM_101	BI2
X304-4	Binary input 3 +	COM_101	BI3
X304-5	Binary input 4 +	COM_101	BI4
X304-6	Common - for inputs 5-8		
X304-7	Binary input 5 +	COM_101	BI5
X304-8	Binary input 6 +	COM_101	BI6
X304-9	Binary input 7 +	COM_101	BI7
X304-10	Binary input 8 +	COM_101	BI8
X304-11	Common - for inputs 9-11		
X304-12	Binary input 9 +	COM_101	BI9
X304-13	Binary input 10 +	COM_101	BI10
X304-14	Binary input 11 +	COM_101	BI11
X304-15	Common - for inputs 12-14		
X304-16	Binary input 12 +	COM_101	BI12
X304-17	Binary input 13 +	COM_101	BI13
X304-18	Binary input 14 +	COM_101	BI14

Table 1198: Binary inputs X319, 4U half 19"

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X319-1	- for input 1	BIO_3	BI1
X319-2	Binary input 1 +	BIO_3	BI1
X319-3	-		
X319-4	Common - for inputs 2-3		
X319-5	Binary input 2 +	BIO_3	BI2
X319-6	Binary input 3 +	BIO_3	BI3
X319-7	-		
X319-8	Common - for inputs 4-5		
X319-9	Binary input 4 +	BIO_3	BI4
X319-10	Binary input 5 +	BIO_3	BI5
X319-11	-		
X319-12	Common - for inputs 6-7		
X319-13	Binary input 6 +	BIO_3	BI6
X319-14	Binary input 7 +	BIO_3	BI7
X319-15	-		
X319-16	Common - for inputs 8-9		
X319-17	Binary input 8 +	BIO_3	BI8
X319-18	Binary input 9 +	BIO_3	BI9

Table 1199: Binary inputs X324, 4U half 19"

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X324-1	- for input 1	BIO_4	BI1
X324-2	Binary input 1 +	BIO_4	BI1
X324-3	-		
X324-4	Common - for inputs 2-3		
X324-5	Binary input 2 +	BIO_4	BI2
X324-6	Binary input 3 +	BIO_4	BI3
X324-7	-		
X324-8	Common - for inputs 4-5		
X324-9	Binary input 4 +	BIO_4	BI4
X324-10	Binary input 5 +	BIO_4	BI5
X324-11	-		
X324-12	Common - for inputs 6-7		
X324-13	Binary input 6 +	BIO_4	BI6
X324-14	Binary input 7 +	BIO_4	BI7

Table continues on next page

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X324-15	-		
X324-16	Common - for inputs 8-9		
X324-17	Binary input 8 +	BIO_4	BI8
X324-18	Binary input 9 +	BIO_4	BI9

Table 1200: Binary inputs X324, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X324-1	- for input 1	BIO_3	BI1
X324-2	Binary input 1 +	BIO_3	BI1
X324-3	-		
X324-4	Common - for inputs 2-3		
X324-5	Binary input 2 +	BIO_3	BI2
X324-6	Binary input 3 +	BIO_3	BI3
X324-7	-		
X324-8	Common - for inputs 4-5		
X324-9	Binary input 4 +	BIO_3	BI4
X324-10	Binary input 5 +	BIO_3	BI5
X324-11	-		
X324-12	Common - for inputs 6-7		
X324-13	Binary input 6 +	BIO_3	BI6
X324-14	Binary input 7 +	BIO_3	BI7
X324-15	-		
X324-16	Common - for inputs 8-9		
X324-17	Binary input 8 +	BIO_3	BI8
X324-18	Binary input 9 +	BIO_3	BI9

Table 1201: Binary inputs X329, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X329-1	- for input 1	BIO_4	BI1
X329-2	Binary input 1 +	BIO_4	BI1
X329-3	-		
X329-4	Common - for inputs 2-3		
X329-5	Binary input 2 +	BIO_4	BI2
X329-6	Binary input 3 +	BIO_4	BI3
X329-7	-		
Table continues on next page			

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X329-8	Common - for inputs 4-5		
X329-9	Binary input 4 +	BIO_4	BI4
X329-10	Binary input 5 +	BIO_4	BI5
X329-11	-		
X329-12	Common - for inputs 6-7		
X329-13	Binary input 6 +	BIO_4	BI6
X329-14	Binary input 7 +	BIO_4	BI7
X329-15	-		
X329-16	Common - for inputs 8-9		
X329-17	Binary input 8 +	BIO_4	BI8
X329-18	Binary input 9 +	BIO_4	BI9

Table 1202: Binary inputs X334, 6U half 19"

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X334-1	- for input 1	BIO_5	BI1
X334-2	Binary input 1 +	BIO_5	BI1
X334-3	-		
X334-4	Common - for inputs 2-3		
X334-5	Binary input 2 +	BIO_5	BI2
X334-6	Binary input 3 +	BIO_5	BI3
X334-7	-		
X334-8	Common - for inputs 4-5		
X334-9	Binary input 4 +	BIO_5	BI4
X334-10	Binary input 5 +	BIO_5	BI5
X334-11	-		
X334-12	Common - for inputs 6-7		
X334-13	Binary input 6 +	BIO_5	BI6
X334-14	Binary input 7 +	BIO_5	BI7
X334-15	-		
X334-16	Common - for inputs 8-9		
X334-17	Binary input 8 +	BIO_5	BI8
X334-18	Binary input 9 +	BIO_5	BI9

Table 1203: Binary inputs X339, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X339-1	- for input 1	BIO_6	BI1
X339-2	Binary input 1 +	BIO_6	BI1
X339-3	-		
X339-4	Common - for inputs 2-3		
X339-5	Binary input 2 +	BIO_6	BI2
X339-6	Binary input 3 +	BIO_6	BI3
X339-7	-		
X339-8	Common - for inputs 4-5		
X339-9	Binary input 4 +	BIO_6	BI4
X339-10	Binary input 5 +	BIO_6	BI5
X339-11	-		
X339-12	Common - for inputs 6-7		
X339-13	Binary input 6 +	BIO_6	BI6
X339-14	Binary input 7 +	BIO_6	BI7
X339-15	-		
X339-16	Common - for inputs 8-9		
X339-17	Binary input 8 +	BIO_6	BI8
X339-18	Binary input 9 +	BIO_6	BI9

13.2.4 RTD inputs

Table 1204: Module inputs, 4U half 19”

Terminal	600RTD01	ACT info	
		Hardware module instance	Hardware channel
X316 – 1,2,3	Sensor/ R/ V/ mA input	RTD_3	AI1
X316 - 4	GND		
X316 – 5,6,7	Sensor/ R/ V/ mA input	RTD_3	AI2
X316 – 8,9,10	Sensor/ R/ V/ mA input	RTD_3	AI3
X316 – 11	GND		
X316 – 12,13,14	Sensor/ R/ V/ mA input	RTD_3	AI4
X316 – 15,16,17	Sensor/ R/ V/ mA input	RTD_3	AI5
X316 – 18	GND		

Table 1205: Module inputs, 4U half 19”

Terminal	600RTD01	ACT info	
		Hardware module instance	Hardware channel
X319 – 1,2,3	Sensor/ R/ V/ mA input	RTD_3	AI1
X319 – 4,5,6	Sensor/ R/ V/ mA input	RTD_3	AI2
X319 – 7	GND		
X319 – 8,9,10	Sensor/ R/ V/ mA input	RTD_3	AI3

Table 1206: Module inputs, 6U half 19”

Terminal	600RTD01	ACT info	
		Hardware module instance	Hardware channel
X321 – 1,2,3	Sensor/ R/ V/ mA input	RTD_3	AI1
X321 - 4	GND		
X321 – 5,6,7	Sensor/ R/ V/ mA input	RTD_3	AI2
X321 – 8,9,10	Sensor/ R/ V/ mA input	RTD_3	AI3
X321 – 11	GND		
X321 – 12,13,14	Sensor/ R/ V/ mA input	RTD_3	AI4
X321 – 15,16,17	Sensor/ R/ V/ mA input	RTD_3	AI5
X321 – 18	GND		

Table 1207: Module inputs, 6U half 19”

Terminal	600RTD01	ACT info	
		Hardware module instance	Hardware channel
X324 – 1,2,3	Sensor/ R/ V/ mA input	RTD_3	AI1
X324 – 4,5,6	Sensor/ R/ V/ mA input	RTD_3	AI2
X324 – 7	GND		
X324 – 8,9,10	Sensor/ R/ V/ mA input	RTD_3	AI3

13.3 Outputs

13.3.1 Outputs for tripping and controlling

Output contacts PO1, PO2 and PO3 are power output contacts used, for example, for controlling circuit breakers.

Each signal connector terminal is dimensioned for one 0.5...2.5 mm^2 wire or for two 0.5...1.0 mm^2 wires.

Check the DC polarity of the TCS outputs.

Table 1208: Output contacts X307, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
  X307-1 X307-2	Power output 1, normally open (TCS) - +	PSM_102	BO1_PO_TCS
  X307-3 X307-4	Power output 2, normally open (TCS) - +	PSM_102	BO2_PO_TCS
  X307-5 X307-6	Power output 3, normally open (TCS) - +	PSM_102	BO3_PO_TCS
X307-7 X307-8	Power output 4, normally open	PSM_102	BO4_PO
X307-9 X307-10	Power output 5, normally open	PSM_102	BO5_PO
X307-11 X307-12	Power output 6, normally open	PSM_102	BO6_PO

Table 1209: Output contacts X316, 4U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X316-1 X316-2	Power output 1, normally open	BIO_3	BO1_PO
X316-3	Power output 2, normally open	BIO_3	BO2_PO

Table continues on next page

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X316-4			
X316-5 X316-6	Power output 3, normally open	BIO_3	BO3_PO

Table 1210: Output contacts X321, 4U half 19"

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X321-1 X321-2	Power output 1, normally open	BIO_4	BO1_PO
X321-3 X321-4	Power output 2, normally open	BIO_4	BO2_PO
X321-5 X321-6	Power output 3, normally open	BIO_4	BO3_PO

Table 1211: Output contacts X321, 6U half 19"

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X321-1 X321-2	Power output 1, normally open	BIO_3	BO1_PO
X321-3 X321-4	Power output 2, normally open	BIO_3	BO2_PO
X321-5 X321-6	Power output 3, normally open	BIO_3	BO3_PO

Table 1212: Output contacts X326, 6U half 19"

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X326-1 X326-2	Power output 1, normally open	BIO_4	BO1_PO
X326-3 X326-4	Power output 2, normally open	BIO_4	BO2_PO
X326-5 X326-6	Power output 3, normally open	BIO_4	BO3_PO

Table 1213: Output contacts X327, 4U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
 X327-1 X327-2	Power output 1, normally open (TCS) - +	PSM_102	BO1_PO_TCS
 X327-3 X327-4	Power output 2, normally open (TCS) - +	PSM_102	BO2_PO_TCS
 X327-5 X327-6	Power output 3, normally open (TCS) – +	PSM_102	BO3_PO_TCS
X327-7 X327-8	Power output 4, normally open	PSM_102	BO4_PO
X327-9 X327-10	Power output 5, normally open	PSM_102	BO5_PO
X327-11 X327-12	Power output 6, normally open	PSM_102	BO6_PO

Table 1214: Output contacts X331, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X331-1 X331-2	Power output 1, normally open	BIO_5	BO1_PO
X331-3 X331-4	Power output 2, normally open	BIO_5	BO2_PO
X331-5 X331-6	Power output 3, normally open	BIO_5	BO3_PO

Table 1215: Output contacts X336, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X336-1 X336-2	Power output 1, normally open	BIO_6	BO1_PO
X336-3 X336-4	Power output 2, normally open	BIO_6	BO2_PO
X336-5 X336-6	Power output 3, normally open	BIO_6	BO3_PO

13.3.2 Outputs for signalling

Signal output contacts are used for signalling on starting and tripping of the IED. If the IED is ordered with pre-configuration, the necessary start and alarm signals from used functions are routed to signalling outputs. See the application manual for more details.

Each signal connector terminal is dimensioned for one 0.5...2.5 mm^2 wire or for two 0.5...1.0 mm^2 wires.

Table 1216: Output contacts X307, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X307-13 X307-14	Signal output 1, normally open	PSM_102	BO7_SO
X307-15 X307-16	Signal output 2, normally open	PSM_102	BO8_SO
X307-17 X307-18	Signal output 3, normally open	PSM_102	BO9_SO

Table 1217: Output contacts X316, 4U half 19”

Terminal	Description	ACT info	
		Hardware Module instance	Hardware channel
X316-7 X316-8	Signal output 1, normally open Signal output 1	BIO_3	BO4_SO
X316-9 X316-10	Signal output 2, normally open Signal output 2	BIO_3	BO5_SO
X316-11 X316-12	Signal output 3, normally open Signal output 3	BIO_3	BO6_SO
X316-13 X316-14 X316-15	Signal output 4, normally open Signal output 5, normally open Signal outputs 4 and 5, common	BIO_3 BIO_3	BO7_SO BO8_SO
X316-16 X316-17 X316-18	Signal output 6, normally closed Signal output 6, normally open Signal output 6, common	BIO_3	BO9_SO

Table 1218: Output contacts X321, 4U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X321-7 X321-8	Signal output 1, normally open Signal output 1	BIO_4	BO4_SO
X321-9 X321-10	Signal output 2, normally open Signal output 2	BIO_4	BO5_SO
X321-11 X321-12	Signal output 3, normally open Signal output 3	BIO_4	BO6_SO
X321-13 X321-14 X321-15	Signal output 4, normally open Signal output 5, normally open Signal outputs 4 and 5, common	BIO_4 BIO_4	BO7_SO BO8_SO
X321-16 X321-17 X321-18	Signal output 6, normally closed Signal output 6, normally open Signal output 6, common	BIO_4	BO9_SO

Table 1219: Output contacts X321, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X321-7 X321-8	Signal output 1, normally open Signal output 1	BIO_3	BO4_SO
X321-9 X321-10	Signal output 2, normally open Signal output 2	BIO_3	BO5_SO
X321-11 X321-12	Signal output 3, normally open Signal output 3	BIO_3	BO6_SO
X321-13 X321-14 X321-15	Signal output 4, normally open Signal output 5, normally open Signal outputs 4 and 5, common	BIO_3 BIO_3	BO7_SO BO8_SO
X321-16 X321-17 X321-18	Signal output 6, normally closed Signal output 6, normally open Signal output 6, common	BIO_3	BO9_SO

Table 1220: Output contacts X326, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X326-7 X326-8	Signal output 1, normally open Signal output 1	BIO_4	BO4_SO
X326-9 X326-10	Signal output 2, normally open Signal output 2	BIO_4	BO5_SO
Table continues on next page			

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X326-11 X326-12	Signal output 3, normally open Signal output 3	BIO_4	BO6_SO
X326-13 X326-14 X326-15	Signal output 4, normally open Signal output 5, normally open Signal outputs 4 and 5, common	BIO_4 BIO_4	BO7_SO BO8_SO
X326-16 X326-17 X326-18	Signal output 6, normally closed Signal output 6, normally open Signal output 6, common	BIO_4	BO9_SO

Table 1221: Output contacts X327, 4U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X327-13 X327-14	Signal ouput 1, normally open	PSM_102	BO7_SO
X327-15 X327-16	Signal ouput 2, normally open	PSM_102	BO8_SO
X327-17 X327-18	Signal ouput 3, normally open	PSM_102	BO9_SO

Table 1222: Output contacts X331, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X331-7 X331-8	Signal output 1, normally open Signal output 1	BIO_5	BO4_SO
X331-9 X331-10	Signal output 2, normally open Signal output 2	BIO_5	BO5_SO
X331-11 X331-12	Signal output 3, normally open Signal output 3	BIO_5	BO6_SO
X331-13 X331-14 X331-15	Signal output 4, normally open Signal output 5, normally open Signal outputs 4 and 5, common	BIO_5 BIO_5	BO7_SO BO8_SO
X331-16 X331-17 X331-18	Signal output 6, normally closed Signal output 6, normally open Signal output 6, common	BIO_5	BO9_SO

Table 1223: Output contacts X336, 6U half 19”

Terminal	Description	ACT info	
		Hardware module instance	Hardware channel
X336-7 X336-8	Signal output 1, normally open Signal output 1	BIO_6	BO4_SO
X336-9 X336-10	Signal output 2, normally open Signal output 2	BIO_6	BO5_SO
X336-11 X336-12	Signal output 3, normally open Signal output 3	BIO_6	BO6_SO
X337-13 X336-14 X336-15	Signal output 4, normally open Signal output 5, normally open Signal outputs 4 and 5, common	BIO_6 BIO_6	BO7_SO BO8_SO
X336-16 X336-17 X336-18	Signal output 6, normally closed Signal output 6, normally open Signal output 6, common	BIO_6	BO9_SO

13.3.3 mA outputs

Table 1224: Module outputs, 4U half 19”

Terminal	600RTD01	ACT info	
		Hardware module instance	Hardware channel
X319 – 11,12	mA output	RTD_3	AO1
X319 – 13,14	mA output	RTD_3	AO2
X319 – 15,16	mA output	RTD_3	AO3
X319 – 17,18	mA output	RTD_3	AO4

Table 1225: Module outputs, 6U half 19”

Terminal	600RTD01	ACT info	
		Hardware module instance	Hardware channel
X324 – 11,12	mA output	RTD_3	AO1
X324 – 13,14	mA output	RTD_3	AO2
X324 – 15,16	mA output	RTD_3	AO3
X324 – 17,18	mA output	RTD_3	AO4

13.3.4 IRF

The IRF contact functions as a change-over output contact for the self-supervision system of the IED. Under normal operating conditions, the IED is energized and one of the two contacts is closed. When a fault is detected by the self-supervision system or the auxiliary voltage is disconnected, the closed contact drops off and the other contact closes.

Each signal connector terminal is dimensioned for one 0.5...2.5 mm^2 wire or for two 0.5...1.0 mm^2 wires.

Table 1226: IRF contact X309

Case	Terminal	Description
6U half 19”	X309-1	Closed; no IRF, and U_{aux} connected
	X309-2	Closed; IRF, or U_{aux} disconnected
	X309-3	IRF, common

Table 1227: IRF contact X329

Case	Terminal	Description
4U half 19”	X329-1	Closed; no IRF, and U_{aux} connected
	X329-2	Closed; IRF, or U_{aux} disconnected
	X329-3	IRF, common

13.4 Communication connections

The IED's LHMI is provided with an RJ-45 connector. The connector is intended for configuration and setting purposes.

Rear communication via the X1/LAN1 connector uses a communication module with the galvanic RJ-45 or optical LC Ethernet connection.

The HMI connector X0 is used for connecting an external HMI to the IED. The X0/HMI connector must not be used for any other purpose. An external HMI can be used only when the IED has no integrated HMI.

13.4.1 Ethernet RJ-45 front connection

The IED's LHMI is provided with an RJ-45 connector designed for point-to-point use. The connector is intended for configuration and setting purposes. The interface on the PC side has to be configured in a way that it obtains the IP address automatically. There is a DHCP server inside IED for the front interface only.

The events and setting values and all input data such as memorized values and disturbance records can be read via the front communication port.

Only one of the possible clients can be used for parametrization at a time.

- PCM600
- LHMI
- WHMI

The default IP address of the IED through this port is 192.168.0.254.

The front port supports TCP/IP protocol. A standard Ethernet CAT 5 crossover cable is used with the front port.

If IED is ordered without LHMI then LAN1 port has to be used for configuration and setting purposes. The default IP address for the LAN1 port is 192.168.2.10. DHCP is not available from LAN1 port.

13.4.2 Ethernet connection for station communication

The default IP address of the IED through the Ethernet connection is 192.168.2.10. The physical connector is X1/LAN1. The interface speed is 100 Mbps both for the 100BASE-FX LC alternative and for the 100BASE-TX RJ-45 alternative.

13.4.3 Optical serial rear connection

Serial communication can be used via optical connection in star topology. Connector type is either glass (ST connector) or plastic (snap-in connector). Connection's idle state is indicated either with light on or light off. The physical connector is X9/Rx,Tx.

13.4.4 Communication interfaces and protocols

Table 1228: Supported station communication interfaces and protocols

Protocol	Ethernet		Serial	
	100BASE-TX RJ-45	100BASE-FX LC	Glass fibre (ST connector)	Plastic fibre (snap-in connector)
IEC 61850–8–1	●	●	-	-
DNP3	●	●	-	-
IEC 60870-5-103	-	-	●	●
● = Supported				

13.4.5 Recommended third-party industrial Ethernet switches

- RuggedCom RS900
- RuggedCom RS1600
- RuggedCom RSG2100

13.5 Terminal diagrams

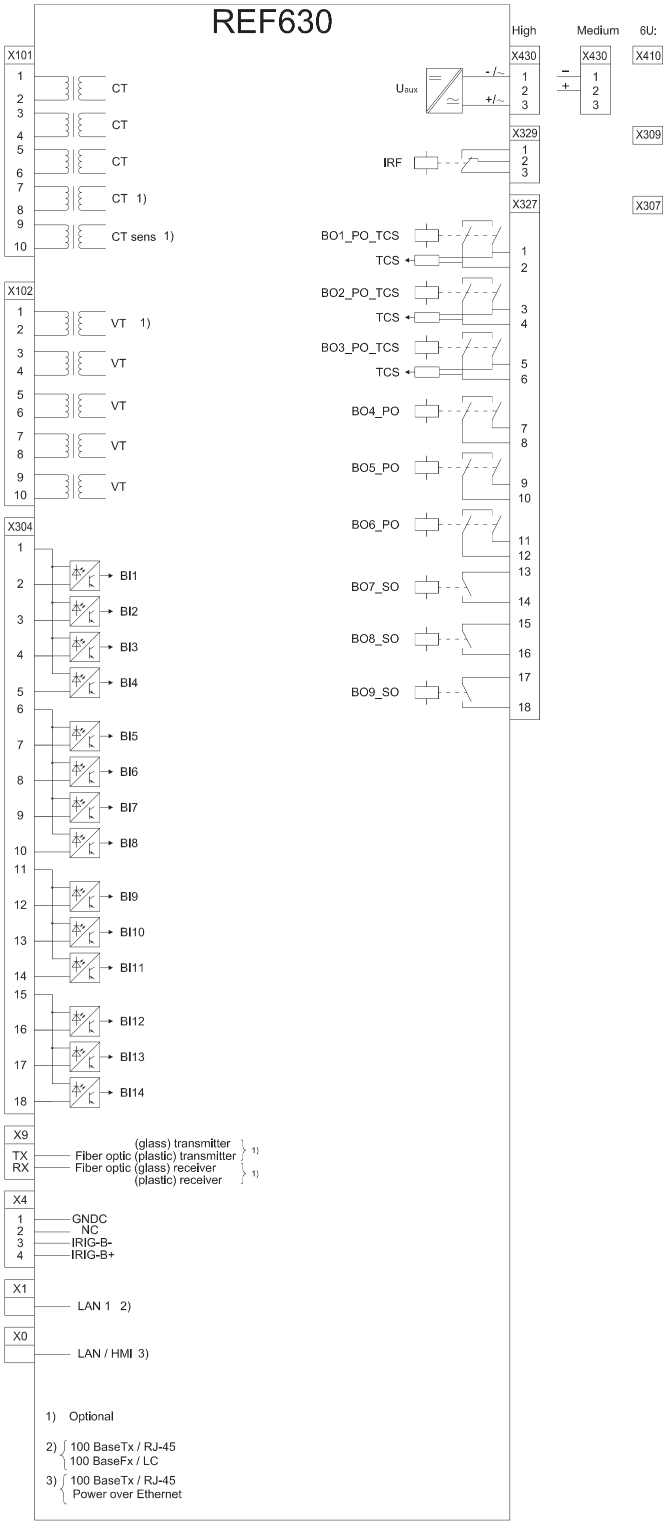
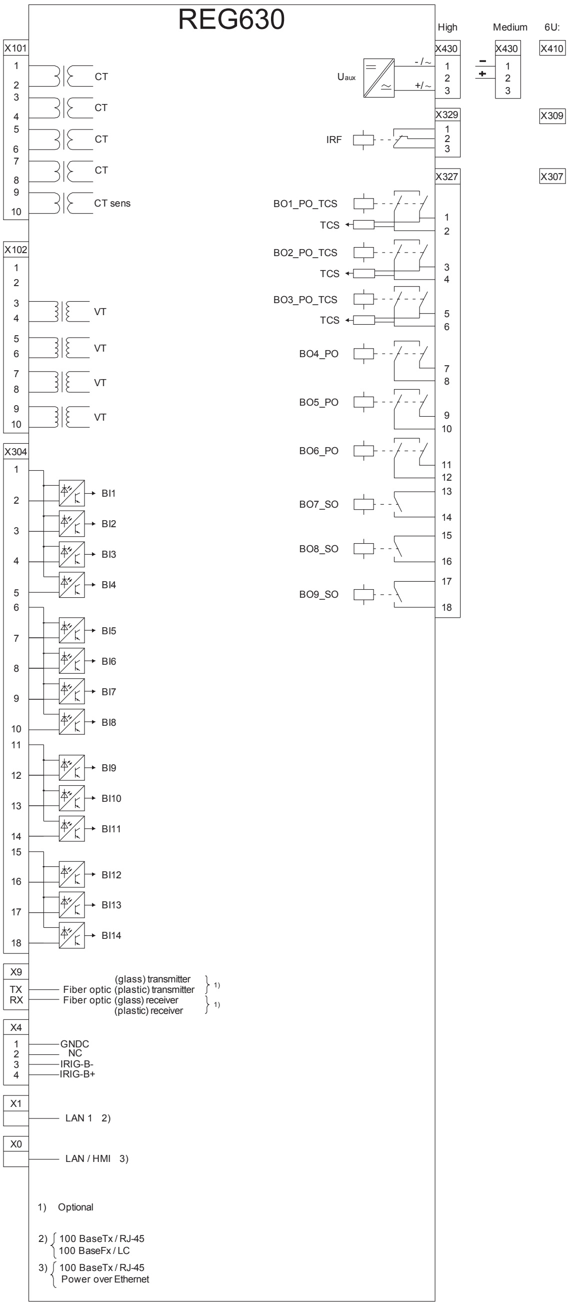


Figure 682: REF630 terminal diagram



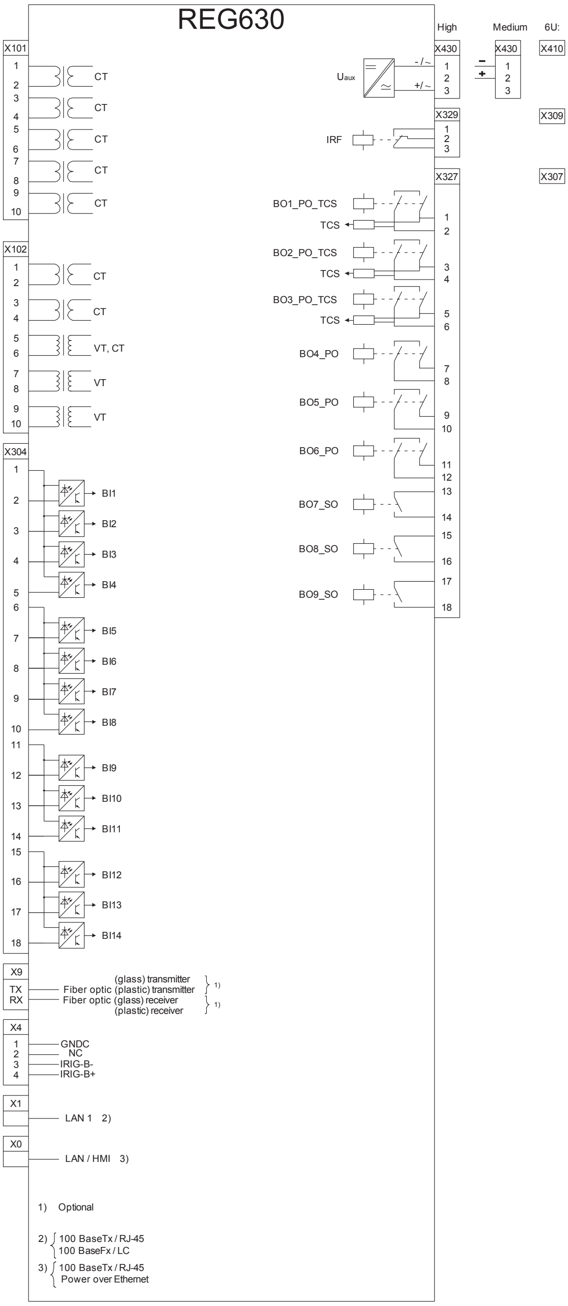


Figure 683: REG630 terminal diagram

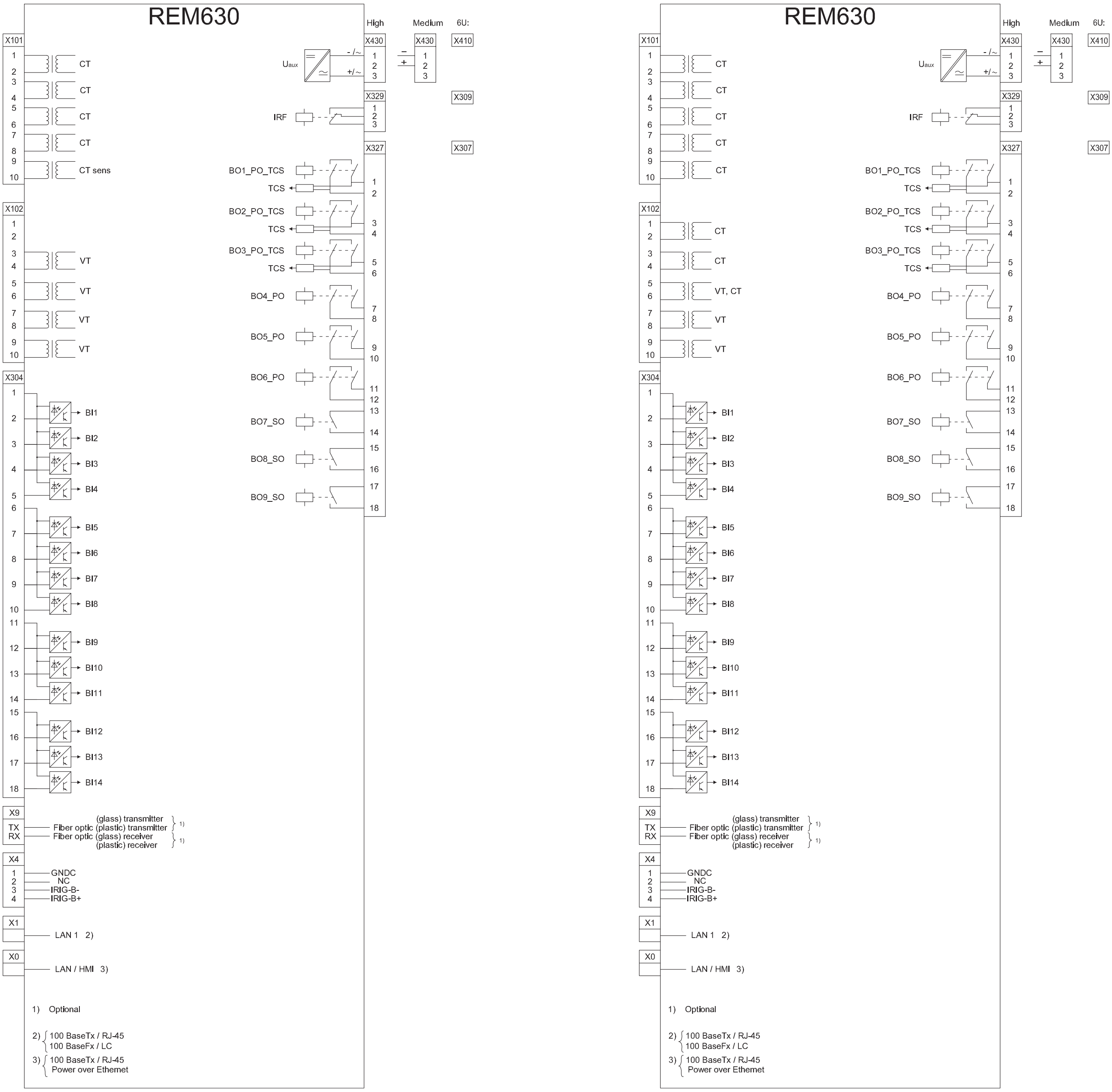


Figure 684: REM630 terminal diagram

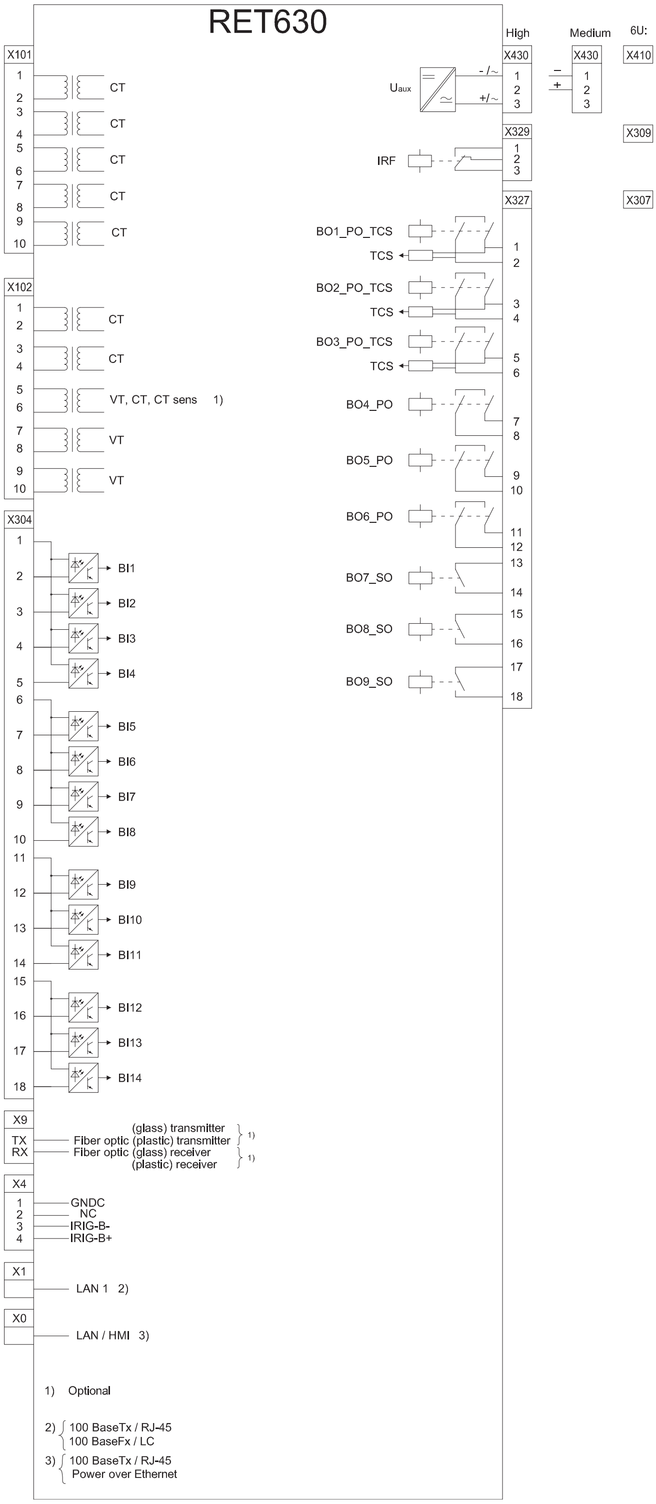


Figure 685: RET630 terminal diagram

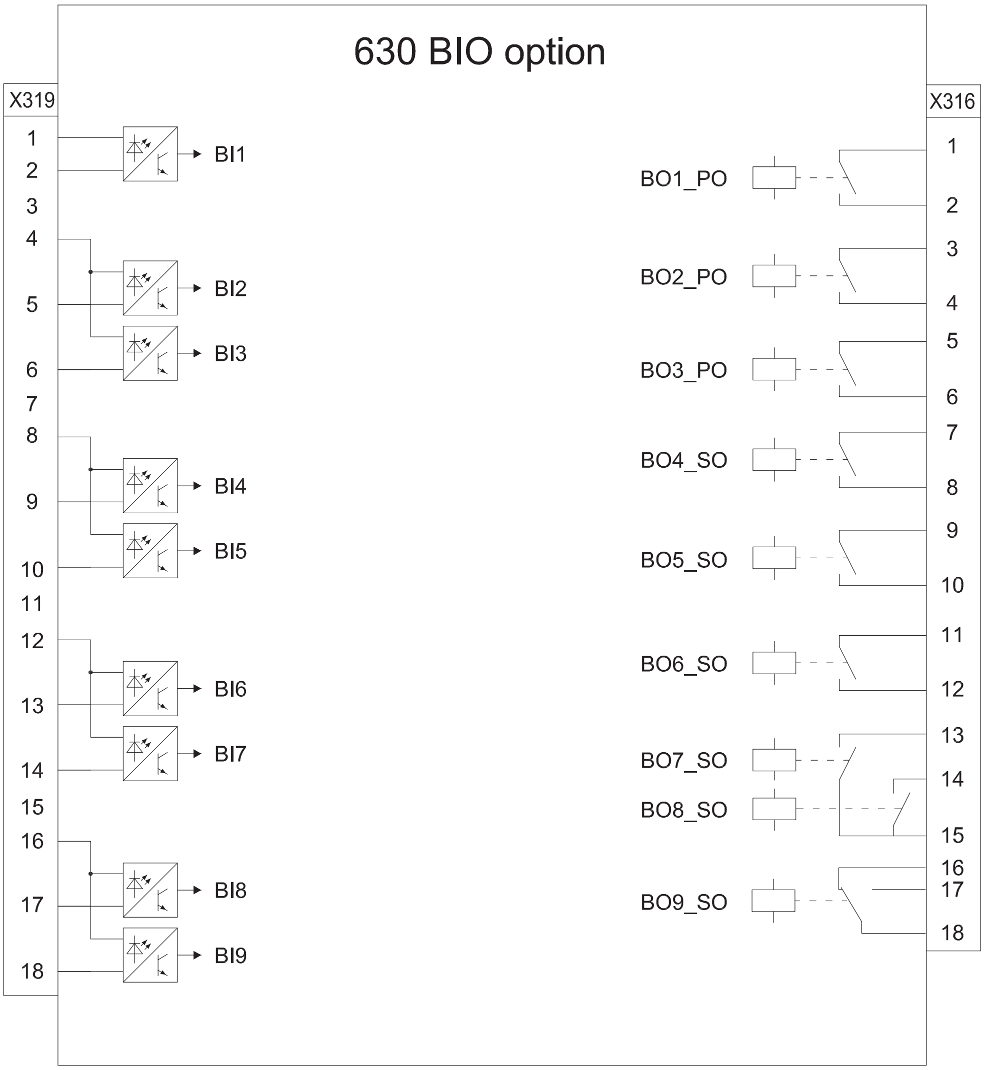


Figure 686: 630 series BIO module option

Table 1229: BIO options

Unit	BI/BO
4U	X319 + X316 1)
	X324 + X321
6U	X324 + X321 1)
	X329 + X326
	X334 + X331
	X339 + X336

1) Occupied by RTD module when ordered

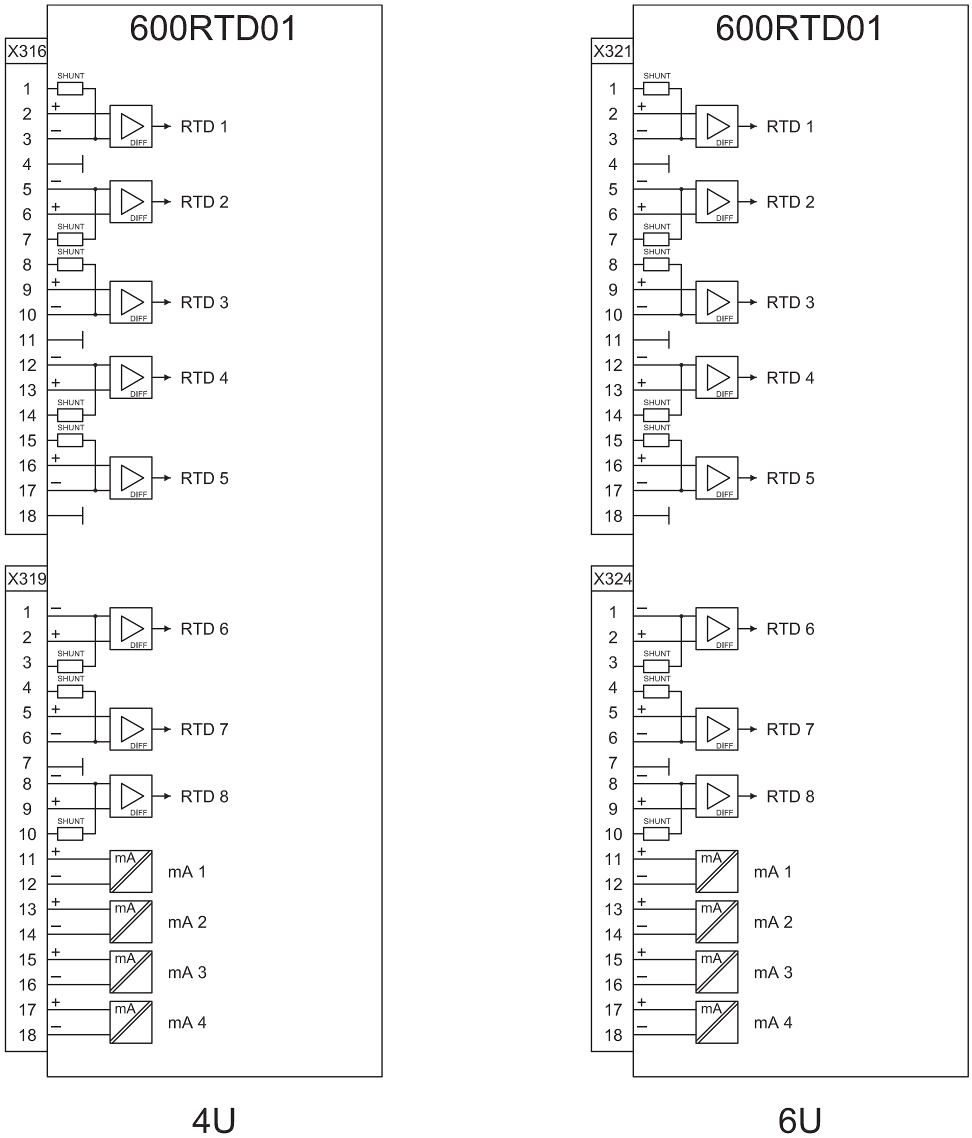


Figure 687: 630 series RTD module option

Section 14 Technical data

Table 1230: Dimensions of the IED - half 19" rack

Description	Value
Width	220 mm
Height	177 mm (4U) 265.9 mm (6U)
Depth	249.5 mm
Weight box	6.2 kg (4U) 5.5 kg (6U)[1)]
Weight LHMI	1.0 kg (4U)

1) Without LHMI

Table 1231: Power supply

Description	600PSM03	600PSM02
U_{aux}nominal	100, 110, 120, 220, 240 V AC, 50 and 60 Hz	48, 60, 110, 125 V DC
	110, 125, 220, 250 V DC	
U_{aux}variation	85...110% of U_n (85...264 V AC)	80...120% of U_n (38.4...150 V DC)
	80...120% of U_n (88...300 V DC)	
Maximum load of auxiliary voltage supply	35 W	
Ripple in the DC auxiliary voltage	Max 15% of the DC value (at frequency of 100 Hz)	
Maximum interruption time in the auxiliary DC voltage without resetting the protection relay	50 ms at U_{aux}	
Power supply input must be protected by an external miniature circuit breaker	For example, type S282 UC-K. The rated maximum load of aux voltage which is given as 35 watts. Depending on the voltage used, select a suitable MCB based on the respective current. Type S282 UC-K has a rated current of 0.75 A at 400 V AC.	

Table 1232: Energizing inputs

Description		Value	
Rated frequency		50/60 Hz	
Operating range		Rated frequency ±5 Hz	
Current inputs	Rated current, I_n	0.1/0.5 A[1)]	1/5 A[2)]
	Thermal withstand capability:		
	• Continuously	4 A	20 A
	• For 1 s	100 A	500 A
	• For 10 s	25 A	100 A
	Dynamic current withstand:		
	• Half-wave value	250 A	1250 A
	Input impedance	<100 mΩ	<20 mΩ
Voltage inputs	Rated voltage, U_n	100 V AC/ 110 V AC/ 115 V AC/ 120 V AC	
	Voltage withstand:		
	• Continuous	425 V AC	
	• For 10 s	450 V AC	
	Burden at rated voltage	<0.05 VA	

1) Residual current
2) Phase currents or residual current

Table 1233: Binary inputs

Description	Value
Operating range	Maximum input voltage 300 V DC
Rated voltage	24...250 V DC
Current drain	1.6...1.8 mA
Power consumption/input	<0.3 W
Threshold voltage	15...221 V DC (parametrizable in the range in steps of 1% of the rated voltage)
Threshold voltage accuracy	±3.0%
Ripple in the DC auxiliary voltage	Max 15% of the DC value (at frequency of 100 Hz)

Adjust the binary input threshold voltage correctly. It is recommended to set the threshold voltage to 70% of the nominal auxiliary voltage. The factory default is 16 V to ensure the binary inputs' operation regardless of the auxiliary voltage used (24, 48, 60, 110, 125, 220 or 250 V DC). However, the default value is not optimal for the higher auxiliary voltages. The binary input threshold voltage should be set as high as possible to prevent any inadvertent activation of the binary inputs due to possible external disturbances. At the same time, the threshold should be set so that the correct operation is not jeopardized in case of undervoltage of the auxiliary voltage.

Table 1234: RTD inputs

Description		Value	
RTD inputs	Supported RTD sensor	100 Ω platinum	TCR 0.00385 (DIN 43760)
		250 Ω platinum	TCR 0.00385
		100 Ω nickel	TCR 0.00618 (DIN 43760)
		120 Ω nickel	TCR 0.00618
		10 Ω copper	TCR 0.00427
	Supported resistance range	0…10 kΩ	
	Maximum leadresistance (three-wire measurement)	100 Ω platinum	25 Ω per lead
		250 Ω platinum	25 Ω per lead
		100 Ω nickel	25 Ω per lead
		120 Ω nickel	25 Ω per lead
		10 Ω copper	2.5 Ω per lead
		Resistance	25 Ω per lead
	Isolation	4 kV	Inputs to all outputs and protective earth
	RTD / resistance sensing current	Maximum 0.275 mA rms	
	Operation accuracy / temperature	• ±1°C	Pt and Ni sensors for measuring range -40°C...200°C and -40°C...70°C ambient temperature
		• ±2°C	CU sensor for measuring range -40°C...200°C in room temperature
		• ±4°C	CU sensors -40°C...70°C ambient temperature
		• ±5°C	From -40°C...-100ºC of measurement range
	Operation accuracy / Resistance	±2.5 Ω	0...400 Ω range
		±1.25%	400 Ω...10KΩ ohms range
	Response time	< Filter time +350 ms	
Table continues on next page			

Description		Value	
mA inputs	Supported current range	-20…+20 mA	
	Current input impedance	100 Ω ±0.1%	
	Operation accuracy	±0.1% ±20 ppm per °C of full-scale	Ambient temperature -40°C...70°C
Voltage inputs	Supported voltage range	-10 V DC...+10 V DC	
	Operation accuracy	±0.1% ±40 ppm per °C of full-scale	Ambient temperature -40°C...70°C

Table 1235: Signal output and IRF output

Description	Value
Rated voltage	250 V AC/DC
Continuous contact carry	5 A
Make and carry for 3.0 s	10 A
Make and carry 0.5 s	15 A
Breaking capacity when the control-circuit time constant L/R<40 ms, at U < 48/110/220 V DC	≤0.5 A/≤0.1 A/≤0.04 A
Minimum contact load	100 mA at 24 V AC/DC

Table 1236: Power output relays without TCS function

Description	Value
Rated voltage	250 V AC/DC
Continuous contact carry	8 A
Make and carry for 3.0 s	15 A
Make and carry for 0.5 s	30 A
Breaking capacity when the control-circuit time constant L/R<40 ms, at U< 48/110/220 V DC	≤1 A/≤0.3 A/≤0.1 A
Minimum contact load	100 mA at 24 V AC/DC

Table 1237: Power output relays with TCS function

Description	Value
Rated voltage	250 V DC
Continuous contact carry	8 A
Make and carry for 3.0 s	15 A
Make and carry for 0.5 s	30 A
Breaking capacity when the control-circuit time constant L/R<40 ms, at U < 48/110/220 V DC	≤1 A/≤0.3 A/≤0.1 A
Minimum contact load	100 mA at 24 V DC

Table continues on next page

Description	Value
Control voltage range	20...250 V DC
Current drain through the supervision circuit	~1.0 mA
Minimum voltage over the TCS contact	20 V DC

Table 1238: mA outputs

Description		Value
mA outputs	Output range	-20 mA…+20 mA
	Operation accuracy	±0.2 mA
	Maximum load (including wiring resistance)	700 Ω
	Hardware response time	~80 ms
	Isolation level	4 kV

Table 1239: Ethernet interfaces

Ethernet interface	Protocol	Cable	Data transfer rate
LAN1 (X1)	TCP/IP protocol	Fibre-optic cable with LC connector or shielded twisted pair CAT 5e cable or better	100 MBits/s

Table 1240: LAN (X1) fibre-optic communication link

Wave length	Fibre type	Connector	Permitted path attenuation1)	Distance
1300 nm	MM 62.5/125 μm or MM 50/125 μm glass fibre core	LC	<7.5 dB	2 km

1) Maximum allowed attenuation caused by connectors and cable together

Table 1241: X4/IRIG-B interface

Type	Protocol	Cable
Screw terminal, pin row header	IRIG-B	Shielded twisted pair cable Recommended: CAT 5, Belden RS-485 (9841-9844) or Alpha Wire (Alpha 6222-6230)

Table 1242: X9 Optical serial interface characteristics

Wave length	Fibre type	Connector	Permitted path attenuation	Distance
820 nm	MM 62.5/125	ST	4 dB/km	1000 m
820 mm	MM 50/125	ST	4 dB/km	400 m
660 mm	1 mm	Snap-in		10 m

Table 1243: Degree of protection of flush-mounted protection relay

Description	Value
Front side	IP 40
Rear side, connection terminals	IP 20

Table 1244: Degree of protection of the LHMI

Description	Value
Front and side	IP 42

Table 1245: Environmental conditions

Description	Value
Operating temperature range	-25...+55ºC (continuous)
Short-time service temperature range	-40...+70ºC (<16h) Note: Degradation in MTBF and HMI performance outside the temperature range of -25...+55ºC
Relative humidity	<93%, non-condensing
Atmospheric pressure	86...106 kPa
Altitude	up to 2000 m
Transport and storage temperature range	-40...+85ºC

Table 1246: Environmental tests

Description	Type test value	Reference
Dry heat test (humidity <50%)	• 96 h at +55ºC • 16 h at +85ºC	IEC 60068-2-2
Cold test	• 96 h at -25ºC • 16 h at -40ºC	IEC 60068-2-1
Damp heat test, cyclic	• 6 cycles at +25…55°C, Rh >93%	IEC 60068-2-30
Storage test	• 96 h at -40ºC • 96 h at +85ºC	IEC 60068-2-1 IEC 60068-2-2

Section 15 IED and functionality tests

Table 1247: Electromagnetic compatibility tests

Description	Type test value	Reference
100 kHz and 1 MHz burst disturbance test		IEC 61000-4-18, level 3 IEC 60255-26
• Common mode	2.5 kV	
• Differential mode	1.0 kV	
3 MHz, 10 MHz and 30 MHz burst disturbance test		IEC 61000-4-18 IEC 60255-26
• Common mode	2.5 kV	
Electrostatic discharge test		IEC 61000-4-2, level 4 IEC 60255-26
• Contact discharge	8 kV	
• Air discharge	15 kV	
Radio frequency interference tests		
• Conducted, common mode	10 V (rms), f=150 kHz...80 MHz	IEC 61000-4-6 , level 3 IEC 60255-26
• Radiated, pulse-modulated	10 V/m (rms), f=900 MHz	ENV 50204 IEC 60255-26
• Radiated, amplitude-modulated	10 V/m (rms), f=80...2700 MHz	IEC 61000-4-3, level 3 IEC 60255-26
Fast transient disturbance tests		IEC 61000-4-4 IEC 60255-26
• All ports	4 kV	
Surge immunity test		IEC 61000-4-5, level 3/2 IEC 60255-26
• Communication	1 kV line-to-earth	
• Binary inputs, voltage inputs	2 kV line-to-earth 1 kV line-to-line	
• Other ports	4 kV line-to-earth, 2 kV line-to-line	
Power frequency (50 Hz) magnetic field		IEC 61000-4-8
• 1...3 s	1000 A/m	

Table continues on next page

Description	Type test value	Reference
• Continuous	300 A/m	
Pulse magnetic field immunity test	1000 A/m 8/20μs	IEC 61000-4-9
Damped oscillatory magnetic field immunity test		IEC 61000-4-10
• 2 s	100 A/m	
• 1 MHz	400 transients/s	
Power frequency immunity test	Binary inputs only	IEC 60255-26 IEC 61000-4-16
• Common mode	300 V rms	
• Differential mode	150 V rms	
Voltage dips and short interruptions	0%/50 ms Criterion A 40%/200 ms Criterion C 70%/500 ms Criterion C 0%/5000 ms Criterion C	IEC 61000-4-11 IEC 61000-4-29 IEC 60255-26
Electromagnetic emission tests		EN 55011, class A IEC 60255-26 CISPR 11 CISPR 12
• Conducted, RF-emission (mains terminal)		
0.15...0.50 MHz	<79 dB(μV) quasi peak <66 dB(μV) average	
0.5...30 MHz	<73 dB(μV) quasi peak <60 dB(μV) average	
• Radiated RF-emission		
30...230 MHz	<40 dB(μV/m) quasi peak, measured at 10 m distance	
230...1000 MHz	<47 dB(μV/m) quasi peak, measured at 10 m distance	

Table 1248: Safety-related tests

Description	Type test value	Reference
Overvoltage category	III	IEC 60255-27
Pollution degree	2	IEC 60255-27
Insulation class	Class I	IEC 60255-27
Dielectric tests	500 V, 50 Hz, 1 min, RS-485 and IRIG-B 1 kV, 50 Hz, 1 min, across open contacts 500 V, 50 Hz, 1 min, Ethernet RJ-45 2 kV, 50 Hz, 1 min, all other circuits	IEC 60255-27
Table continues on next page		

Description	Type test value	Reference
Impulse voltage test	1 kV, 1.2/50 µs, 0.5 J, RS-485 and IRIG-B 1 kV, 1.2/50 µs, 0.5 J, Ethernet RJ-45 5 kV, 1.2/50 µs, 0.5 J, all other circuits	IEC 60255-27
Insulation resistance measurements	>100 MΩ, 500 V DC	IEC 60255-27
Protective bonding resistance	<0.1 Ω, 4 A, 60 s	IEC 60255-27
Maximum temperature of parts and materials	Tested	IEC 60255-27
Flammability of insulating materials, components and fire enclosures	Evaluated / Tested	IEC 60255-27
Single-fault condition	Tested	IEC 60255-27

Table 1249: Mechanical tests

Description	Reference	Requirement
Vibration tests (sinusoidal)	IEC 60068-2-6 (test Fc) IEC 60255-21-1	Class 1
Shock and bump test	IEC 60068-2-27 (test Ea shock) IEC 60068-2-29 (test Eb bump) IEC 60255-21-2	Class 1
Seismic test	IEC 60255-21-3 (method A)	Class 1

Table 1250: Product safety

Description	Reference
LV directive	2014/35/EU
Standard	EN 60255-27 EN 60255-1

Table 1251: EMC compliance

Description	Reference
EMC directive	2014/30/EU
Standard	EN 60255-26

Section 16 Applicable standards and regulations

EU CE:

- EMC Directive 2014/30/EU
- Low-voltage directive 2014/35/EU
- RoHS Directive 2011/65/EU
- WEEE directive 2012/19/EU

- EN 60255-1
- EN 60255-26
- EN 60255-27
- EN 61000-6-2
- EN 61000-6-4

UK UKCA:

- Electromagnetic Compatibility Regulations 2016
- Electrical Equipment (Safety) Regulations 2016
- The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012

- BS EN 60255-1
- BS EN 60255-26
- BS EN 60255-27
- BS EN 61000-6-2
- BS EN 61000-6-4

IEC:

- IEC 60255-1
- IEC 60255-26
- IEC 60255-27
- IEC 61000-6-2
- IEC 61000-6-4
- IEC 61850

Section 17 Glossary

100BASE-FX	A physical medium defined in the IEEE 802.3 Ethernet standard for local area networks (LANs) that uses fiber optic cabling
100BASE-TX	A physical medium defined in the IEEE 802.3 Ethernet standard for local area networks (LANs) that uses twisted-pair cabling category 5 or higher with RJ-45 connectors
ACT	1. Application Configuration tool in PCM600 2. Trip status in IEC 61850
AIM	Analog input module
ANSI	American National Standards Institute
AVR	Automatic voltage regulator
BIO	Binary input and output
CAT 5	A twisted pair cable type designed for high signal integrity
CAT 5e	An enhanced version of CAT 5 that adds specifications for far end crosstalk
CB	Circuit breaker
CBB	Cycle building block
CBFP	Circuit breaker failure protection
CFG	Configuration file
CMT	Communication Management tool in PCM600
COMTRADE	Common format for transient data exchange for power systems. Defined by the IEEE Standard.
Connectivity package	A collection of software and information related to a specific protection and control IED, providing system products and tools to connect and interact with the IED
CPU	Central processing unit
CR	Carrier receive signal
CS	Carrier send signal
CT	Current transformer
DAT	1. Data attribute type 2. Data file

Data set	The content basis for reporting and logging containing references to the data and data attribute values
DC	1. Direct current 2. Disconnector 3. Double command
DCB	Directional comparison blocking scheme
DCUB	Directional comparison unblocking scheme
DFT	Discrete Fourier transform
DHCP	Dynamic Host Configuration Protocol
DNP3	A distributed network protocol originally developed by Westronic. The DNP3 Users Group has the ownership of the protocol and assumes responsibility for its evolution.
DT	Definite time
DUTT	Direct underreach transfer trip
Ethernet	A standard for connecting a family of frame-based computer networking technologies into a LAN
FIFO	First in, first out
FLC	Full load current
GDE	Graphical Display Editor in PCM600
GFC	General fault criteria
GOOSE	Generic Object-Oriented Substation Event
GPS	Global Positioning System
HMI	Human-machine interface
HSI	Human-system interface
HV	High voltage
HW	Hardware
I/O	Input/output
IDMT	Inverse definite minimum time
IEC	International Electrotechnical Commission
IEC 60870-5-103	1. Communication standard for protective equipment 2. A serial master/slave protocol for point-to-point communication
IEC 61850	International standard for substation communication and modeling

IEC 61850-8-1	A communication protocol based on the IEC 61850 standard series
IED	Intelligent electronic device
INF	Information number
IP	Internet protocol
IRF	1. Internal fault 2. Internal relay fault
IRIG-B	Inter-Range Instrumentation Group's time code format B
LAN	Local area network
LC	Connector type for glass fiber cable, IEC 61754-20
LDC	Line drop compensation
LED	Light-emitting diode
LHMI	Local human-machine interface
LLDB	Live line dead bus
MCB	Miniature circuit breaker
MicroSCADA	Substation automation system
MM	1. Multimode 2. Multimode optical fiber
MMS	1. Manufacturing message specification 2. Metering management system
MTBF	Mean time between failures
MV	Medium voltage
OPC server	A software application that acts as an API or protocol converter
PC	1. Personal computer 2. Polycarbonate
PCM600	Protection and Control IED Manager
Peak-to-peak	1. The amplitude of a waveform between its maximum positive value and its maximum negative value 2. A measurement principle where the measurement quantity is made by calculating the average from the positive and negative peak values without including the DC component. The peak-to-peak mode allows considerable CT saturation without impairing the performance of the operation.

Peak-to-peak with peak backup	A measurement principle similar to the peak-to-peak mode but with the function starting on two conditions: the peak-to-peak value is above the set start current or the peak value is above two times the set start value
POTT	Permissive overreach transfer trip
PSM	Power supply module
PST	1. Parameter Setting tool in PCM600 2. Product Selection Tool
PUTT	Permissive underreach transfer trip
RCA	Also known as MTA or base angle. Characteristic angle.
REF630	Feeder protection and control relay
REG630	Generator protection and control relay
REM630	Motor protection and control IED
RET630	Transformer protection and control IED
RJ-45	Galvanic connector type
RLS	Recursive least squares
RMS	Root-mean-square (value)
RS-485	Serial link according to EIA standard RS485
RTC	Real-time clock
RTD	Resistance temperature detector
Rx	Receive/Received
SCADA	Supervision, control and data acquisition
SCS	Station control system
SMAI	Signal matrix analog input
SMS	1. Short Message Service 2. Station monitoring system
SMT	Signal Matrix tool in PCM600
Snap-in	Connector type for plastic fiber cable
SNTP	Simple Network Time Protocol
SOTF	Switch onto fault
ST	Connector type for glass fiber cable
SW	Software
TCP/IP	Transmission Control Protocol/Internet Protocol
TCS	Trip-circuit supervision

TRM	Transformer input module
Tx	Transmit/Transmitted
UTC	Coordinated universal time
VDR	Voltage-depended resistor
VT	Voltage transformer
WAN	Wide area network
WEI	Weak-end infeed logic
WHMI	Web human-machine interface

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