RELION® PROTECTION AND CONTROL

620 series

Technical Manual

Document ID: 1MRS757644

Issued: 2023-03-28

Revision: J

Product version: 2.0 FP1

Disclaimer

The data, examples and diagrams in this manual are included solely for the concept or product description and are not to be deemed as a statement of guaranteed properties. All persons responsible for applying the equipment addressed in this manual must satisfy themselves that each intended application is suitable and acceptable, including that any applicable safety or other operational requirements are complied with. In particular, any risks in applications where a system failure and/or product failure would create a risk for harm to property or persons (including but not limited to personal injuries or death) shall be the sole responsibility of the person or entity applying the equipment, and those so responsible are hereby requested to ensure that all measures are taken to exclude or mitigate such risks.

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Conformity

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.

Contents

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

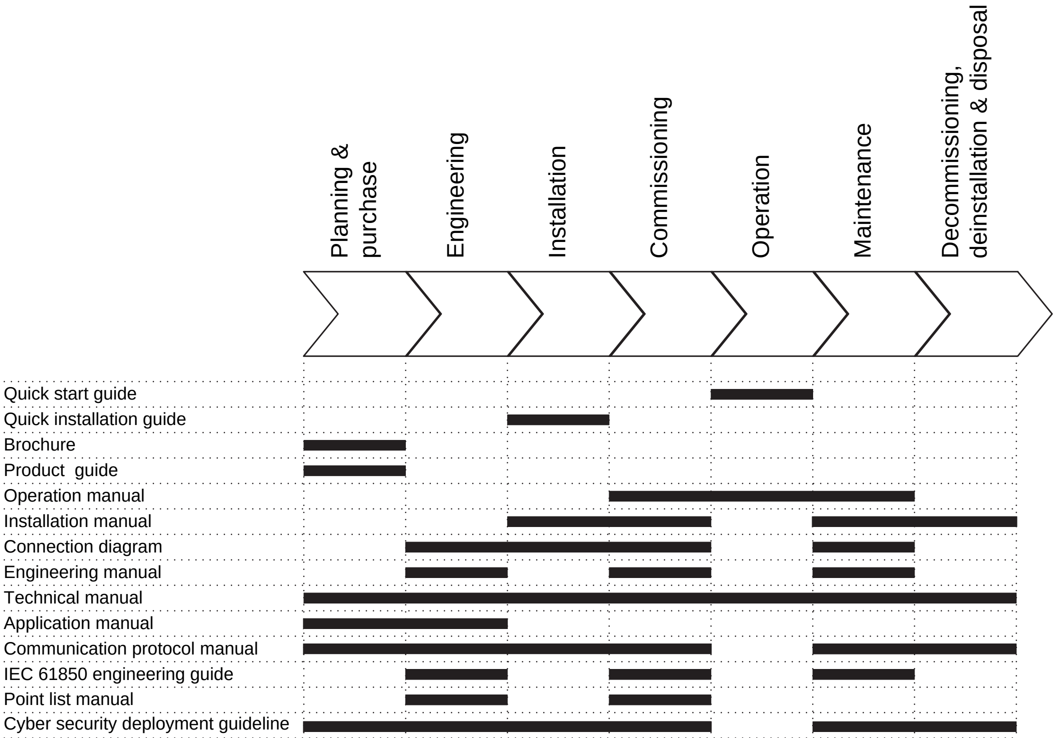

Figure 1: The intended use of documents during the product life cycle

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

1.3.2 Document revision history

Document revision/date	Product series version	History
A/2013-05-07	20	First release
B/2014-07-01	20	Content updated
C/2015-07-15	20	Content updated
D/2015-12-11	2.0 FP1	Content updated to correspond to the product series version
E/2016-09-27	2.0 FP1	Content updated
F/2019-06-19	2.0 FP1	Content updated
G/2021-12-21	2.0 FP1	Content updated
H/2022-02-04	2.0 FP1	Content fixed
J/2023-03-28	2.0 FP1	Content updated

Download the latest documents from the ABB Web site .

1.3.3 Related documentation

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

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**.
- 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.
- Parameter values are indicated with quotation marks.

  The corresponding parameter values are "On" and "Off".
- Input/output messages and monitored data names are shown in Courier font.

When the function starts, the START output is set to TRUE.

- This document assumes that the parameter setting visibility is "Advanced".
- Values of quantities are expressed with a number and an SI unit. The corresponding imperial units may be given in parentheses.
- This document assumes that the parameter setting visibility is "Advanced".
- Protective earthing is indicated in figures with the symbol ⏚.

1.4.3 Functions, codes and symbols

All available functions are listed in the table. All of them may not be applicable to all products.

Table 1: Functions included in the relays

Function	IEC 61850	IEC 60617	ANSI
Protection			
Three-phase non-directional overcurrent protection, low stage	PHLPTOC1	3I> (1)	51P-1 (1)
	PHLPTOC2	3I> (2)	51P-1 (2)
Three-phase non-directional overcurrent protection, high stage	PHHPTOC1	3I>> (1)	51P-2 (1)
	PHHPTOC2	3I>> (2)	51P-2 (2)
Three-phase non-directional overcurrent protection, instantaneous stage	PHIPTOC1	3I>>> (1)	50P/51P (1)
	PHIPTOC2	3I>>> (2)	50P/51P (2)
Three-phase directional overcurrent protection, low stage	DPHLPDOC1	3I> -> (1)	67-1 (1)
	DPHLPDOC2	3I> -> (2)	67-1 (2)
Three-phase directional overcurrent protection, high stage	DPHHPDOC1	3I>> -> (1)	67-2 (1)
	DPHHPDOC2	3I>> -> (2)	67-2 (2)
Three-phase voltage-dependent overcurrent protection	PHPVOC1	3I(U)> (1)	51V (1)
	PHPVOC2	3I(U)> (2)	51V (2)
Non-directional earth-fault protection, low stage	EFLPTOC1	Io> (1)	51N-1 (1)
	EFLPTOC2	Io> (2)	51N-1 (2)
Non-directional earth-fault protection, high stage	EFHPTOC1	Io>> (1)	51N-2 (1)
	EFHPTOC2	Io>> (2)	51N-2 (2)
Non-directional earth-fault protection, instantaneous stage	EFIPTOC1	Io>>> (1)	50N/51N (1)

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Directional earth-fault protection, low stage	DEFLPDEF1	Io> -> (1)	67N-1 (1)
	DEFLPDEF2	Io> -> (2)	67N-1 (2)
	DEFLPDEF3	Io> -> (3)	67N-1 (3)
Directional earth-fault protection, high stage	DEFHPDEF1	Io>> -> (1)	67N-2 (1)
Admittance-based earth-fault protection	EFPADM1	Yo> -> (1)	21YN (1)
	EFPADM2	Yo> -> (2)	21YN (2)
	EFPADM3	Yo> -> (3)	21YN (3)
Wattmetric-based earth-fault protection	WPWDE1	Po> -> (1)	32N (1)
	WPWDE2	Po> -> (2)	32N (2)
	WPWDE3	Po> -> (3)	32N (3)
Multifrequency admittance-based earth-fault protection	MFADPSDE1	Io> -> Y (1)	67YN (1)
Transient/intermittent earth-fault protection	INTRPTEF1	Io> -> IEF (1)	67NIEF (1)
Harmonics-based earth-fault protection	HAEFPTOC1	Io>HA (1)	51NHA (1)
Negative-sequence overcurrent protection	NSPTOC1	I2> (1)	46 (1)
	NSPTOC2	I2> (2)	46 (2)
Phase discontinuity protection	PDNSPTOC1	I2/I1> (1)	46PD (1)
Residual overvoltage protection	ROVPTOV1	Uo> (1)	59G (1)
	ROVPTOV2	Uo> (2)	59G (2)
	ROVPTOV3	Uo> (3)	59G (3)
Three-phase undervoltage protection	PHPTUV1	3U< (1)	27 (1)
	PHPTUV2	3U< (2)	27 (2)
	PHPTUV3	3U< (3)	27 (3)
	PHPTUV4	3U< (4)	27 (4)
Single-phase undervoltage protection, secondary side	PHAPTUV1	U_A< (1)	27_A (1)
Three-phase overvoltage protection	PHPTOV1	3U> (1)	59 (1)
	PHPTOV2	3U> (2)	59 (2)
	PHPTOV3	3U> (3)	59 (3)
Single-phase overvoltage protection, secondary side	PHAPTOV1	U_A> (1)	59_A (1)

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Positive-sequence undervoltage protection	PSPTUV1	U1< (1)	47U+ (1)
	PSPTUV2	U1< (2)	47U+ (2)
Negative-sequence overvoltage protection	NSPTOV1	U2> (1)	47O- (1)
	NSPTOV2	U2> (2)	47O- (2)
Frequency protection	FRPFRQ1	f>/f<,df/dt (1)	81 (1)
	FRPFRQ2	f>/f<,df/dt (2)	81 (2)
	FRPFRQ3	f>/f<,df/dt (3)	81 (3)
	FRPFRQ4	f>/f<,df/dt (4)	81 (4)
	FRPFRQ5	f>/f<,df/dt (5)	81 (5)
	FRPFRQ6	f>/f<,df/dt (6)	81 (6)
Overexcitation protection	OEPVPH1	U/f> (1)	24 (1)
	OEPVPH2	U/f> (2)	24 (2)
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR1	3Ith>F (1)	49F (1)
Three-phase thermal overload protection, two time constants	T2PTTR1	3Ith>T/G/C (1)	49T/G/C (1)
Negative-sequence overcurrent protection for machines	MNSPTOC1	I2>M (1)	46M (1)
	MNSPTOC2	I2>M (2)	46M (2)
Loss of phase (undercurrent)	PHPTUC1	3I< (1)	37 (1)
	PHPTUC2	3I< (2)	37 (2)
Loss of load supervision	LOFLPTUC1	3I< (1)	37 (1)
	LOFLPTUC2	3I< (2)	37 (2)
Motor load jam protection	JAMPTOC1	Ist> (1)	51LR (1)
Motor start-up supervision	STTPMSU1	Is2t n< (1)	49,66,48,51LR (1)
Phase reversal protection	PREVPTOC1	I2>> (1)	46R (1)
Thermal overload protection for motors	MPTTR1	3Ith>M (1)	49M (1)
Stabilized and instantaneous differential protection for machines	MPDIF1	3dI>M/G (1)	87M/G (1)
High-impedance/ flux-balance based differential protection for motors	MHZPDIF1	3dIHi>M (1)	87MH (1)

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Stabilized and instantaneous differential protection for two-winding transformers	TR2PTDF1	3dI>T (1)	87T (1)
Numerical stabilized low-impedance restricted earth-fault protection	LREFPNDF1	dIoLo> (1)	87NL (1)
	LREFPNDF2	dIoLo> (2)	87NL (2)
High-impedance based restricted earth-fault protection	HREFPDIF1	dIoHi> (1)	87NH (1)
	HREFPDIF2	dIoHi> (2)	87NH (2)
Circuit breaker failure protection	CCBRBRF1	3I>/Io>BF (1)	51BF/51NBF (1)
	CCBRBRF2	3I>/Io>BF (2)	51BF/51NBF (2)
	CCBRBRF3	3I>/Io>BF (3)	51BF/51NBF (3)
Three-phase inrush detector	INRPHAR1	3I2f> (1)	68 (1)
Master trip	TRPPTRC1	Master Trip (1)	94/86 (1)
	TRPPTRC2	Master Trip (2)	94/86 (2)
	TRPPTRC3	Master Trip (3)	94/86 (3)
	TRPPTRC4	Master Trip (4)	94/86 (4)
Arc protection	ARCSARC1	ARC (1)	50L/50NL (1)
	ARCSARC2	ARC (2)	50L/50NL (2)
	ARCSARC3	ARC (3)	50L/50NL (3)
High-impedance fault detection	PHIZ1	HIF (1)	HIZ (1)
Load-shedding and restoration	LSHDPFRQ1	UFLS/R (1)	81LSH (1)
	LSHDPFRQ2	UFLS/R (2)	81LSH (2)
	LSHDPFRQ3	UFLS/R (3)	81LSH (3)
	LSHDPFRQ4	UFLS/R (4)	81LSH (4)
	LSHDPFRQ5	UFLS/R (5)	81LSH (5)
	LSHDPFRQ6	UFLS/R (6)	81LSH (6)
Multipurpose protection	MAPGAPC1	MAP (1)	MAP (1)
	MAPGAPC2	MAP (2)	MAP (2)
	MAPGAPC3	MAP (3)	MAP (3)
	MAPGAPC4	MAP (4)	MAP (4)
	MAPGAPC5	MAP (5)	MAP (5)
	MAPGAPC6	MAP (6)	MAP (6)
	MAPGAPC7	MAP (7)	MAP (7)
	MAPGAPC8	MAP (8)	MAP (8)
	MAPGAPC9	MAP (9)	MAP (9)
	MAPGAPC10	MAP (10)	MAP (10)

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Function	IEC 61850	IEC 60617	ANSI
	MAPGAPC11	MAP (11)	MAP (11)
	MAPGAPC12	MAP (12)	MAP (12)
	MAPGAPC13	MAP (13)	MAP (13)
	MAPGAPC14	MAP (14)	MAP (14)
	MAPGAPC15	MAP (15)	MAP (15)
	MAPGAPC16	MAP (16)	MAP (16)
	MAPGAPC17	MAP (17)	MAP (17)
	MAPGAPC18	MAP (18)	MAP (18)
Automatic switch-on-to-fault logic (SOF)	CVPSOF1	CVPSOF (1)	SOFT/21/50 (1)
Voltage vector shift protection	VVSPPAM1	VS (1)	78V (1)
Directional reactive power undervoltage protection	DQPTUV1	Q> -> ,3U< (1)	32Q,27 (1)
	DQPTUV2	Q> -> ,3U< (2)	32Q,27 (2)
Underpower protection	DUPPDPR1	P< (1)	32U (1)
	DUPPDPR2	P< (2)	32U (2)
Reverse power/directional overpower protection	DOPPDPR1	P>/Q> (1)	32R/32O (1)
	DOPPDPR2	P>/Q> (2)	32R/32O (2)
	DOPPDPR3	P>/Q> (3)	32R/32O (3)
Three-phase underexcitation protection	UEXPDIS1	X< (1)	40 (1)
	UEXPDIS2	X< (2)	40 (2)
Low-voltage ride-through protection	LVRTPTUV1	U<RT (1)	27RT (1)
	LVRTPTUV2	U<RT (2)	27RT (2)
	LVRTPTUV3	U<RT (3)	27RT (3)
Rotor earth-fault protection	MREFPTOC1	Io>R (1)	64R (1)
High-impedance differential protection for phase A	HIAPDIF1	dHi_A> (1)	87A (1)
High-impedance differential protection for phase B	HIBPDIF1	dHi_B> (1)	87B (1)
High-impedance differential protection for phase C	HICPDIF1	dHi_C> (1)	87C (1)
Circuit breaker uncorresponding position start-up	UPCALH1	CBUPS (1)	CBUPS (1)
	UPCALH2	CBUPS (2)	CBUPS (2)
	UPCALH3	CBUPS (3)	CBUPS (3)
Three-independent-phase non- direction-	PH3LPTOC1	3I_3> (1)	51P-1_3 (1)
	PH3LPTOC2	3I_3> (2)	51P-1_3 (2)

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Function	IEC 61850	IEC 60617	ANSI
al overcurrent protection, low stage			
Three-independent-phase non- directional overcurrent protection, high stage	PH3HPTOC1	3I_3>> (1)	51P-2_3 (1)
	PH3HPTOC2	3I_3>> (2)	51P-2_3 (2)
Three-independent-phase non- directional overcurrent protection, instantaneous stage	PH3IPTOC1	3I_3>>> (1)	50P/51P_3 (1)
Directional three-independent-phase directional overcurrent protection, low stage	DPH3LPDOC1	3I_3> -> (1)	67-1_3 (1)
	DPH3LPDOC2	3I_3> -> (2)	67-1_3 (2)
Directional three-independent-phase directional overcurrent protection, high stage	DPH3HPDOC1	3I_3>> -> (1)	67-2_3 (1)
	DPH3HPDOC2	3I_3>> -> (2)	67-2_3 (2)
Three-phase overload protection for shunt capacitor banks	COLPTOC1	3I> 3I< (1)	51C/37 (1)
Current unbalance protection for shunt capacitor banks	CUBPTOC1	dI>C (1)	51NC-1 (1)
Shunt capacitor bank switching resonance protection, current based	SRCPTOC1	TD> (1)	55TD (1)
Control			
Circuit-breaker control	CBXCBR1	I <-> O CB (1)	I <-> O CB (1)
	CBXCBR2	I <-> O CB (2)	I <-> O CB (2)
	CBXCBR3	I <-> O CB (3)	I <-> O CB (3)
Disconnector control	DCXSWI1	I <-> O DCC (1)	I <-> O DCC (1)
	DCXSWI2	I <-> O DCC (2)	I <-> O DCC (2)
	DCXSWI3	I <-> O DCC (3)	I <-> O DCC (3)
	DCXSWI4	I <-> O DCC (4)	I <-> O DCC (4)
Earthing switch control	ESXSWI1	I <-> O ESC (1)	I <-> O ESC (1)
	ESXSWI2	I <-> O ESC (2)	I <-> O ESC (2)
	ESXSWI3	I <-> O ESC (3)	I <-> O ESC (3)
Disconnector position indication	DCSXSWI1	I <-> O DC (1)	I <-> O DC (1)
	DCSXSWI2	I <-> O DC (2)	I <-> O DC (2)
	DCSXSWI3	I <-> O DC (3)	I <-> O DC (3)

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Function	IEC 61850	IEC 60617	ANSI
	DCSXSWI4	I <-> O DC (4)	I <-> O DC (4)
Earthing switch indication	ESSXSWI1	I <-> O ES (1)	I <-> O ES (1)
	ESSXSWI2	I <-> O ES (2)	I <-> O ES (2)
	ESSXSWI3	I <-> O ES (3)	I <-> O ES (3)
Emergency start-up	ESMGAPC1	ESTART (1)	ESTART (1)
Autoreclosing	DARREC1	O -> I (1)	79 (1)
	DARREC2	O -> I (2)	79 (2)
Synchronism and energizing check	SECRSYN1	SYNC (1)	25 (1)
Tap changer position indication	TPOSYLTC1	TPOSM (1)	84M (1)
Tap changer control with voltage regulator	OLATCC1	COLTC (1)	90V (1)
Condition monitoring and supervision			
Circuit-breaker condition monitoring	SSCBR1	CBCM (1)	CBCM (1)
	SSCBR2	CBCM (2)	CBCM (2)
	SSCBR3	CBCM (3)	CBCM (3)
Trip circuit supervision	TCSSCBR1	TCS (1)	TCM (1)
	TCSSCBR2	TCS (2)	TCM (2)
Current circuit supervision	CCSPVC1	MCS 3I (1)	MCS 3I (1)
	CCSPVC2	MCS 3I (2)	MCS 3I (2)
Current transformer supervision for high-impedance protection scheme for phase A	HZCCASPVC1	MCS I_A (1)	MCS I_A (1)
Current transformer supervision for high-impedance protection scheme for phase B	HZCCBSPVC1	MCS I_B (1)	MCS I_B (1)
Current transformer supervision for high-impedance protection scheme for phase C	HZCCCSPVC1	MCS I_C (1)	MCS I_C (1)
Advanced current circuit supervision for transformers	CTSRCTF1	MCS 3I,I2 (1)	MCS 3I,I2 (1)
Fuse failure supervision	SEQSPVC1	FUSEF (1)	60 (1)

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Runtime counter for machines and devices	MDSOPT1	OPTS (1)	OPTM (1)
	MDSOPT2	OPTS (2)	OPTM (2)
Measurement			
Three-phase current measurement	CMMXU1	3I (1)	3I (1)
	CMMXU2	3I (2)	3I (2)
Sequence current measurement	CSMSQI1	I1, I2, I0 (1)	I1, I2, I0 (1)
	CSMSQI2	I1, I2, I0 (B) (1)	I1, I2, I0 (B) (1)
Residual current measurement	RESCMMXU1	Io (1)	In (1)
	RESCMMXU2	Io (2)	In (2)
Three-phase voltage measurement	VMMXU1	3U (1)	3V (1)
Single-phase voltage measurement	VAMMXU2	U_A (2)	V_A (2)
	VAMMXU3	U_A (3)	V_A (3)
Residual voltage measurement	RESVMMXU1	Uo (1)	Vn (1)
Sequence voltage measurement	VSMSQI1	U1, U2, U0 (1)	V1, V2, V0 (1)
Three-phase power and energy measurement	PEMMXU1	P, E (1)	P, E (1)
Load profile record	LDPRLRC1	LOADPROF (1)	LOADPROF (1)
Frequency measurement	FMMXU1	f (1)	f (1)
Fault location			
Fault locator	SCEFRFLO1	FLOC (1)	21FL (1)
Power quality			
Current total demand distortion	CMHAI1	PQM3I (1)	PQM3I (1)
Voltage total harmonic distortion	VMHAI1	PQM3U (1)	PQM3V (1)
Voltage variation	PHQVVR1	PQMU (1)	PQMV (1)
Voltage unbalance	VSQVUB1	PQUUB (1)	PQVUB (1)
Other			
Minimum pulse timer (2 pcs)	TPGAPC1	TP (1)	TP (1)
	TPGAPC2	TP (2)	TP (2)
	TPGAPC3	TP (3)	TP (3)
	TPGAPC4	TP (4)	TP (4)

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Function	IEC 61850	IEC 60617	ANSI
Minimum pulse timer (2 pcs, second resolution)	TPSGAPC1	TPS (1)	TPS (1)
	TPSGAPC2	TPS (2)	TPS (2)
Minimum pulse timer (2 pcs, minute resolution)	TPMGAPC1	TPM (1)	TPM (1)
	TPMGAPC2	TPM (2)	TPM (2)
Pulse timer (8 pcs)	PTGAPC1	PT (1)	PT (1)
	PTGAPC2	PT (2)	PT (2)
Time delay off (8 pcs)	TOFGAPC1	TOF (1)	TOF (1)
	TOFGAPC2	TOF (2)	TOF (2)
	TOFGAPC3	TOF (3)	TOF (3)
	TOFGAPC4	TOF (4)	TOF (4)
Time delay on (8 pcs)	TONGAPC1	TON (1)	TON (1)
	TONGAPC2	TON (2)	TON (2)
	TONGAPC3	TON (3)	TON (3)
	TONGAPC4	TON (4)	TON (4)
Set-reset (8 pcs)	SRGAPC1	SR (1)	SR (1)
	SRGAPC2	SR (2)	SR (2)
	SRGAPC3	SR (3)	SR (3)
	SRGAPC4	SR (4)	SR (4)
Move (8 pcs)	MVGAPC1	MV (1)	MV (1)
	MVGAPC2	MV (2)	MV (2)
	MVGAPC3	MV (3)	MV (3)
	MVGAPC4	MV (4)	MV (4)
Integer value move	MVI4GAPC1	MVI4 (1)	MVI4 (1)
	MVI4GAPC2	MVI4 (2)	MVI4 (2)
	MVI4GAPC3	MVI4 (3)	MVI4 (3)
	MVI4GAPC4	MVI4 (4)	MVI4 (4)
Analog value scaling	SCA4GAPC1	SCA4 (1)	SCA4 (1)
	SCA4GAPC2	SCA4 (2)	SCA4 (2)
	SCA4GAPC3	SCA4 (3)	SCA4 (3)
	SCA4GAPC4	SCA4 (4)	SCA4 (4)
Generic control point (16 pcs)	SPCGAPC1	SPC (1)	SPC (1)
	SPCGAPC2	SPC (2)	SPC (2)
	SPCGAPC3	SPC (3)	SPC (3)
Remote generic control points	SPCRGAPC1	SPCR (1)	SPCR (1)
Local generic control points	SPCLGAPC1	SPCL (1)	SPCL (1)

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Function	IEC 61850	IEC 60617	ANSI
Generic up-down counters	UDFCNT1	UDCNT (1)	UDCNT (1)
	UDFCNT2	UDCNT (2)	UDCNT (2)
	UDFCNT3	UDCNT (3)	UDCNT (3)
	UDFCNT4	UDCNT (4)	UDCNT (4)
	UDFCNT5	UDCNT (5)	UDCNT (5)
	UDFCNT6	UDCNT (6)	UDCNT (6)
	UDFCNT7	UDCNT (7)	UDCNT (7)
	UDFCNT8	UDCNT (8)	UDCNT (8)
	UDFCNT9	UDCNT (9)	UDCNT (9)
	UDFCNT10	UDCNT (10)	UDCNT (10)
	UDFCNT11	UDCNT (11)	UDCNT (11)
	UDFCNT12	UDCNT (12)	UDCNT (12)
Programmable buttons (16 buttons)	FKEYGGIO1	FKEY (1)	FKEY (1)
Logging functions			
Disturbance recorder	RDRE1	DR (1)	DFR (1)
Fault recorder	FLTRFRC1	FAULTREC (1)	FAULTREC (1)
Sequence event recorder	SER1	SER (1)	SER (1)

2 620 series overview

2.1 Overview

620 series is a product family of relays designed for protection, control, measurement and supervision of utility substations and industrial switchgear and equipment. The design of the relay has been guided by the IEC 61850 standard for communication and interoperability of substation automation devices.

The protection relays feature draw-out-type design with a variety of mounting methods, compact size and ease of use. Depending on the product, optional functionality is available at the time of order for both software and hardware, for example, ARC protection.

The 620 series protection relays support a range of communication protocols including IEC 61850 with GOOSE messaging, IEC 61850-9-2 LE, IEC 60870-5-103, Modbus® and DNP3.

2.1.1 Product series version history

Product series version	Product series history
2.0	New products: • REF620 with configurations A and B • REM620 with configuration A • RET620 with configuration A
2.0 FP1	New configuration • REM620 B Platform enhancements • IEC 61850 Edition 2 • Support for IEC 61850-9-2 LE • Currents sending support with IEC 61850-9-2 LE • Synchronism and energizing check support with IEC 61850-9-2 LE • IEEE 1588 v2 time synchronization • Configuration migration support • Software closable Ethernet ports • Report summary via WHMI • Multifrequency admittance-based E/F • Fault locator • Profibus adapter support • Setting usability improvements

2.1.2 PCM600 and IED connectivity package version

- Protection and Control IED Manager PCM600 2.6 (Rollup 20150626) or later
- REF620 Connectivity Package Ver.2.1 or later
- REM620 Connectivity Package Ver.2.1 or later
- RET620 Connectivity Package Ver.2.1 or later

Download connectivity packages from the ABB Web site *www.abb.com/substationautomation* 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.

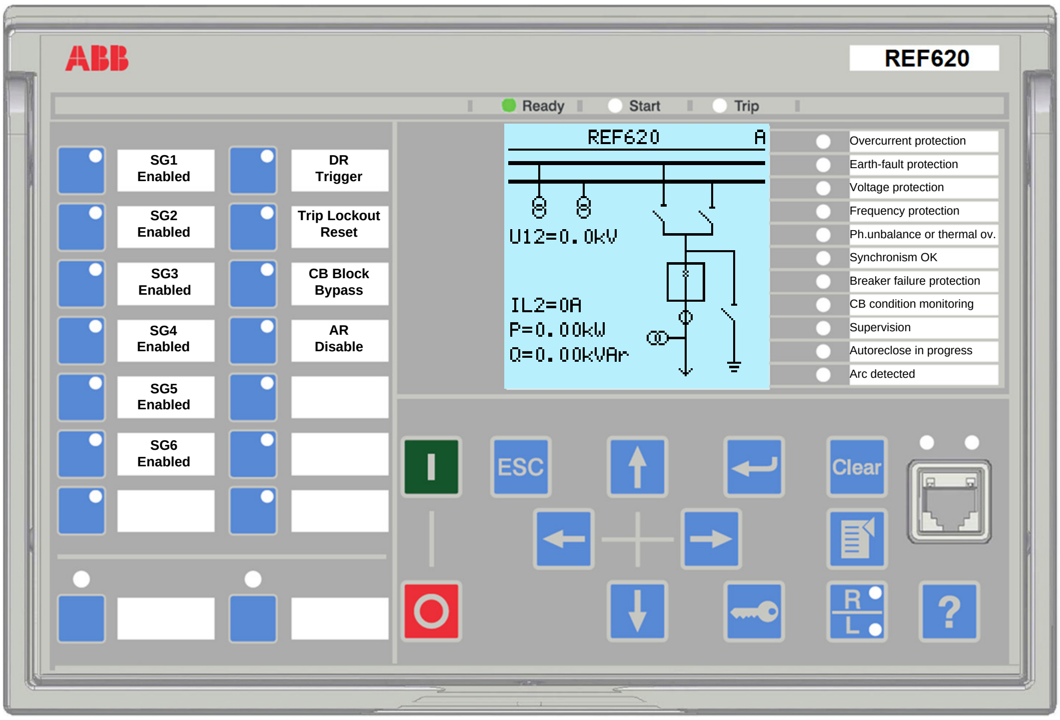


Figure 2: Example of the LHMI

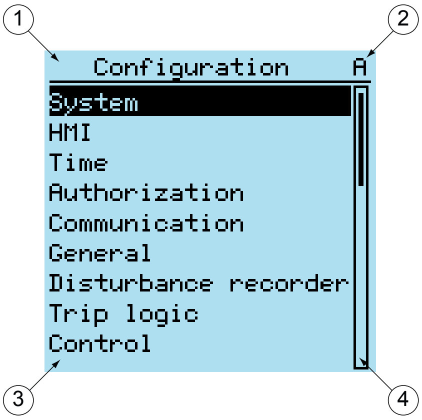
2.2.1 Display

The LHMI includes a graphical display that supports one character size. The character size depends on the selected language. The amount of characters and rows fitting the view depends on the character size.

Table 2: Display

Character size[1]	Rows in the view	Characters per row
Small, mono-spaced (6 × 12 pixels)	10	20
Large, variable width (13 × 14 pixels)	7	8 or more

The display view is divided into four basic areas.



1 Header
2 Icon
3 Content
4 Scroll bar (displayed when needed)

Figure 3: Display layout

2.2.2 LEDs

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

There are 11 matrix programmable LEDs on front of the LHMI. 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 give open or close commands to objects in the primary circuit, for example, a circuit breaker, a contactor or a disconnector. The push buttons are also used to acknowledge alarms, reset indications, provide help and switch between local and remote control mode.

[1] Depending on the selected language

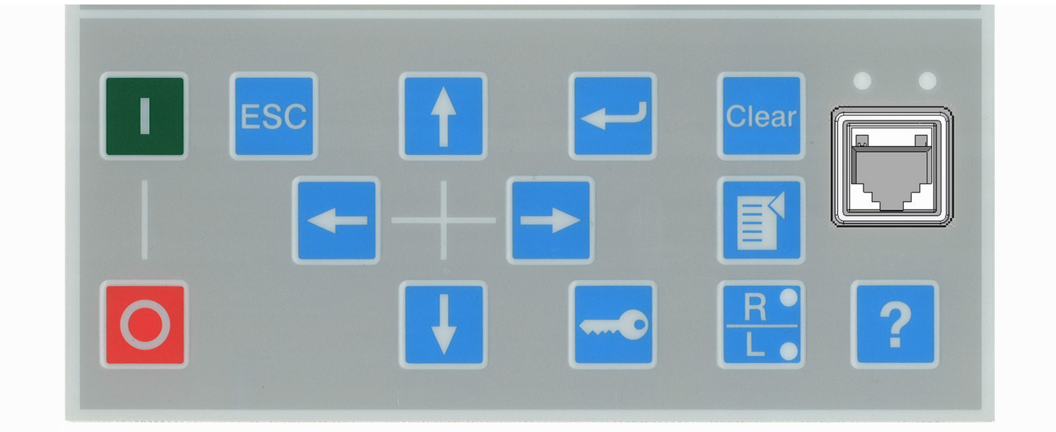


Figure 4: LHMI keypad with object control, navigation and command push buttons and RJ-45 communication port

2.2.3.1 Programmable push buttons with LEDs

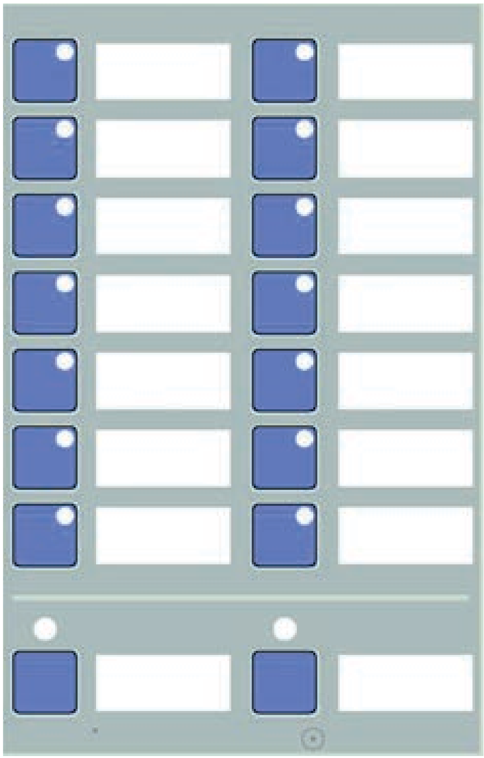


Figure 5: Programmable push buttons with LEDs

The LHMI keypad on the left side of the protection relay contains 16 programmable push buttons with red LEDs.

The buttons and LEDs are freely programmable, and they can be configured both for operation and acknowledgement purposes. That way, it is possible to get acknowledgements of the executed actions associated with the buttons. This combination can be useful, for example, for quickly selecting or changing a setting group, selecting or operating equipment, indicating field contact status or indicating or acknowledging individual alarms.

The LEDs can also be independently configured to bring general indications or important alarms to the operator's attention.

To provide a description of the button function, it is possible to insert a paper sheet behind the transparent film next to the button.

2.3 Web HMI

The WHMI allows secure access to the protection relay via a Web browser. When the *Secure Communication* parameter in the protection relay is activated, the Web server is forced to take a secured (HTTPS) connection to WHMI using TLS encryption. The WHMI is verified with Internet Explorer 8.0, 9.0, 10.0 and 11.0.

WHMI is disabled by default.

Control operations are not allowed by WHMI.

WHMI offers several functions.

- Programmable LEDs and event lists
- System supervision
- Parameter settings
- Measurement display
- Disturbance records
- Fault records
- Load profile record
- Phasor diagram
- Single-line diagram
- Importing/Exporting parameters
- Report summary

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

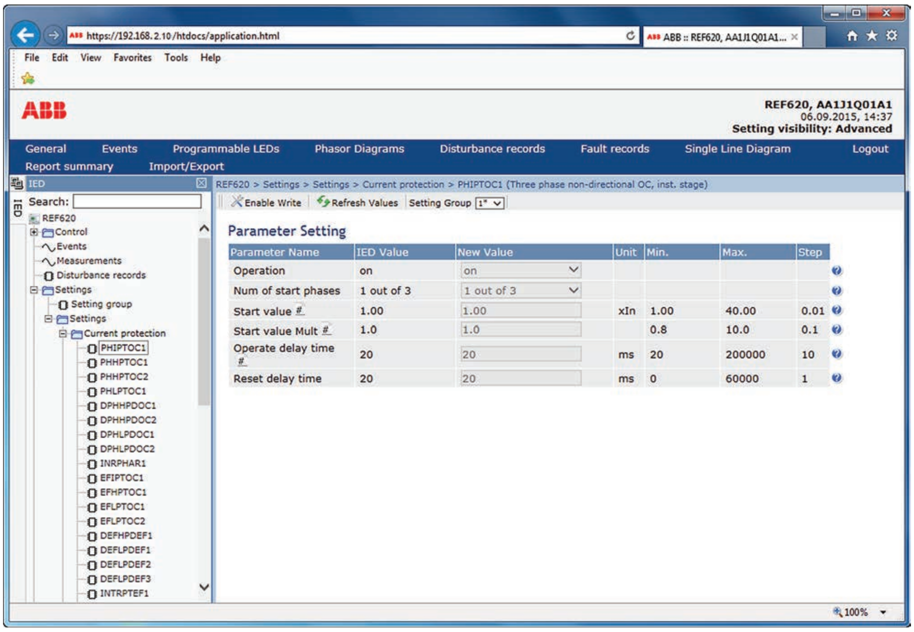


Figure 6: Example view of the WHMI

The WHMI can be accessed locally and remotely.

- Locally by connecting the laptop to the protection relay via the front communication port.
- Remotely over LAN/WAN.

2.4 Authorization

Four user categories have been predefined for the LHMI and the WHMI, each with different rights and default passwords.

The default passwords in the protection relay delivered from the factory can be changed with Administrator user rights.

If the relay-specific Administrator password is forgotten, ABB can provide a one-time reliable key to access the protection relay. For support, contact ABB. The recovery of the Administrator password takes a few days.

User authorization is disabled by default for LHMI but WHMI always uses authorization.

Table 3: Predefined user categories

Username	User rights
VIEWER	Read only access
OPERATOR	• Selecting remote or local state with (only locally) • Changing setting groups

Table continues on the next page

Username	User rights
	• Controlling • Clearing indications
ENGINEER	• Changing settings • Clearing event list • Clearing disturbance records • Changing system settings such as IP address, serial baud rate or disturbance recorder settings • Setting the protection relay to test mode • Selecting language
ADMINISTRATOR	• All listed above • Changing password • Factory default activation

For user authorization for PCM600, see PCM600 documentation.

2.4.1 Audit trail

The protection relay offers a large set of event-logging functions. Critical system and protection relay security-related events are logged to a separate nonvolatile audit trail for the administrator.

Audit trail is a chronological record of system activities that allows the reconstruction and examination of the sequence of system and security-related events and changes in the protection relay. Both audit trail events and process related events can be examined and analyzed in a consistent method with the help of Event List in LHMI and WHMI and Event Viewer in PCM600.

The protection relay stores 2048 audit trail events to the nonvolatile audit trail. Additionally, 1024 process events are stored in a nonvolatile event list. Both the audit trail and event list work according to the FIFO principle. Nonvolatile memory is based on a memory type which does not need battery backup nor regular component change to maintain the memory storage.

Audit trail events related to user authorization (login, logout, violation remote and violation local) are defined according to the selected set of requirements from IEEE 1686. The logging is based on predefined user names or user categories. The user audit trail events are accessible with IEC 61850-8-1, PCM600, LHMI and WHMI.

Table 4: Audit trail events

Audit trail event	Description
Configuration change	Configuration files changed
Firmware change	Firmware changed
Firmware change fail	Firmware change failed
Setting group remote	User changed setting group remotely
Setting group local	User changed setting group locally
Control remote	DPC object control remote

Table continues on the next page

Audit trail event	Description
Control local	DPC object control local
Test on	Test mode on
Test off	Test mode off
Reset trips	Reset latched trips (TRPPTRC*)
Setting commit	Settings have been changed
Time change	Time changed directly by the user. Note that this is not used when the protection relay is synchronised properly by the appropriate protocol (SNTP, IRIG-B, IEEE 1588 v2).
View audit log	Administrator accessed audit trail
Login	Successful login from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.
Logout	Successful logout from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.
Password change	Password changed
Firmware reset	Reset issued by user or tool
Audit overflow	Too many audit events in the time period
Violation remote	Unsuccessful login attempt from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.
Violation local	Unsuccessful login attempt from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.

PCM600 Event Viewer can be used to view the audit trail events and process related events. Audit trail events are visible through dedicated Security events view. Since only the administrator has the right to read audit trail, authorization must be used in PCM600. The audit trail cannot be reset, but PCM600 Event Viewer can filter data. Audit trail events can be configured to be visible also in LHMI/WHMI Event list together with process related events.

To expose the audit trail events through Event list, define the *Authority logging* level parameter via **Configuration** > **Authorization** > **Security**. This exposes audit trail events to all users.

Table 5: Comparison of authority logging levels

Audit trail event	Authority logging level					
	None	Configuration change	Setting group	Setting group, control	Settings edit	All
Configuration change		●	●	●	●	●
Firmware change		●	●	●	●	●
Firmware change fail		●	●	●	●	●
Setting group remote			●	●	●	●
Setting group local			●	●	●	●
Control remote				●	●	●
Control local				●	●	●

Table continues on the next page

Audit trail event	Authority logging level					
Test on				●	●	●
Test off				●	●	●
Reset trips				●	●	●
Setting commit					●	●
Time change						●
View audit log						●
Login						●
Logout						●
Password change						●
Firmware reset						●
Violation local						●
Violation remote						●

2.5 Communication

The protection relay supports a range of communication protocols including IEC 61850, IEC 61850-9-2 LE, IEC 60870-5-103, Modbus® and DNP3. Profibus DPV1 communication protocol is supported by using the protocol converter SPA-ZC 302. Operational information and controls are available through these protocols. However, some communication functionality, for example, horizontal communication between the protection relays, is only enabled by the IEC 61850 communication protocol.

The IEC 61850 communication implementation supports all monitoring and control functions. Additionally, parameter settings, disturbance recordings and fault records can be accessed using the IEC 61850 protocol. Disturbance recordings are available to any Ethernet-based application in the IEC 60255-24 standard COMTRADE file format. The protection relay can send and receive binary signals from other devices (so-called horizontal communication) using the IEC 61850-8-1 GOOSE profile, where the highest performance class with a total transmission time of 3 ms is supported. Furthermore, the protection relay supports sending and receiving of analog values using GOOSE messaging. The protection relay meets the GOOSE performance requirements for tripping applications in distribution substations, as defined by the IEC 61850 standard.

The protection relay can support five simultaneous clients. If PCM600 reserves one client connection, only four client connections are left, for example, for IEC 61850 and Modbus.

All communication connectors, except for the front port connector, are placed on integrated optional communication modules. The protection relay can be connected to Ethernet-based communication systems via the RJ-45 connector (100Base-FX) or the fiber-optic LC connector (100Base-FX).

2.5.1 Self-healing Ethernet ring

For the correct operation of self-healing loop topology, it is essential that the external switches in the network support the RSTP protocol and that it is enabled in the switches. Otherwise, connecting the loop topology can cause problems to the network. The protection relay itself does not support link-down detection or RSTP. The ring recovery process is based on the aging of the MAC addresses, and the link-up/link-down events can cause temporary breaks in communication. For a better performance of the self-healing loop, it is recommended that the external switch furthest from the protection relay loop is assigned as the root switch (bridge priority = 0) and the bridge priority increases towards the protection relay loop. The end links of the protection relay loop can be attached to the same external switch or to two adjacent external switches. A self-healing Ethernet ring requires a communication module with at least two Ethernet interfaces for all protection relays.

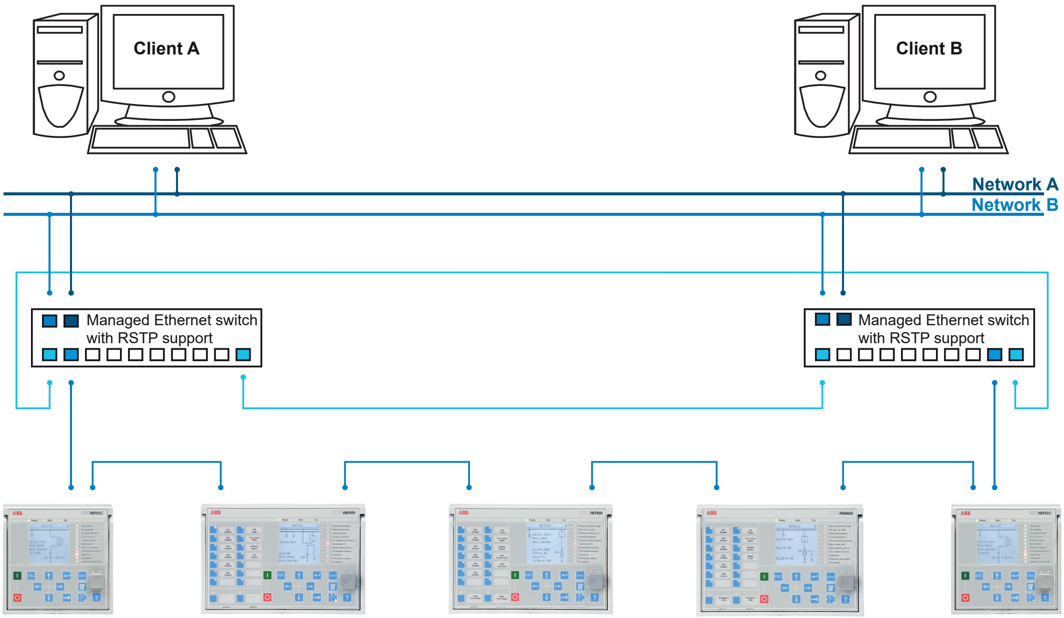


Figure 7: Self-healing Ethernet ring solution

The Ethernet ring solution supports the connection of up to 30 protection relays. If more than 30 protection relays are to be connected, it is recommended that the network is split into several rings with no more than 30 protection relays per ring. Each protection relay has a 50-µs store-and-forward delay, and to fulfil the performance requirements for fast horizontal communication, the ring size is limited to 30 protection relays.

2.5.2 Ethernet redundancy

IEC 61850 specifies a network redundancy scheme that improves the system availability for substation communication. It is based on two complementary protocols defined in the IEC 62439-3:2012 standard: parallel redundancy protocol PRP and high-availability seamless redundancy HSR protocol. Both protocols rely on the duplication of all transmitted information via two Ethernet ports for one logical network connection. Therefore, both are able to overcome the failure of a link or switch with a zero-switchover time, thus fulfilling the stringent real-time requirements for the substation automation horizontal communication and time synchronization.

PRP specifies that each device is connected in parallel to two local area networks. HSR applies the PRP principle to rings and to the rings of rings to achieve cost-effective redundancy. Thus, each device incorporates a switch element that forwards frames from port to port. The HSR/PRP option is available for all 615 series protection relays. However, RED615 supports this option only over fiber optics.

IEC 62439-3:2012 cancels and replaces the first edition published in 2010. These standard versions are also referred to as IEC 62439-3 Edition 1 and IEC 62439-3 Edition 2. The protection relay supports IEC 62439-3:2012 and it is not compatible with IEC 62439-3:2010.

PRP

Each PRP node, called a double attached node with PRP (DAN), is attached to two independent LANs operated in parallel. These parallel networks in PRP are called LAN A and LAN B. The networks are completely separated to ensure failure independence, and they can have different topologies. Both networks operate in parallel, thus providing zero-time recovery and continuous checking of redundancy to avoid communication failures. Non-PRP nodes, called single attached nodes (SANs), are either attached to one network only (and can therefore communicate only with DANs and SANs attached to the same network), or are attached through a redundancy box, a device that behaves like a DAN.

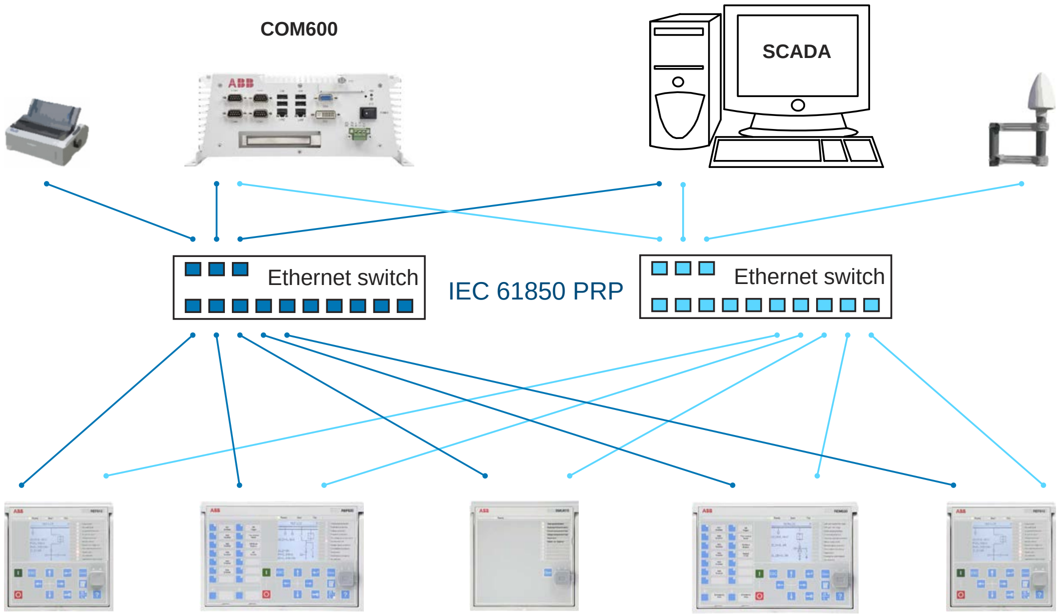


Figure 8: PRP solution

In case a laptop or a PC workstation is connected as a non-PRP node to one of the PRP networks, LAN A or LAN B, it is recommended to use a redundancy box device or an Ethernet switch with similar functionality between the PRP network and SAN to remove additional PRP information from the Ethernet frames. In some cases, default PC workstation adapters are not able to handle the maximum-length Ethernet frames with the PRP trailer.

There are different alternative ways to connect a laptop or a workstation as SAN to a PRP network.

- Via an external redundancy box (RedBox) or a switch capable of connecting to PRP and normal networks

- By connecting the node directly to LAN A or LAN B as SAN
- By connecting the node to the protection relay's interlink port

HSR

HSR applies the PRP principle of parallel operation to a single ring, treating the two directions as two virtual LANs. For each frame sent, a node, DAN, sends two frames, one over each port. Both frames circulate in opposite directions over the ring and each node forwards the frames it receives, from one port to the other. When the originating node receives a frame sent to itself, it discards that to avoid loops; therefore, no ring protocol is needed. Individually attached nodes, SANs, such as laptops and printers, must be attached through a “redundancy box” that acts as a ring element. For example, a 615 or 620 series protection relay with HSR support can be used as a redundancy box.

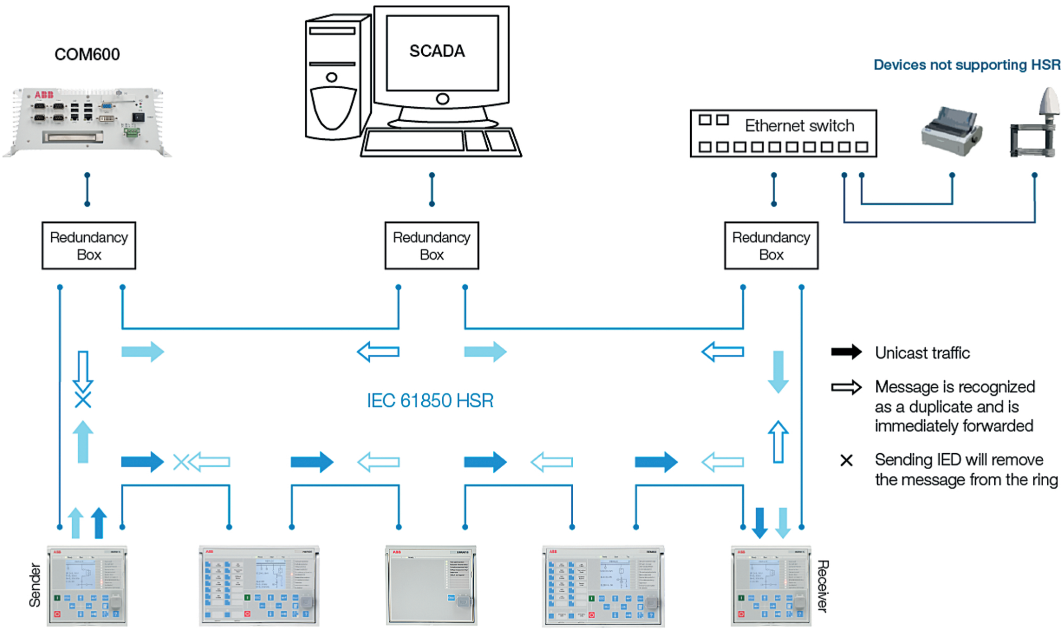


Figure 9: HSR solution

2.5.3 Process bus

Process bus IEC 61850-9-2 defines the transmission of Sampled Measured Values within the substation automation system. International Users Group created a guideline IEC 61850-9-2 LE that defines an application profile of IEC 61850-9-2 to facilitate implementation and enable interoperability. Process bus is used for distributing process data from the primary circuit to all process bus compatible devices in the local network in a real-time manner. The data can then be processed by any protection relay to perform different protection, automation and control functions.

UniGear Digital switchgear concept relies on the process bus together with current and voltage sensors. The process bus enables several advantages for the UniGear Digital like simplicity with reduced wiring, flexibility with data availability to all devices, improved diagnostics and longer maintenance cycles.

With process bus the galvanic interpanel wiring for sharing busbar voltage value can be replaced with Ethernet communication. Transmitting measurement samples over process bus brings also higher error detection because the signal transmission is automatically supervised. Additional contribution to the higher availability is the possibility to use redundant Ethernet network for transmitting SMV signals.

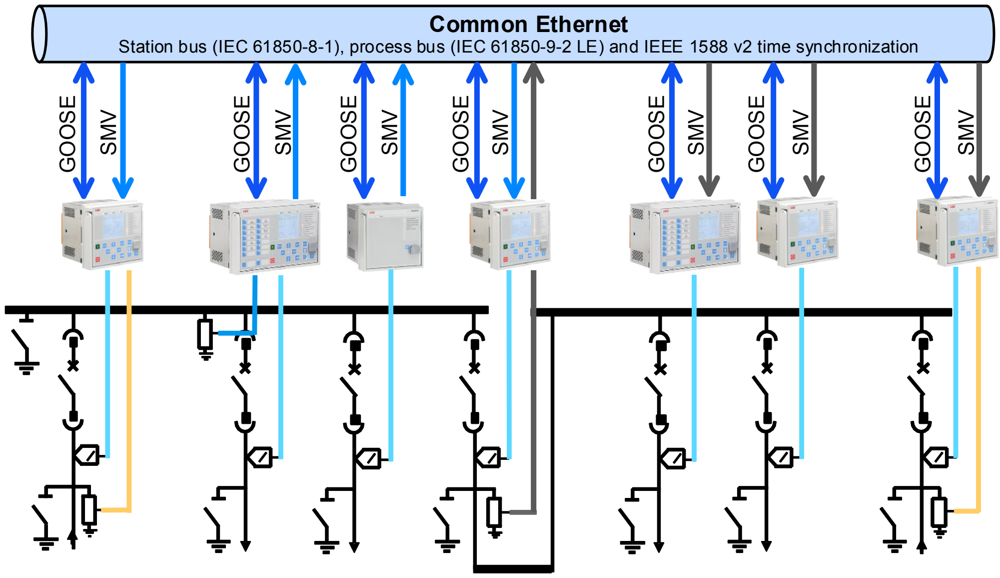


Figure 10: Process bus application of voltage sharing and synchrocheck

The 620 series supports IEC 61850 process bus with sampled values of analog currents and voltages. The measured values are transferred as sampled values using the IEC 61850-9-2 LE protocol which uses the same physical Ethernet network as the IEC 61850-8-1 station bus. The intended application for sampled values is sharing the measured voltages from one 620 series protection relay to other devices with phase voltage based functions and 9-2 support.

The 620 series protection relays with process bus based applications use IEEE 1588 v2 Precision Time Protocol (PTP) according to IEEE C37.238-2011 Power Profile for high accuracy time synchronization. With IEEE 1588 v2, the cabling infrastructure requirement is reduced by allowing time synchronization information to be transported over the same Ethernet network as the data communications.

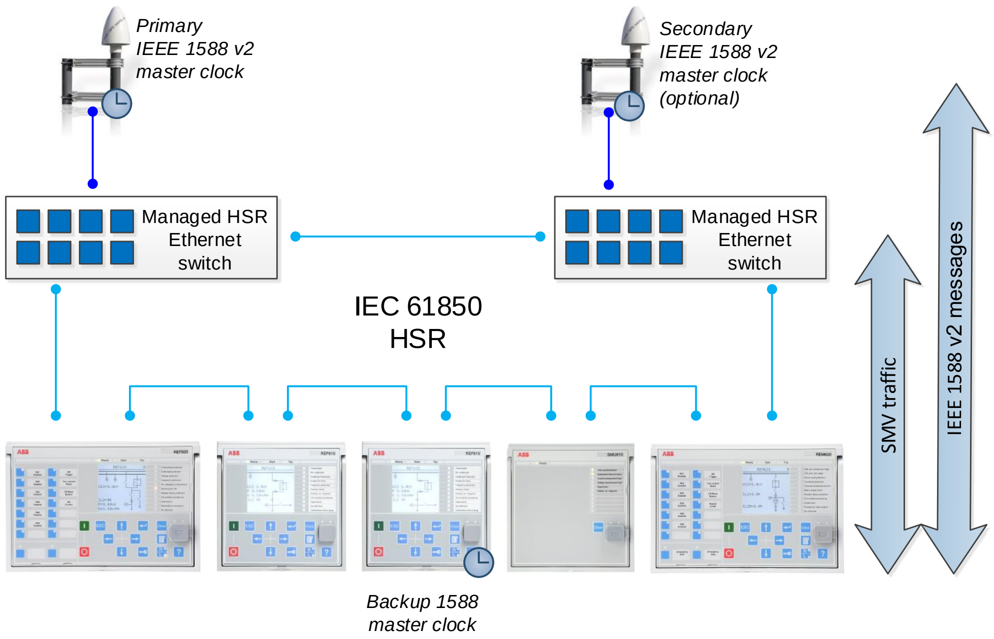


Figure 11: Example network topology with process bus, redundancy and IEEE 1588 v2 time synchronization

The process bus option is available for all 620 series protection relays equipped with phase voltage inputs. Another requirement is a communication card with IEEE 1588 v2 support (COM0031...COM0034 or COM0037). See the IEC 61850 engineering guide for detailed system requirements and configuration details.

2.5.4 Secure communication

The protection relay supports secure communication for WHMI and file transfer protocol. If the *Secure Communication* parameter is activated, protocols require TLS based encryption method support from the clients. In this case WHMI must be connected from a Web browser using the HTTPS protocol and in case of file transfer the client must use FTPS.

3 Basic functions

3.1 General parameters

3.1.1 Analog input settings, phase currents

Table 6: Analog input settings, phase currents

Parameter	Values (Range)	Unit	Step	Default	Description
Primary current	1.0...6000.0	A	0.1	100.0	Rated primary current
Secondary current [1]	2=1A 3=5A			2=1A	Rated secondary current
Amplitude Corr A	0.9000...1.1000		0.0001	1.0000	Phase A amplitude correction factor
Amplitude Corr B	0.9000...1.1000		0.0001	1.0000	Phase B amplitude correction factor
Amplitude Corr C	0.9000...1.1000		0.0001	1.0000	Phase C amplitude correction factor
Nominal current [2]	39...4000	A	1	1300	Network Nominal Current (In)
Rated secondary Val	1.000...150.000	mV/Hz	0.001	3.000	Rated Secondary Value (RSV) ratio
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the phase CTs
Angle Corr A	-8.000 … 8.000	deg	0.0001	0.0000	Phase A angle correction factor
Angle Corr B	-8.000 … 8.000	deg	0.0001	0.0000	Phase B angle correction factor
Angle Corr C	-8.000 … 8.000	deg	0.0001	0.0000	Phase C angle correction factor

1 For CT
2 For sensor

3.1.2 Analog input settings, residual current

Table 7: Analog input settings, residual current

Parameter	Values (Range)	Unit	Step	Default	Description
Primary current	1.0...6000.0	A	0.1	100.0	Primary current
Secondary current	1=0.2A 2=1A 3=5A			2=1A	Secondary current
Amplitude Corr	0.9000...1.1000		0.0001	1.0000	Amplitude correction
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the residual CT
Angle correction	-8.000 … 8.000	deg	0.0001	0.0000	Angle correction factor

3.1.3 Analog input settings, phase voltages

Table 8: Analog input settings, phase voltages

Parameter	Values (Range)	Unit	Step	Default	Description
Primary voltage [1]	0.100...440.000	kV	0.001	20.000	Primary rated voltage
Secondary voltage	60...210	V	1	100	Secondary rated voltage
VT connection	1=Wye 2=Delta 3=U12 4=UL1			2=Delta	Voltage transducer measurement connection
Amplitude Corr A	0.9000...1.1000		0.0001	1.0000	Phase A Voltage phasor magnitude correction of an external voltage transformer
Amplitude Corr B	0.9000...1.1000		0.0001	1.0000	Phase B Voltage phasor magnitude correction of an external voltage transformer
Amplitude Corr C	0.9000...1.1000		0.0001	1.0000	Phase C Voltage phasor magnitude correction of an external voltage transformer
Division ratio [2]	1000...20000		1	10000	Voltage sensor division ratio
Voltage input type	1=Voltage trafo 3=CVD sensor			1=Voltage trafo	Type of the voltage input
Angle Corr A	-8.000 … 8.000	deg	0.0001	0.0000	Phase A Voltage phasor angle correction of an external voltage transformer

Table continues on the next page

[1] For VT
[2] For sensor

Parameter	Values (Range)	Unit	Step	Default	Description
Angle Corr B	-8.000 … 8.000	deg	0.0001	0.0000	Phase B Voltage phasor angle correction of an external voltage transformer
Angle Corr C	-8.000 … 8.000	deg	0.0001	0.0000	Phase C Voltage phasor angle correction of an external voltage transformer

3.1.4 Analog input settings, residual voltage

Table 9: Analog input settings, residual voltage

Parameter	Values (Range)	Unit	Step	Default	Description
Primary voltage	0.100 ... 440.000 [1]	kV	0.001	11.547	Primary voltage
Secondary voltage	60...210	V	1	100	Secondary voltage
Amplitude Corr	0.9000 ... 1.1000		0.0001	1.0000	Amplitude correction
Angle correction	-8.000 … 8.000	deg	0.0001	0.0000	Angle correction factor

1 In 9-2 applications, Primary voltage maximum is limited to 126 kV.

3.1.5 Authorization settings

Table 10: Authorization settings

Parameter	Values (Range)	Unit	Step	Default	Description
Local override	0=False [1] 1=True [2]			1=True	Disable authority
Remote override	0=False [3] 1=True [4]			1=True	Disable authority
Local viewer				0	Set password
Local operator				0	Set password
Local engineer				0	Set password
Local administrator				0	Set password
Remote viewer				0	Set password
Remote operator				0	Set password
Remote engineer				0	Set password
Remote adminis-trator				0	Set password
Authority logging	1=None 2=Configuration change 3=Setting group 4=Setting group, control 5=Settings edit 6=All			4=Setting group, control	Authority logging level

[1] Authorization override disabled, LHMI password required
[2] Authorization override enabled, LHMI password not required
[3] Authorization override disabled, communication tools request a password to enter the IED
[4] Authorization override enabled, other communication tools than WHMI do not request a password to enter the IED

3.1.6 Binary input settings

Table 11: Binary input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Threshold voltage	16...176	Vdc	2	16	Binary input threshold voltage
Input osc. level	2...50	events/s	1	30	Binary input oscillation suppression threshold
Input osc. hyst	2...50	events/s	1	10	Binary input oscillation suppression hysteresis

3.1.7 Binary signals in card location Xnnn

Table 12: Binary input signals in card location Xnnn

Name	Type	Description
Xnnn-Input m [1], [2]	BOOLEAN	See the application manual for terminal connections

Table 13: Binary output signals in card location Xnnn

Name	Type	Default	Description
Xnnn-Pmm [1], [3]	BOOLEAN	0=False	See the application manual for terminal connections

[1] Xnnn = Slot ID, for example, X100, X110, as applicable
[2] m =For example, 1, 2, depending on the serial number of the binary input in a particular BIO card
[3] Pmm = For example, PO1, PO2, SO1, SO2, as applicable

3.1.8 Binary input settings in card location Xnnn

Table 14: Binary input settings in card location Xnnn

Name [1]	Value	Unit	Step	Default
Input m [2] filter time	5…1000	ms		5
Input m inversion	0= False 1= True			0=False

3.1.9 Ethernet front port settings

Table 15: Ethernet front port settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP address				192.168.0.254	IP address for front port (fixed)
Mac address				XX-XX-XX-XX-XX-XX	Mac address for front port

3.1.10 Ethernet rear port settings

Table 16: Ethernet rear port settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP address				192.168.2.10	IP address for rear port(s)
Subnet mask				255.255.255.0	Subnet mask for rear port(s)
Default gateway				192.168.2.1	Default gateway for rear port(s)
Mac address				XX-XX-XX-XX-XX-XX	Mac address for rear port(s)

[1] Xnnn = Slot ID, for example, X100, X110, as applicable
[2] m = For example, 1, 2, depending on the serial number of the binary input in a particular BIO card

3.1.11 General system settings

Table 17: General system settings

Parameter	Values (Range)	Unit	Step	Default	Description
Rated frequency	1=50Hz 2=60Hz			1=50Hz	Rated frequency of the network
Phase rotation	1=ABC 2=ACB			1=ABC	Phase rotation order
Blocking mode	1=Freeze timer 2=Block all 3=Block OPERATE output			1=Freeze timer	Behaviour for function BLOCK inputs
Bay name [1]				REx620 [2]	Bay name in system
IDMT Sat point	10...50	I/I>	1	50	Overcurrent IDMT saturation point
SMV Max Delay	0=1.90 1.58 ms 1=3.15 2.62 ms 2=4.40 3.67 ms 3=5.65 4.71 ms 4=6.90 5.75 ms			1=3.15 2.62 ms	SMV Maximum allowed delay

[1] Used in the IED main menu header and as part of the disturbance recording identification
[2] Depending on the product variant

3.1.12 HMI settings

Table 18: HMI settings

Parameter	Values (Range)	Unit	Step	Default	Description
FB naming convention	1=IEC61850 2=IEC60617 3=IEC-ANSI			1=IEC61850	FB naming convention used in IED
Default view	1=Measurements 2=Main menu 3=SLD			1=Measurements	LHMI default view
Backlight timeout	1...60	min	1	3	LHMI backlight timeout
Web HMI mode	1=Active read only 2=Active 3=Disabled			3=Disabled	Web HMI functionality
Web HMI timeout	1...60	min	1	3	Web HMI login timeout
SLD symbol format	1=IEC 2=ANSI			1=IEC	Single Line Diagram symbol format
Autoscroll delay	0...30	s	1	0	Autoscroll delay for Measurements view
Setting visibility	1=Basic 2=Advanced			1=Basic	Setting visibility for HMI

3.1.13 IEC 60870-5-103 settings

Table 19: IEC 60870-5-103 settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			5=off	Selects if this protocol instance is enabled or disabled
Serial port	1=COM 1 2=COM 2			1=COM 1	COM port
Address	1...255		1	1	Unit address
Start delay	0...20	char	1	4	Start frame delay in chars
End delay	0...20	char	1	4	End frame delay in chars
DevFunType	0...255		1	9	Device Function Type
UsrFunType	0...255		1	10	Function type for User Class 2 Frame
UsrInfNo	0...255		1	230	Information Number for User Class2 Frame
Class1Priority	0=Ev High 1=Ev/DR Equal 2=DR High			0=Ev High	Class 1 data sending priority relationship between Events and Disturbance Recorder data.

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Class2Interval	0...86400	s	1	30	Interval in seconds to send class 2 response
Frame1InUse	-1=Not in use 0=User frame 1=Standard frame 1 2=Standard frame 2 3=Standard frame 3 4=Standard frame 4 5=Standard frame 5 6=Private frame 6 7=Private frame 7			6=Private frame 6	Active Class2 Frame 1
Frame2InUse	-1=Not in use 0=User frame 1=Standard frame 1 2=Standard frame 2 3=Standard frame 3 4=Standard frame 4 5=Standard frame 5 6=Private frame 6 7=Private frame 7			-1=Not in use	Active Class2 Frame 2
Frame3InUse	-1=Not in use 0=User frame 1=Standard frame 1 2=Standard frame 2 3=Standard frame 3 4=Standard frame 4 5=Standard frame 5 6=Private frame 6 7=Private frame 7			-1=Not in use	Active Class2 Frame 3
Frame4InUse	-1=Not in use 0=User frame 1=Standard frame 1 2=Standard frame 2 3=Standard frame 3 4=Standard frame 4 5=Standard frame 5 6=Private frame 6 7=Private frame 7			-1=Not in use	Active Class2 Frame 4
Class1OvInd	0=No indication 1=Both edges 2=Rising edge			2=Rising edge	Overflow Indication

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Class1OvFType	0...255		1	10	Function Type for Class 1 overflow indication
Class1OvInfNo	0...255		1	255	Information Number for Class 1 overflow indication
Class1OvBackOff	0...500		1	500	Backoff Range for Class1 buffer
GI Optimize	0=Standard behaviour 1=Skip spontaneous 2=Only overflown 3=Combined			0=Standard behaviour	Optimize GI traffic
DR Notification	0=False 1=True			0=False	Disturbance Recorder spontaneous indications enabled/disabled
Block Monitoring	0=Not in use 1=Discard events 2=Keep events			0=Not in use	Blocking of Monitoring Direction
Internal Overflow	0=False 1=True			0=False	Internal Overflow: TRUE-System level overflow occured (indication only)
EC_FRZ	0=False 1=True			0=False	Control point for freezing energy counters

3.1.14 IEC 61850-8-1 MMS settings

Table 20: IEC 61850-8-1 MMS settings

Parameter	Values (Range)	Unit	Step	Default	Description
Unit mode	1=Primary [1] 0=Nominal [2] 2=Primary-Nominal [3]			0=Nominal	IEC 61850-8-1 unit mode

1 MMS client expects primary values from event reporting and data attribute reads.

2 MMS client expects nominal values from event reporting and data attribute reads; this is the default for PCM600.

3 For PCM600 use only, When *Unit mode* is set to "Primary", the PCM600 client can force its session to "Nominal" by selecting "Primary-Nominal" and thus parameterizing in native form. The selection is not stored and is therefore effective only for one session. This value has no effect if selected via the LHMI.

3.1.15 Modbus settings

Table 21: Modbus settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			5=off	Enable or disable this protocol instance
Port	1=COM 1 2=COM 2 3=Ethernet - TCP 1			3=Ethernet - TCP 1	Port selection for this protocol instance. Select between serial and Ethernet based communication.
Mapping selection	1...2		1	1	Chooses which mapping scheme will be used for this protocol instance.
Address	1...254		1	1	Unit address
Link mode	1=RTU 2=ASCII			1=RTU	Selects between ASCII and RTU mode. For TCP, this should always be RTU.
TCP port	1...65535		1	502	Defines the listening port for the Modbus TCP server. Default = 502.
Parity	0=none 1=odd 2=even			2=even	Parity for the serial connection.
Start delay	0...20		1	4	Start delay in character times for serial connection
End delay	0...20		1	4	End delay in character times for serial connections
CRC order	0=Hi-Lo 1=Lo-Hi			0=Hi-Lo	Selects between normal or swapped byte order for checksum for serial connection. Default: Hi-Lo.
Client IP				0.0.0.0	Sets the IP address of the client. If set to zero, connection from any client is accepted.
Write authority	0=Read only 1=Disable 0x write 2=Full access			2=Full access	Selects the control authority scheme
Time format	0=UTC 1=Local			1=Local	Selects between UTC and local time for events and timestamps.
Event ID selection	0=Address 1=UID			0=Address	Selects whether the events are reported using the MB address or the UID number.
Event buffering	0=Keep oldest 1=Keep newest			0=Keep oldest	Selects whether the oldest or newest events are kept in the case of event buffer overflow.

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Event backoff	1...500		1	200	Defines how many events have to be read after event buffer overflow to allow new events to be buffered. Applicable in "Keep oldest" mode only.
ControlStructPWd 1				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 2				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 3				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 4				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 5				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 6				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 7				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 8				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.

3.1.16 DNP3 settings

Table 22: DNP3 general settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			5=off	Operation Off / On
Port	1=COM 1 2=COM 2 3=Ethernet - TCP 1 4=Ethernet TCP+UDP 1			3=Ethernet - TCP 1	Communication interface selection
Unit address	1...65519		1	1	DNP unit address
Master address	1...65519		1	3	DNP master and UR address
Mapping select	1...2		1	1	Mapping select
ClientIP				0.0.0.0	IP address of client
TCP port	20000...65535		1	20000	TCP Port used on ethernet communication
TCP write authority	0=No clients 1=Reg. clients 2=All clients			2=All clients	0=no client controls allowed; 1=Controls allowed by registered clients; 2=Controls allowed by all clients
Link keep-alive	0...65535	s	1	0	Link keep-alive interval for DNP
Validate master addr	1=Disable 2=Enable			1=Disable	Validate master address on receive
Self address	1=Disable 2=Enable			2=Enable	Support self address query function
Need time interval	0...65535	min	1	30	Period to set IIN need time bit
Time format	0=UTC 1=Local			1=Local	UTC or local. Coordinate with master.
CROB select timeout	1...65535	s	1	10	Control Relay Output Block select timeout
Data link confirm	0=Never 1=Only Multiframe 2=Always			0=Never	Data link confirm mode
Data link confirm TO	100...65535	ms	1	3000	Data link confirm timeout
Data link retries	0...65535		1	3	Data link retries count
Data link Rx to Tx delay	0...255	ms	1	0	Turnaround transmission delay
Data link inter char delay	0...20	char	1	4	Inter character delay for incoming messages
App layer confirm	1=Disable 2=Enable			1=Disable	Application layer confirm mode
App confirm TO	100...65535	ms	1	5000	Application layer confirm and UR timeout
App layer fragment	256...2048	bytes	1	2048	Application layer fragment size
UR mode	1=Disable 2=Enable			1=Disable	Unsolicited responses mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
UR retries	0...65535		1	3	Unsolicited retries before switching to UR offline mode
UR TO	0...65535	ms	1	5000	Unsolicited response timeout
UR offline interval	0...65535	min	1	15	Unsolicited offline interval
UR Class 1 Min events	0...999		1	2	Min number of class 1 events to generate UR
UR Class 1 TO	0...65535	ms	1	50	Max holding time for class 1 events to generate UR
UR Class 2 Min events	0...999		1	2	Min number of class 2 events to generate UR
UR Class 2 TO	0...65535	ms	1	50	Max holding time for class 2 events to generate UR
UR Class 3 Min events	0...999		1	2	Min number of class 3 events to generate UR
UR Class 3 TO	0...65535	ms	1	50	Max holding time for class 3 events to generate UR
Legacy master UR	1=Disable 2=Enable			1=Disable	Legacy DNP master unsolicited mode support. When enabled relay does not send initial unsolicited message.
Legacy master SBO	1=Disable 2=Enable			1=Disable	Legacy DNP Master SBO sequence number relax enable
Default Var Obj 01	1=1:BI 2=2:BI&status			1=1:BI	1=BI; 2=BI with status.
Default Var Obj 02	1=1:BI event 2=2:BI event&time			2=2:BI event&time	1=BI event; 2=BI event with time.
Default Var Obj 03	1=1:DBI 2=2:DBI&status			1=1:DBI	1=DBI; 2=DBI with status.
Default Var Obj 04	1=1:DBI event 2=2:DBI event&time			2=2:DBI event&time	1=DBI event; 2=DBI event with time.
Default Var Obj 20	1=1:32bit Cnt 2=2:16bit Cnt 5=5:32bit Cnt noflag 6=6:16bit Cnt noflag			2=2:16bit Cnt	1=32 bit counter; 2=16 bit counter; 5=32 bit counter without flag; 6=16 bit counter without flag.
Default Var Obj 21	1=1:32bit FrzCnt 2=2:16bit FrzCnt 5=5:32bit FrzCnt&time 6=6:16bit FrzCnt&time 9=9:32bit FrzCnt noflag 10=10:16bit FrzCnt noflag			6=6:16bit FrzCnt&time	1=32 bit frz counter; 2=16 bit frz counter; 5=32 bit frz counter with time; 6=16 bit frz counter with time; 9=32 bit frz counter without flag;10=16 bit frz counter without flag.
Default Var Obj 22	1=1:32bit Cnt evt 2=2:16bit Cnt evt 5=5:32bit Cnt evt&time 6=6:16bit Cnt evt&time			6=6:16bit Cnt evt&time	1=32 bit counter event; 2=16 bit counter event; 5=32 bit counter event with time; 6=16 bit counter event with time.
Default Var Obj 23	1=1:32bit FrzCnt evt			6=6:16bit FrzCnt evt&time	1=32 bit frz counter event; 2=16 bit frz counter event;

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=2:16bit FrzCnt evt 5=5:32bit FrzCnt evt&time 6=6:16bit FrzCnt evt&time				5=32 bit frz counter event with time; 6=16 bit frz counter event with time.
Default Var Obj 30	1=1:32bit AI 2=2:16bit AI 3=3:32bit AI noflag 4=4:16bit AI noflag 5=5:AI float 6=6:AI double			5=5:AI float	1=32 bit AI; 2=16 bit AI; 3=32 bit AI without flag; 4=16 bit AI without flag; 5=AI float; 6=AI double.
Default Var Obj 32	1=1:32bit AI evt 2=2:16bit AI evt 3=3:32bit AI evt&time 4=4:16bit AI evt&time 5=5: float AI evt 6=6:double AI evt 7=7:float AI evt&time 8=8:double AI evt&time			7=7:float AI evt&time	1=32 bit AI event; 2=16 bit AI event; 3=32 bit AI event with time; 4=16 bit AI event with time; 5=float AI event; 6=double AI event; 7=float AI event with time; 8=double AI event with time.
Default Var Obj 40	1=1:32bit AO 2=2:16bit AO 3=3:AO float 4=4:AO double			2=2:16bit AO	1=32 bit AO; 2=16 bit AO; 3=AO float; 4=AO double.
Default Var Obj 42	1=1:32bit AO evt 2=2:16bit AO evt 3=3:32bit AO evt&time 4=4:16bit AO evt&time 5=5:float AO evt 6=6:double AO evt 7=7:float AO evt&time 8=8:double AO evt&time			4=4:16bit AO evt&time	1=32 bit AO event; 2=16 bit AO event; 3=32 bit AO event with time; 4=16 bit AO event with time; 5=float AO event; 6=double AO event; 7=float AO event with time; 8=double AO event with time.

3.1.17 COM1 serial communication settings

Table 23: COM1 serial communication settings

Parameter	Values (Range)	Unit	Step	Default	Description
Fiber mode	0=No fiber 2=Fiber optic			0=No fiber	Fiber mode for COM1
Serial mode	1=RS485 2Wire 2=RS485 4Wire 3=RS232 no handshake			1=RS485 2Wire	Serial mode for COM1

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	4=RS232 with handshake				
CTS delay	0...60000	ms	1	0	CTS delay for COM1
RTS delay	0...60000	ms	1	0	RTS delay for COM1
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate for COM1

3.1.18 COM2 serial communication settings

Table 24: COM2 serial communication settings

Parameter	Values (Range)	Unit	Step	Default	Description
Fiber mode	0=No fiber 2=Fiber optic			0=No fiber	Fiber mode for COM2
Serial mode	1=RS485 2Wire 2=RS485 4Wire 3=RS232 no handshake 4=RS232 with handshake			1=RS485 2Wire	Serial mode for COM2
CTS delay	0...60000	ms	1	0	CTS delay for COM2
RTS delay	0...60000	ms	1	0	RTS delay for COM2
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate for COM2

3.1.19 Time settings

Table 25: Time settings

Parameter	Values (Range)	Unit	Step	Default	Description
Time format	1=24H:MM:SS:MS			1=24H:MM:SS:MS	Time format

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=12H:MM:SS:MS				
Date format	1=DD.MM.YYYY 2=DD/MM/YYYY 3=DD-MM-YYYY 4=MM.DD.YYYY 5=MM/DD/YYYY 6=YYYY-MM-DD 7=YYYY-DD-MM 8=YYYY/DD/MM			1=DD.MM.YYYY	Date format

3.2 Self-supervision

The protection relay's extensive self-supervision system continuously supervises the relay’s software, hardware and certain external circuits. It handles the run-time fault situation and informs the user about a fault via the LHMI and through the communication channels. The target of the self-supervision is to safeguard the relay’s reliability by increasing both dependability and security. The dependability can be described as the relay’s ability to operate when required. The security can be described as the relay scheme’s ability to refrain from operating when not required. The dependability is increased by letting the system operators know about the problem, giving them a chance to take the necessary actions as soon as possible. The security is increased by preventing the relay from making false decisions, such as issuing false control commands.

There are two types of fault indications.

- Internal faults
- Warnings

3.2.1 Internal faults

When an internal relay fault is detected, the relay protection operation is disabled, the green Ready LED begins to flash and the self-supervision output relay is de-energized, i.e. the change-over contact is released.

Internal fault indications have the highest priority on the LHMI. None of the other LHMI indications can override the internal fault indication.

An indication about the fault is shown as a message on the LHMI. The text `Internal Fault` with an additional text message, a code, date and time, is shown to indicate the fault type.

Different actions are taken depending on the severity of the internal fault. In case of a temporary fault, the protection relay tries to recover from the situation by restarting. Restarting varies per fault type. The restart procedure includes two stages; when the relay detects a fault, it restarts itself in a few seconds after the fault occurrence. If the relay did not recover after the first fast self-recovery attempts (typically 1-2 restarts), or the fault reoccurs during the next 60 minutes, the next self-recovery attempts (typically 3 restarts) are delayed for 10 minutes. Exact recovery mechanism is described in *Table 26*. In case of a permanent fault, the protection relay stays in the internal fault mode. All output relays are de-energized and contacts are released for the internal fault. The protection relay continues to perform internal tests during the fault situation. If the internal fault disappears, the green Ready LED stop flashing and the protection relay returns to the normal service state. Internal Fault: All ok event appears in the event list after succesfull recovery.

One possible cause for an internal fault situation is a so-called soft error. The soft error is a probabilistic phenomenon which is rare in a single device, statistically not happening more often than once in a relay's lifetime. No hardware failures are expected and a full recovery from the soft error is possible by a self-supervision controlled restart of the relay.

The self-supervision signal output operates on the closed-circuit principle. Under normal conditions, the protection relay is energized and the contact gaps 3-5 in slot X100 is closed. If the auxiliary power supply fails or an internal fault is detected, the contact gaps 3-5 are opened.

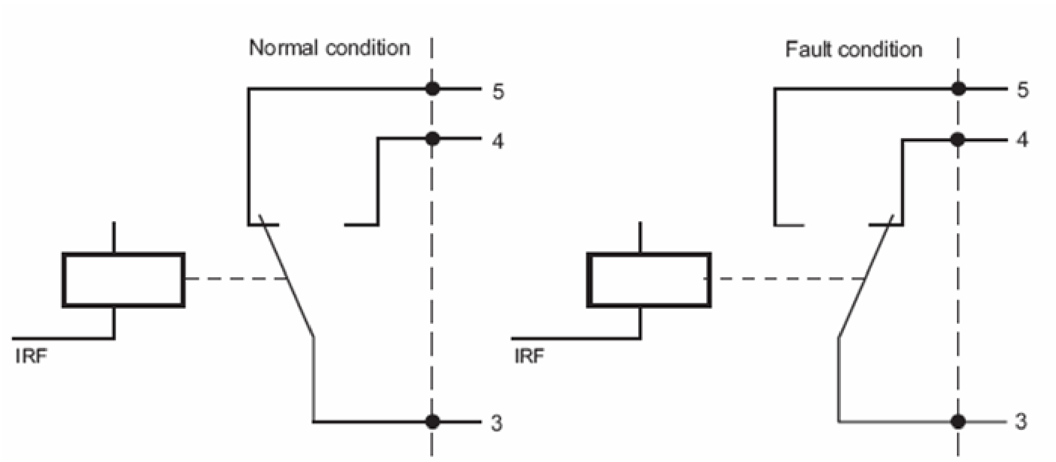


Figure 12: Output contact

The internal fault code indicates the type of internal relay fault. When a fault appears, the code must be recorded so that it can be reported to ABB customer service.

Table 26: Internal fault indications and codes

Fault indication	Fault code	Additional information	Fast self-recovery attempt (# of attempts)	Slow 10 min self-recovery (# of attempts)	Immediate permanent IRF-mode	Action in permanent fault state
Internal Fault System error	2	Start up error: HW/SW mismatch	No	No	Yes	If relay SW has just been updated, redo it. If not recovered, contact your nearest ABB representative to check the next possible corrective action.
Internal Fault System error	2	Start up or runtime error: Data bus error, CPU module	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault System error	2	Start up error: SCL file missing	No	No	Yes	Do factory restore or rewrite configuration using PCM600.

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt (# of attempts)	Slow 10 min self-recovery (# of attempts)	Immediate permanen t IRF-mode	Action in permanent fault state
Internal Fault System error	2	Start up error: Miss-ing order number	No	No	Yes	Do factory restore. If not recovered, con-tact your nearest ABB representative to check the next possible corrective ac-tion.
Internal Fault System error	2	Start up error: FPGA HW error, CPU mod-ule	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restart-ing, continue relay normal operation. If not recover by restarting, replace the re-lay, most probably hardware failure in CPU module.
Internal Fault System error	2	Start up error: FPGA image corrupted, CPU module	Yes (2)	Yes (3)	No	Restart the relay or if relay SW has just been updated, redo it. If recovered by restarting, continue relay normal opera-tion. If not recovered by restarting or redoing SW update, replace the relay, most probably hardware failure in CPU module.
Internal Fault System error	2	Runtime error: CPU internal fault	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restart-ing, continue relay normal operation. If not recover by restarting, replace the re-lay, most probably hardware failure in CPU module.
Internal Fault File system error	7	Start up error or runtime error: file system error	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restart-ing, continue relay normal operation. If not recover by restarting, replace the re-lay, most probably hardware failure in CPU module.
Internal Fault Test	8	Internal fault test activated manually by the user.	No	No	-	Just check the "Internal fault test" -set-ting parameter position, if relay is in test mode
Internal Fault SW watchdog error	10	Start up error: Watchdog reset has occurred too many times within an hour. **Note!** This is different indication than *Warning code 10: Watchdog reset*	No	No	Yes	Restart the relay. If recovered by restart-ing, continue relay normal operation. If not recover by restarting, replace the re-lay.
Internal Fault SO-relay(s),X105	40	Runtime error: Faul-ty Signal Output re-lay(s) in card loca-ted in slot X105.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recov-ered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X105.
Internal Fault SO-relay(s),X115	41	Runtime error: Faul-ty Signal Output re-lay(s) in card loca-ted in slot X115.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recov-ered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X115.
Internal Fault SO-relay(s),X100	43	Runtime error: Faul-ty Signal Output re-lay(s) in card loca-ted in slot X100.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recov-ered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X100.
Internal Fault SO-relay(s),X110	44	Runtime error: Faul-ty Signal Output re-lay(s) in card loca-ted in slot X110.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recov-ered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X110.
Internal Fault SO-relay(s),X120	45	Runtime error: Faul-ty Signal Output re-lay(s) in card loca-ted in slot X120.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recov-ered by restarting, continue relay normal operation. If not recover by restarting,

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt (# of attempts)	Slow 10 min self-recovery (# of attempts)	Immediate permanen t IRF-mode	Action in permanent fault state
						exchange the hardware module in slot X120.
Internal Fault SO-relay(s),X130	46	Runtime error: Faulty Signal Output relay(s) in card located in slot X130.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X130.
Fault in PO-relay(s) attached to X105	50	Runtime error: Faulty Power Output relay(s) in card located in slot X105.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X105.
Fault in PO-relay(s) attached to X115	51	Runtime error: Faulty Power Output relay(s) in card located in slot X115.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X115.
Fault in PO-relay(s) attached to X100	53	Runtime error: Faulty Power Output relay(s) in card located in slot X100.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X100.
Internal Fault PO-relay(s),X110	54	Runtime error: Faulty Power Output relay(s) in card located in slot X110.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X110.
Internal Fault PO-relay(s),X120	55	Runtime error: Faulty Power Output relay(s) in card located in slot X120.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X120.
Internal Fault PO-relay(s),X130	56	Runtime error: Faulty Power Output relay(s) in card located in slot X130.	Yes (2)	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X130.
Internal Fault Light sensor error	57	Runtime error: Faulty ARC light sensor input(s).	Yes (2)	Yes (3)	No	Check light sensors and their connection to relay. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the communication module including ARC inputs in slot X000.
Internal Fault Conf. error,X105	60	Start up error: Card in slot X105 is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot X105 is proper type and properly installed. Check that the plug-in unit is properly installed and plug-in unit handle is properly fixed to closed position. Then restart the relay. If does not recover by restarting, it is hardware module failure most likely. Exchange the hardware module in slot X105.
Internal Fault Conf. error,X115	61	Start up error: Card in slot X115 is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot X115 is proper type and properly installed. Check that the plug-in unit is properly installed and plug-in unit handle is properly fixed to closed position. Then restart the relay.If does not recover by restarting, it is hardware module failure most likely. Exchange the hardware module in slot X115.

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt (# of attempts)	Slow 10 min self-recovery (# of attempts)	Immediate permanent IRF-mode	Action in permanent fault state
Internal Fault Conf. error,X000	62	Start up error: Card in slot X000 is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	"Check that the communication card in slot X000 is proper type and properly installed. Check that the plug-in unit is properly installed and plug-in unit handle is properly fixed to closed position. Then restart the relay. If does not recover by restarting, it is hardware module failure most likely. Exchange the communication module in slot X000. In some rare cases also communication storm may cause this. Detach the ethernet communication cable(s) from the communication module and reboot the relay. If not recover,exchange the communication module in slot X000. "
Internal Fault Conf. error,X100	63	Start up error: Card in slot X100 is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot X100 is proper type and properly installed. Check that the plug-in unit is properly installed and plug-in unit handle is properly fixed to closed position. Then restart the relay. If does not recover by restarting, it is hardware module failure most likely. Exchange the hardware module in slot X100.
Internal Fault Conf. error,X110	64	Start up error: Card in slot X110 is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot X110 is proper type and properly installed. Check that the plug-in unit is properly installed and plug-in unit handle is properly fixed to closed position. Then restart the relay. If does not then recover by restarting, hardware module failure most likely. Exchange the hardware module in slot X110.
Internal Fault Conf. error,X120	65	Start up error: Card in slot X120 is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot X120 is proper type and properly installed. Check that the plug-in unit is properly installed and plug-in unit handle is properly fixed to closed position. Then restart the relay. If does not recover by restarting, it is hardware module failure most likely. Exchange the hardware module in slot X120.
Internal Fault Conf. error,X130	66	Start up error: Card in slot X130 is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot X130 is proper type and properly installed. Check that the plug-in unit is properly installed and plug-in unit handle is properly fixed to closed position. Then restart the relay. If does not recover by restarting, it is hardware module failure most likely. Exchange the hardware module in slot X130.
Internal Fault Card error,X105	70	Card in slot X105 is faulty.	Yes (2)	Yes (3)	No	Exchange the hardware module in slot X105.
Internal Fault Card error,X115	71	Card in slot X115 is faulty.	Yes (2)	Yes (3)	No	Exchange the hardware module in slot X115.
Internal Fault Card error,X000	72	Card in slot X000 is faulty.	Yes (2)	Yes (3)	No	"Check the plug-in unit connector pins in the card by detaching the plug-in unit. If pins are OK, exchange the communication module in slot X000. In some rare cases also communication storm may cause this. Detach the ethernet communication cable(s) from the communication module and reboot the relay. If not recover,exchange the communication module in slot X000. "

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt (# of attempts)	Slow 10 min self-recovery (# of attempts)	Immediate permanent IRF-mode	Action in permanent fault state
Internal Fault Card error,X100	73	Card in slot X100 is faulty.	Yes (2)	Yes (3)	No	Exchange the hardware module in slot X100.
Internal Fault Card error,X110	74	Card in slot X110 is faulty.	Yes (2)	Yes (3)	No	Exchange the hardware module in slot X110.
Internal Fault Card error,X120	75	Card in slot X120 is faulty.	Yes (2)	Yes (3)	No	Exchange the hardware module in slot X120.
Internal Fault Card error,X130	76	Card in slot X130 is faulty.	Yes (2)	Yes (3)	No	Check the plug-in unit connector pins in the card by detaching the plug-in unit. If pins are OK, exchange the hardware module in slot X130.
Internal Fault LHMI module	79	Runtime error: LHMI LCD error. The fault indication may not be seen on the LHMI during the fault.	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, check LHMI connection cable and connection to be proberly fixed. If then not recovered by restarting, exchange the LHMI module.
Internal Fault RAM error	80	Runtime error: Error in the RAM memory on the CPU module.	Yes (2)	Yes (10)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault ROM error	81	Runtime error: Error in the ROM memory on the CPU module.	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault EEPROM error	82	Start up error: Error in the EEPROM memory on the CPU module.	No	No	Yes	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault EEPROM error	82	Start up error: CRC check failure in the EEPROM memory on boot-up on the CPU module.	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault FPGA error	83	Runtime error: Error in the FPGA on the CPU module.	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault RTC error	84	Start up error: Error in the RTC on the CPU module.	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault RTD card error,X105	90	Runtime error: RTD card located in slot X105 may have permanent fault. Temporary error has occurred too many times within a short time.	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the RTD hardware module in slot X105.
Internal Fault RTD card error,X110	94	Runtime error: RTD card located in slot X110 may have permanent fault. Temporary error has oc-	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the RTD hardware module in slot X110.

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt (# of attempts)	Slow 10 min self-recovery (# of attempts)	Immediate permanent IRF-mode	Action in permanent fault state
		curred too many times within a short time.				
Internal Fault RTD card error,X130	96	Runtime error: RTD card located in slot X130 may have permanent fault. Temporary error has occurred too many times within a short time.	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot X130.
Internal Fault COM card error	116	Runtime error: Error in the COM card.	Yes (2)	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the communication module in slot X000.

For further information on internal fault indications, see the operation manual.

3.2.2 Warnings

In case of a warning, the protection relay continues to operate except for those protection functions possibly affected by the fault, and the green Ready LED remains lit as during normal operation.

Warnings are indicated with the text `Warning` additionally provided with the name of the warning, a numeric code and the date and time on the LHMI. The warning indication message can be manually cleared.

If a warning appears, record the name and code so that it can be provided to ABB customer service.

Table 27: Warning indications and codes

Warning indication	Warning code	Additional information
Warning System warning	2	An internal system error has occurred.
Warning Watchdog reset	10	A watchdog reset has occurred.
Warning Power down det.	11	The auxiliary supply voltage has dropped too low.
Warning IEC61850 error	20	Error when building the IEC 61850 data model.
Warning Modbus error	21	Error in the Modbus communication.
Warning	22	Error in the DNP3 communication.

Table continues on the next page

Warning indication	Warning code	Additional information
DNP3 error		
Warning Dataset error	24	Error in the Data set(s).
Warning Report cont. error	25	Error in the Report control block(s).
Warning GOOSE contr. error	26	Error in the GOOSE control block(s).
Warning SCL config error	27	Error in the SCL configuration file or the file is missing.
Warning Logic error	28	Too many connections in the configuration.
Warning SMT logic error	29	Error in the SMT connections.
Warning GOOSE input error	30	Error in the GOOSE connections.
ACT error	31	Error in the ACT connections.
Warning GOOSE Rx. error	32	Error in the GOOSE message receiving.
Warning AFL error	33	Analog channel configuration error.
SMV Warning	34	Error in the SMV configuration
Warning Comm. channel down	35	Redundant Ethernet (HSR/PRP) communication interrupted.
Warning Unack card comp.	40	A new composition has not been acknowledged/accepted.
Warning Protection comm.	50	Error in protection communication.
Warning ARC1 cont. light	85	A continuous light has been detected on the ARC light input 1.
Warning ARC2 cont. light	86	A continuous light has been detected on the ARC light input 2.
Warning	87	A continuous light has been detected on the ARC light input 3.

Table continues on the next page

Warning indication	Warning code	Additional information
ARC3 cont. light		
Warning RTD card error,X105	90	Temporary error occurred in RTD card located in slot X105
Warning RTD card error,X110	94	Temporary error occurred in RTD card located in slot X110
Warning RTD card error,X130	96	Temporary error occurred in RTD card located in slot X130.
Warning RTD meas. error,X105	100	Measurement error in RTD card located in slot X105.
Warning RTD meas. error,X110	104	Measurement error in RTD card located in slot X110.
Warning RTD meas. error,X130	106	Measurement error in RTD card located in slot X130.

For further information on warning indications, see the operation manual.

3.2.3 Fail-safe principle for relay protection

The relay behavior during an internal fault situation has to be considered when engineering trip circuits under the fail-safe principle. The considerations discussed and examples given are mainly based on the need of protection scheme reliability.

The reliability need can be divided into two subparts: dependability and security. The dependability can be described as the protection scheme's ability to operate when required. The security can be described as the protection scheme's ability to refrain from operating when not required. The protection scheme fail-safe principle is typically related to satisfying these two performance criteria. Depending on the requirements set to the electricity distribution process, one of the criteria may get more attention than the other. However, in some industrial electricity distribution networks, the main (productization) process is so dependent on reliable electricity supply that both criteria are addressed equally.

The examples presented focus on the relay's protection role in the fail-safe circuitry using traditional hardwiring. If communication between the relays, or to an upper level system, is a part of the fail-safe functionality, it must be also be a part of the circuitry.

3.2.3.1 Motor feeder

The target is to prevent the motor from running uncontrollably and to secure the emergency stop circuit functionality.

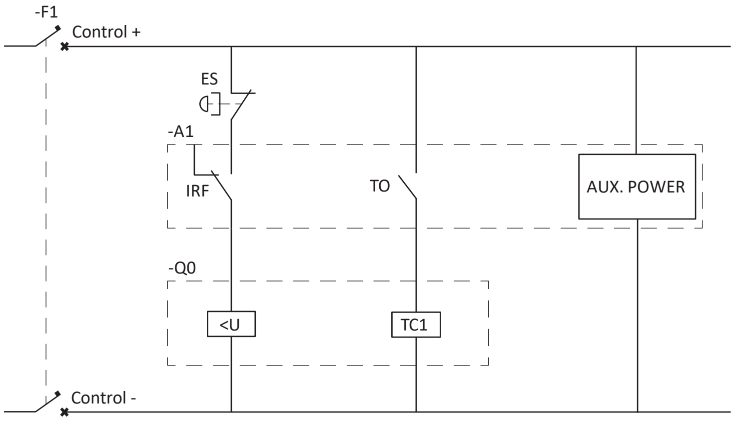


Figure 13: Motor feeder fail-safe trip circuit principle, example 1

A1	Protection relay
ES	Emergency stop
Q0	Circuit breaker (CB)
TO	Protection relay trip output
IRF	Internal relay fault indication
<U	CB undervoltage trip coil
TC1	CB trip coil 1
DCS	Distributed process control system
F1	Miniature circuit breaker

In example 1, the fail-safe approach aims at securing motor shutdown via an emergency switch and in case the control voltage disappears. In case of a temporary internal relay fault, the circuit breaker is immediately tripped before the relay recovers from the situation. In case the IRF output relay is directly connected to the undervoltage trip coil circuit, the output's performance figures (make and break values) must be checked.

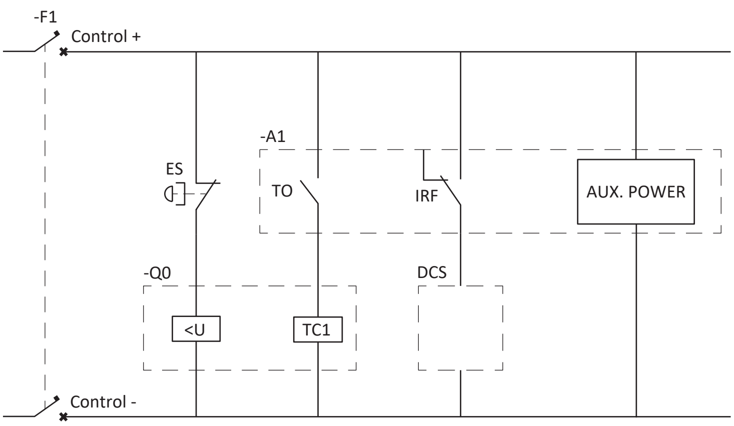


Figure 14: Motor feeder fail-safe trip circuit principle, example 2

A1	Protection relay
ES	Emergency stop
Q0	Circuit breaker (CB)

Table continues on the next page

TO	Protection relay trip output
IRF	Internal relay fault indication
<U	CB undervoltage trip coil
TC1	CB trip coil 1
DCS	Distributed process control system
F1	Miniature circuit breaker

In example 2, the fail-safe approach aims at securing motor shutdown via an emergency switch and in case the control voltage disappears. In case of internal relay fault, the necessary actions must be initiated by the process operators or by the control system.

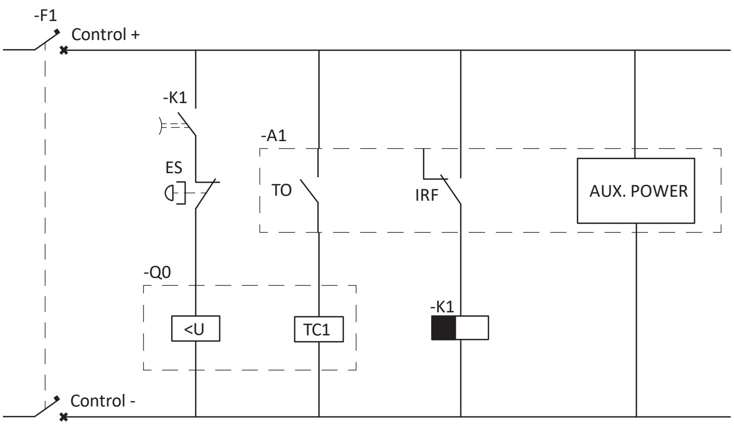


Figure 15: Motor feeder fail-safe trip circuit principle, example 3

A1	Protection relay
ES	Emergency stop
Q0	Circuit breaker (CB)
TO	Protection relay trip output
IRF	Internal relay fault indication
<U	CB undervoltage trip coil
TC1	CB trip coil 1
K1	OFF delay time relay
F1	Miniature circuit breaker

In example 3, the fail-safe approach aims at securing motor shutdown via an emergency switch and in case the control voltage disappears. In case of internal relay fault, the circuit breaker is tripped via an undervoltage coil after a preset time delay. The additional time delay allows the relay to recover from the internal fault situation without tripping the circuit breaker.

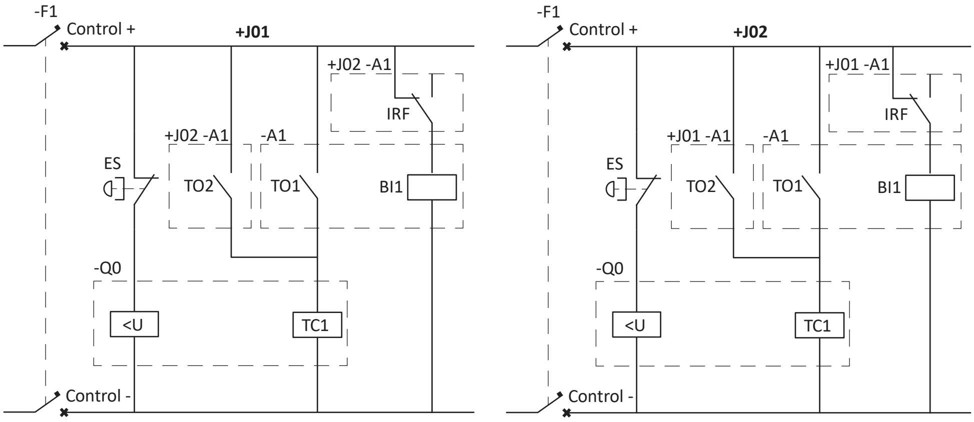


Figure 16: Motor feeder fail-safe trip circuit principle, example 4

J01	Feeder #1 panel
J02	Feeder #2 panel
ES	Emergency stop
Q0	Circuit breaker
TO1	Relay trip output #1
TO2	Relay trip output #2
IRF	Relay internal fault indication
BI1	Relay binary input #1
<U	CB undervoltage trip coil
TC1	CB trip coil 1
F1	Miniature circuit breaker

In example 4, the fail-safe approach aims at securing motor shutdown via an emergency switch and in case the control voltage disappears. The adjacent panels provide backup for each other in internal relay fault situations. In case of an internal relay fault, the situation is noticed by the relay in the adjacent panel and the circuit breaker in the panel with the faulty relay is tripped after a preset time delay. The additional time delay allows the relay to recover from the internal fault situation without tripping the circuit breaker.

3.2.3.2 Other critical feeders

The examples given for motor feeders can be applied for other types of feeders as well. The following examples are for critical feeders in which the protection system dependability, security or both are the drivers.

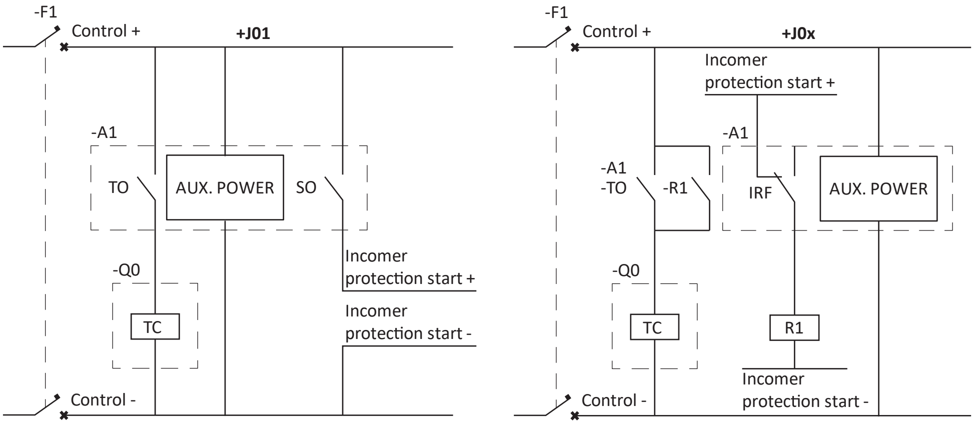


Figure 17: Redundant protection fail-safe principle, example 1

J01	Incomer feeder panel
J0x	Load feeder panels
Q0	Circuit breaker (CB)
TO	Relay trip output
SO	Relay start output
A1	Protection relay
R1	Auxiliary relay
TC	CB trip coil
F1	Miniature circuit breaker

In example 1, the fail-safe approach aims at securing circuit breaker tripping even if a relay fails. The incomer panel relay indicates the start of selected protection functions. This start signal is distributed to all load feeder panels. If a relay in the load feeder panel indicates an IRF status, the start signal of the incomer panel relay results in circuit breaker tripping. This approach offers basic protection for a load feeder while the actual protection relay performs a self-supervision controlled restart sequence.

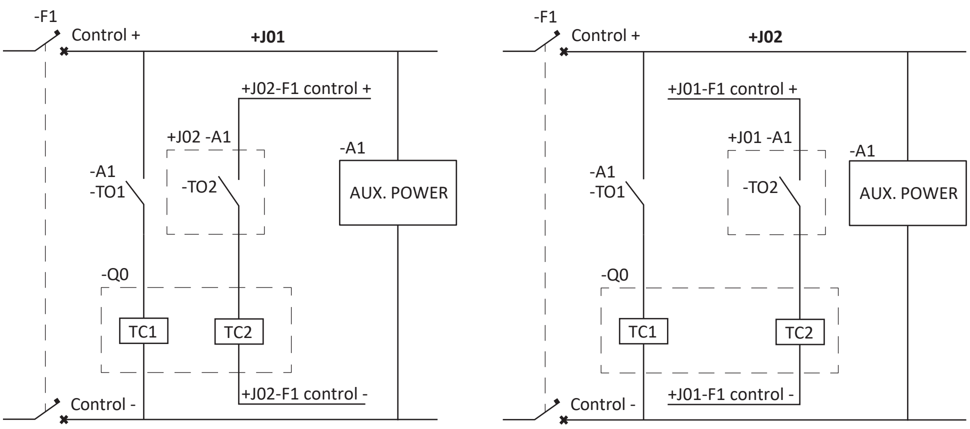


Figure 18: Redundant protection fail-safe principle, example 2

J01	Feeder #1 panel
J02	Feeder #2 panel
Q0	Circuit breaker (CB)
TO1	Relay trip output #1
TO2	Relay trip output #2
A1	Protection relay
TC1	CB trip coil 1
TC2	CB trip coil 2
F1	Miniature circuit breaker

In example 2, the fail-safe approach aims at securing circuit breaker tripping even if a relay fails. A relay in a panel measures also the adjacent panel's currents (and voltages) and receives the necessary primary device's position information. In other words, the relay in a panel functions as a backup relay for the adjacent panel.
This approach allows service continuation while the failed relay is waiting for spare parts or a complete replacement. The backup protection features provided by the adjacent panel's relay do not necessarily fully match the features available in the main relay.

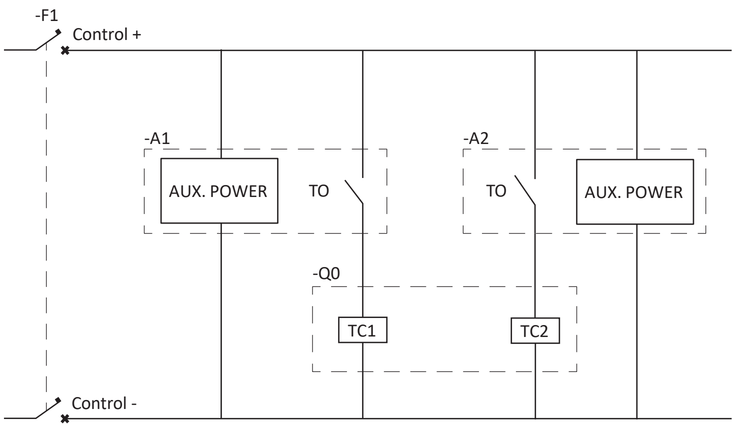


Figure 19: Redundant protection fail-safe principle, example 3

Q0	Circuit breaker (CB)
A1	Protection relay #1
A2	Protection relay #2
TO	Protection relay trip output
TC1	CB trip coil 1
TC2	CB trip coil 2
F1	Miniature circuit breaker

In example 3, the fail-safe approach aims at securing circuit breaker tripping even if one of the redundant relays fails. The scheme is often referred to as the 1-outof- 2 approach. This approach allows service continuation while the failed relay is waiting for spare parts or a complete replacement. The redundancy in this example covers relays and circuit breaker tripping coils but it can be expanded to auxiliary power supplies (two station batteries and isolated distribution), cabling, circuit breaker failure protection, and so on. Another variant of this approach is to have a main relay and a backup relay instead of two fully redundant relays. The backup relay does not have all the features of the main relay, mainly containing a minimum acceptable set of protection functions.

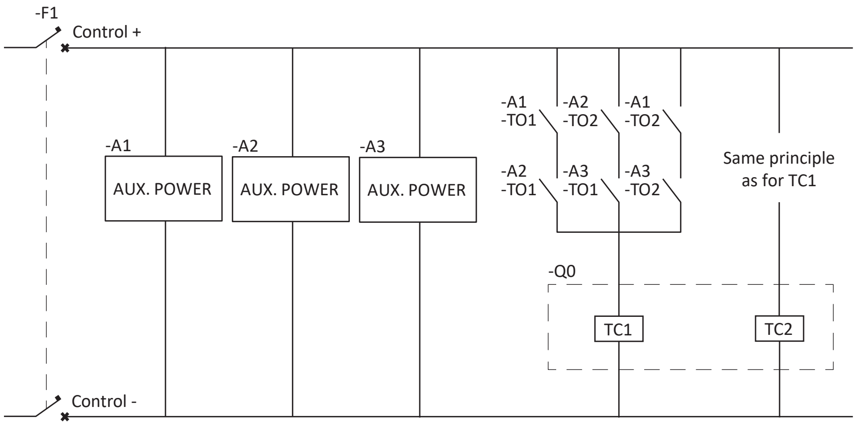


Figure 20: Redundant protection fail-safe principle, example 4

Q0	Circuit breaker (CB)
A1	Protection relay #1
A2	Protection relay #2
A3	Protection relay #3
TO#	Protection relay trip output
TC1	CB trip coil 1
TC2	CB trip coil 2
F1	Miniature circuit breaker

In example 4, the fail-safe approach aims at securing circuit breaker tripping even if one of the redundant relays fails and, in addition, no single relay alone can cause the circuit breaker tripping. The scheme is often referred to as the 2-out-of-3 approach. This approach allows service continuation while the failed relay is waiting for spare parts or a complete replacement. The redundancy in this example covers relays and circuit breaker tripping coils but it can be expanded to auxiliary power supplies (two station batteries and isolated distribution), cabling, circuit breaker failure protection, and so on. All three relays are similar with the same protection functions. This principle is used in cases where the primary process requires absolute dependability and security from the supplying feeder protection.

3.3 LED indication control

3.3.1 Function block

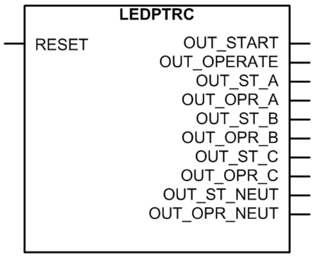


Figure 21: Function block

3.3.2 Functionality

The protection relay includes a global conditioning function LEDPTRC that is used with the protection indication LEDs.

LED indication control should never be used for tripping purposes. There is a separate trip logic function TRPPTRC available in the relay configuration.

LED indication control is preconfigured in a such way that all the protection function general start and operate signals are combined with this function (available as output signals OUT_START and OUT_OPERATE). These signals are always internally connected to Start and Trip LEDs. LEDPTRC collects and combines phase information from different protection functions (available as output signals OUT_ST_A /_B /_C and OUT_OPR_A /_B /_C). There is also combined earth fault information collected from all the earth-fault functions available in the relay configuration (available as output signals OUT_ST_NEUT and OUT_OPR_NEUT).

3.4 Programmable LEDs

3.4.1 Function block

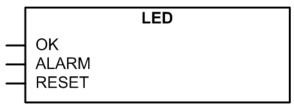


Figure 22: Function block

3.4.2 Functionality

The programmable LEDs reside on the right side of the display on the LHMI.

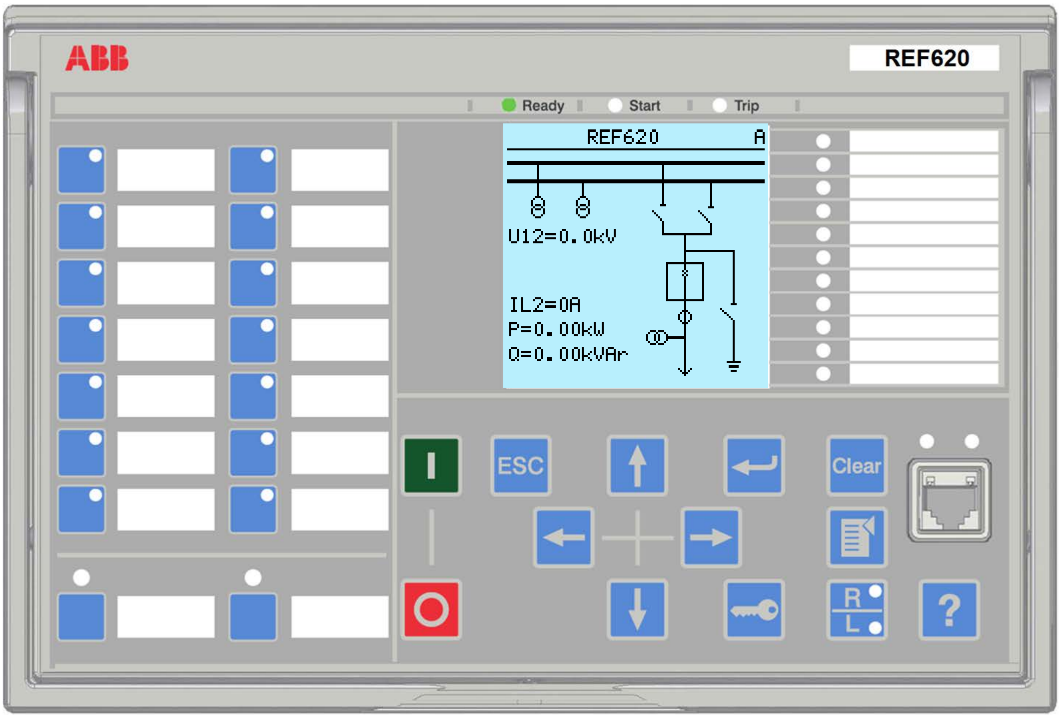


Figure 23: Programmable LEDs on the right side of the display

All the programmable LEDs in the HMI of the protection relay have two colors, green and red. For each LED, the different colors are individually controllable. For example: LEDx is green when AR is in progress and red when AR is locked out.

Each LED has two control inputs, `ALARM` and `OK`. The color setting is common for all the LEDs. It is controlled with the *Alarm colour* setting, the default value being "Red". The `OK` input corresponds to the color that is available, with the default value being "Green".

Changing the *Alarm colour* setting to "Green" changes the color behavior of the `OK` inputs to red.

The `ALARM` input has a higher priority than the `OK` input.

Each LED is seen in the Application Configuration tool as an individual function block. Each LED has user-editable description text for event description. The state ("None", "OK", "Alarm") of each LED can also be read under a common monitored data view for programmable LEDs.

The LED status also provides a means for resetting the individual LED via communication. The LED can also be reset from configuration with the `RESET` input.

The resetting and clearing function for all LEDs is under the **Clear** menu.

The menu structure for the programmable LEDs is presented in *Figure 24*. The common color selection setting *Alarm colour* for all `ALARM` inputs is in the **General** menu, while the LED-specific settings are under the LED-specific menu nodes.

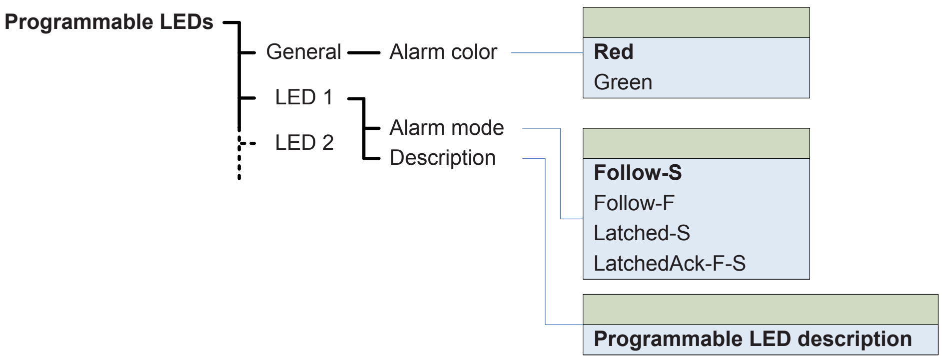


Figure 24: Menu structure

Alarm mode alternatives

The `ALARM` input behavior can be selected with the alarm mode settings from the alternatives "Follow-S", "Follow-F", "Latched-S" and "LatchedAck-F-S". The `OK` input behavior is always according to "Follow-S". The alarm input latched modes can be cleared with the reset input in the application logic.

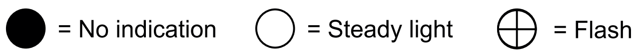


Figure 25: Symbols used in the sequence diagrams

"Follow-S": Follow Signal, ON

In this mode `ALARM` follows the input signal value, Non-latched.

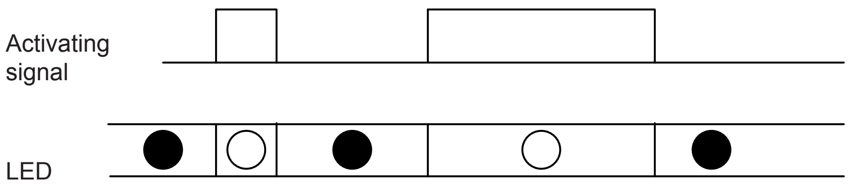


Figure 26: Operating sequence "Follow-S"

"Follow-F": Follow Signal, Flashing

Similar to "Follow-S", but instead the LED is flashing when the input is active, Non-latched.

"Latched-S": Latched, ON

This mode is a latched function. At the activation of the input signal, the alarm shows a steady light. After acknowledgement by the local operator pressing any key on the keypad, the alarm disappears.

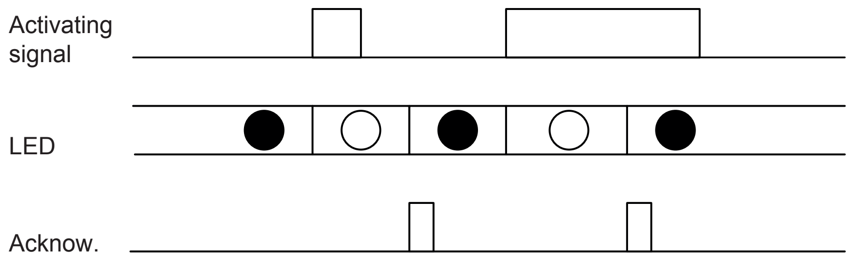


Figure 27: Operating sequence "Latched-S"

"LatchedAck-F-S": Latched, Flashing-ON

This mode is a latched function. At the activation of the input signal, the alarm starts flashing. After acknowledgement, the alarm disappears if the signal is not present and gives a steady light if the signal is present.

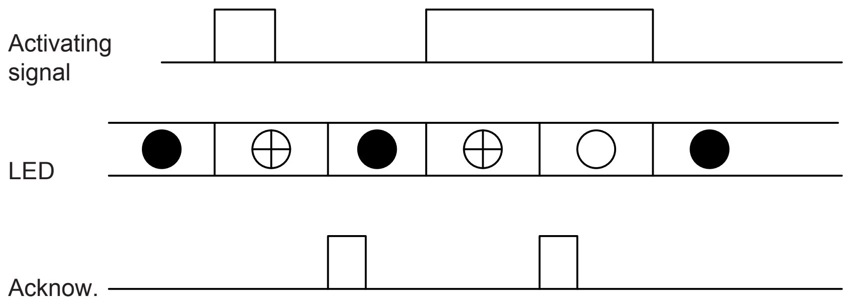


Figure 28: Operating sequence "LatchedAck-F-S"

3.4.3 Signals

Table 28: Input signals

Name	Type	Default	Description
OK	BOOLEAN	0=False	Ok input for LED 1
ALARM	BOOLEAN	0=False	Alarm input for LED 1
RESET	BOOLEAN	0=False	Reset input for LED 1
OK	BOOLEAN	0=False	Ok input for LED 2
ALARM	BOOLEAN	0=False	Alarm input for LED 2
RESET	BOOLEAN	0=False	Reset input for LED 2
OK	BOOLEAN	0=False	Ok input for LED 3
ALARM	BOOLEAN	0=False	Alarm input for LED 3
RESET	BOOLEAN	0=False	Reset input for LED 3
OK	BOOLEAN	0=False	Ok input for LED 4
ALARM	BOOLEAN	0=False	Alarm input for LED 4

Table continues on the next page

Name	Type	Default	Description
RESET	BOOLEAN	0=False	Reset input for LED 4
OK	BOOLEAN	0=False	Ok input for LED 5
ALARM	BOOLEAN	0=False	Alarm input for LED 5
RESET	BOOLEAN	0=False	Reset input for LED 5
OK	BOOLEAN	0=False	Ok input for LED 6
ALARM	BOOLEAN	0=False	Alarm input for LED 6
RESET	BOOLEAN	0=False	Reset input for LED 6
OK	BOOLEAN	0=False	Ok input for LED 7
ALARM	BOOLEAN	0=False	Alarm input for LED 7
RESET	BOOLEAN	0=False	Reset input for LED 7
OK	BOOLEAN	0=False	Ok input for LED 8
ALARM	BOOLEAN	0=False	Alarm input for LED 8
RESET	BOOLEAN	0=False	Reset input for LED 8
OK	BOOLEAN	0=False	Ok input for LED 9
ALARM	BOOLEAN	0=False	Alarm input for LED 9
RESET	BOOLEAN	0=False	Reset input for LED 9
OK	BOOLEAN	0=False	Ok input for LED 10
ALARM	BOOLEAN	0=False	Alarm input for LED 10
RESET	BOOLEAN	0=False	Reset input for LED 10
OK	BOOLEAN	0=False	Ok input for LED 11
ALARM	BOOLEAN	0=False	Alarm input for LED 11
RESET	BOOLEAN	0=False	Reset input for LED 11

3.4.4 Settings

Table 29: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm color	1=Green 2=Red			2=Red	Color for the alarm state of the LED
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 1
Description				Programmable LEDs LED 1	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 2

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Description				Programmable LEDs LED 2	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 3
Description				Programmable LEDs LED 3	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 4
Description				Programmable LEDs LED 4	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 5
Description				Programmable LEDs LED 5	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 6
Description				Programmable LEDs LED 6	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 7
Description				Programmable LEDs LED 7	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 8
Description				Programmable LEDs LED 8	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 9
Description				Programmable LEDs LED 9	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 10
Description				Programmable LEDs LED 10	Programmable LED description

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 11
Description				Programmable LEDs LED 11	Programmable LED description

3.4.5 Monitored data

Table 30: Monitored data

Name	Type	Values (Range)	Unit	Description
Programmable LED 1	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 1
Programmable LED 2	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 2
Programmable LED 3	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 3
Programmable LED 4	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 4
Programmable LED 5	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 5
Programmable LED 6	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 6
Programmable LED 7	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 7
Programmable LED 8	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 8
Programmable LED 9	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 9
Programmable LED 10	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 10
Programmable LED 11	Enum	0=None 1=Ok 3=Alarm		Status of programma-ble LED 11

3.5 Time synchronization

3.5.1 Time master supervision GNRLLTMS

3.5.1.1 Function block

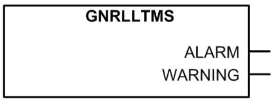


Figure 29: Function block

3.5.1.2 Functionality

The protection relay has an internal real-time clock which can be either free-running or synchronized from an external source. The real-time clock is used for time stamping events, recorded data and disturbance recordings.

The protection relay is provided with a 48 hour capacitor backup that enables the real-time clock to keep time in case of an auxiliary power failure.

The setting *Synch source* determines the method to synchronize the real-time clock. If it is set to “None”, the clock is free-running and the settings *Date* and *Time* can be used to set the time manually. Other setting values activate a communication protocol that provides the time synchronization. Only one synchronization method can be active at a time. IEEE 1588 v2 and SNTP provide time master redundancy.

The protection relay supports SNTP, IRIG-B, IEEE 1588 v2, DNP3, Modbus and IEC 60870-5-103 to update the real-time clock. IEEE 1588 v2 with GPS grandmaster clock provides the best accuracy ±1 µs. The accuracy using IRIG-B and SNTP is ±1 ms.

The protection relay's 1588 time synchronization complies with the IEEE C37.238-2011 Power Profile, interoperable with IEEE 1588 v2. According to the power profile, the frame format used is IEEE 802.3 Ethernet frames with 88F7 Ethertype as communication service and the delay mechanism is P2P. *PTP announce mode* determines the format of PTP announce frames sent by the protection relay when acting as 1588 master, with options “Basic IEEE1588” and “Power Profile”. In the “Power Profile” mode, the TLVs required by the IEEE C37.238-2011 Power Profile are included in announce frames.

IEEE 1588 v2 time synchronization requires a communication card with redundancy support (COM0031...COM0037).

When Modbus TCP or DNP3 over TCP/IP is used, SNTP or IRIG-B time synchronization should be used for better synchronization accuracy.

With the legacy protocols, the synchronization message must be received within four minutes from the previous synchronization. Otherwise bad synchronization status is raised for the protection relay. With SNTP, it is required that the SNTP server responds to a request within 12 ms, otherwise the response is considered invalid.

The relay can use one of two SNTP servers, the primary or the secondary server. The primary server is mainly in use, whereas the secondary server is used if the primary server cannot be reached. While using the secondary SNTP server, the relay tries to switch back to the primary server on every third SNTP request attempt. If both the SNTP servers are offline, event time stamps have the time invalid status. The time is requested from the SNTP server every 60 seconds. Supported SNTP versions are 3 and 4.

IRIG-B time synchronization requires the IRIG-B format B004/B005 according to the 200-04 IRIG-B standard. Older IRIG-B standards refer to these as B000/B001 with IEEE-1344 extensions. The synchronization time can be either UTC time or local time. As no reboot is necessary, the time synchronization starts immediately after the IRIG-B sync source is selected and the IRIG-B signal source is connected.

IRIG-B time synchronization requires a COM card with an IRIG-B input.

3.5.1.3 Signals

Table 31: GNRLLTMS output signals

Name	Type	Description
ALARM	BOOLEAN	Time synchronization alarm
WARNING	BOOLEAN	Time synchronization warning

3.5.1.4 Settings

Table 32: Time settings

Parameter	Values (Range)	Unit	Step	Default	Description
Time format	1=24H:MM:SS:MS 2=12H:MM:SS:MS			1=24H:MM:SS:MS	Time format
Date format	1=DD.MM.YYYY 2=DD/MM/YYYY 3=DD-MM-YYYY 4=MM.DD.YYYY 5=MM/DD/YYYY 6=YYYY-MM-DD 7=YYYY-DD-MM 8=YYYY/DD/MM			1=DD.MM.YYYY	Date format

3.6 Parameter setting groups

3.6.1 Function block

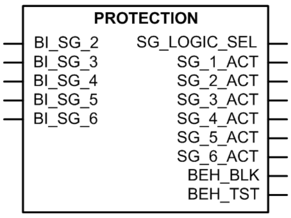


Figure 30: Function block

3.6.2 Functionality

The protection relay supports six setting groups. Each setting group contains parameters categorized as group settings inside application functions. The customer can change the active setting group at run time.

The active setting group can be changed by a parameter or via binary inputs depending on the mode selected with the **Configuration** > **Setting Group** > **SG operation mode** setting.

The default value of all inputs is FALSE, which makes it possible to use only the required number of inputs and leave the rest disconnected. The setting group selection is not dependent on the `SG_x_ACT` outputs.

Table 33: Optional operation modes for setting group selection

SG operation mode	Description
Operator (Default)	Setting group can be changed with the setting **Settings** > **Setting group** > **Active group**. Value of the `SG_LOGIC_SEL` output is FALSE.
Logic mode 1	Setting group can be changed with binary inputs (`BI_SG_2...BI_SG_6`). The highest `TRUE` binary input defines the active setting group. Value of the `SG_LOGIC_SEL` output is TRUE.
Logic mode 2	Setting group can be changed with binary inputs where `BI_SG_4` is used for selecting setting groups 1-3 or 4-6. When binary input `BI_SG_4` is `FALSE`, setting groups 1-3 are selected with binary inputs `BI_SG_2` and `BI_SG_3`. When binary input `BI_SG_4` is `TRUE`, setting groups 4-6 are selected with binary inputs `BI_SG_5` and `BI_SG_6`. Value of the `SG_LOGIC_SEL` output is TRUE.

The setting group (SG) is changed whenever switching the *SG operation mode* setting from "Operator" to either "Logic mode 1" or "Logic mode 2." Thus, it is recommended to select the preferred operation mode at the time of installation and commissioning and not change it throughout the protection relay's service. Changing the *SG operation mode* setting from "Logic mode 1" to "Logic mode 2" or from "Logic mode 2" to "Logic mode 1" does not affect the setting group (SG).

For example, six setting groups can be controlled with three binary inputs. The *SG operation mode* is set to “Logic mode 2” and inputs BI_SG_2 and BI_SG_5 are connected together the same way as inputs BI_SG_3 and BI_SG_6.

Table 34: SG operation mode = “Logic mode 1”

Input					
BI_SG_2	**BI_SG_3**	**BI_SG_4**	**BI_SG_5**	**BI_SG_6**	**Active group**
FALSE	FALSE	FALSE	FALSE	FALSE	1
TRUE	FALSE	FALSE	FALSE	FALSE	2
any	TRUE	FALSE	FALSE	FALSE	3
any	any	TRUE	FALSE	FALSE	4
any	any	any	TRUE	FALSE	5
any	any	any	any	TRUE	6

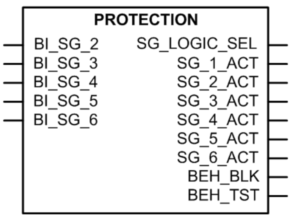
Table 35: SG operation mode = “Logic mode 2”

Input					
BI_SG_2	**BI_SG_3**	**BI_SG_4**	**BI_SG_5**	**BI_SG_6**	**Active group**
FALSE	FALSE	FALSE	any	any	1
TRUE	FALSE	FALSE	any	any	2
any	TRUE	FALSE	any	any	3
any	any	TRUE	FALSE	FALSE	4
any	any	TRUE	TRUE	FALSE	5
any	any	TRUE	any	TRUE	6

The setting group 1 can be copied to any other or all groups from HMI (Copy group 1).

3.7 Test mode

3.7.1 Function blocks



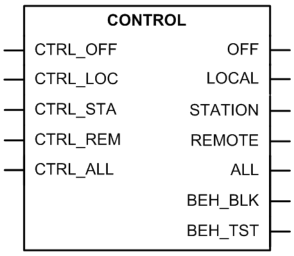


Figure 31: Function blocks

3.7.2 Functionality

The mode of all the logical nodes in the relay's IEC 61850 data model can be set with *Test mode*. *Test mode* is selected through one common parameter via the WHMI path **Tests** > **IED test**. By default, *Test mode* can only be set locally through LHMI. *Test mode* is also available via IEC 61850 communication (LD0.LLN0.Mod).

Table 36: Test mode

Test mode	Description	Protection BEH_BLK
Normal mode	Normal operation	FALSE
IED blocked	Protection working as in “Normal mode” but ACT configuration can be used to block physical outputs to process. Control function commands blocked.	TRUE
IED test	Protection working as in “Normal mode” but protection functions are working in parallel with test parameters.	FALSE
IED test and blocked	Protection working as in “Normal mode” but protection functions are working in parallel with test parameters. ACT configuration can be used to block physical outputs to process. Control function commands blocked.	TRUE

Behavior data objects in all logical nodes follow LD0.LLN0.Mod value. If "Normal mode" is selected, behaviour data objects follow mode (.Mod) data object of the corresponding logical device.

3.7.3 Application configuration and Test mode

The physical outputs from control commands to process are blocked with ”IED blocked” and “IED test and blocked” modes. If physical outputs need to be blocked from the protection, the application configuration must be used to block these signals. Blocking scheme needs to use `BEH_BLK` output of PROTECTION function block.

3.7.4 Control mode

The mode of all logical nodes located under CTRL logical device can be set with *Control mode*. The *Control mode* parameter is available via the HMI or PCM600 path **Configuration** > **Control** > **General**. By default, *Control mode* can only be set locally through LHMI. To set the parameters from WHMI the *Remote test mode* parameter under **Tests** > **IED test** > **Test mode** should first be set to “All Levels”. *Control mode* inherits its value from *Test mode* but *Control mode* ”On”, “Blocked” and “Off” can also be set independently. *Control mode* is also available via IEC 61850 communication (CTRL.LLN0.Mod).

Table 37: Control mode

Control mode	Description	Control BEH_BLK
On	Normal operation	FALSE
Blocked	Control function commands blocked	TRUE
Off	Control functions disabled	FALSE

Behavior data objects under CTRL logical device follow CTRL.LLN0.Mod value. If "On" is selected, behavior data objects follow the mode of the corresponding logical device.

3.7.5 Application configuration and Control mode

The physical outputs from commands to process are blocked with “Blocked“ mode. If physical outputs need to be blocked totally, meaning also commands from the binary inputs, the application configuration must be used to block these signals. Blocking scheme uses `BEH_BLK` output of CONTROL function block.

3.7.6 Authorization

By default, *Test mode* and *Control mode* can only be changed from LHMI. It is possible to write test mode by remote client, if it is needed in configuration. This is done via LHMI only by setting the *Remote test mode* parameter via **Tests** > **IED test** > **Test mode**. Remote operation is possible only when control position of the relay is in remote position. Local and remote control can be selected with R/L button or via Control function block in application configuration.

When using the Signal Monitoring tool to force online values, the following conditions need to be met.

- *Remote force* is set to “All levels”
- *Test mode* is enabled
- Control position of the relay is in remote position

Table 38: Remote test mode

Remote test mode	61850-8-1-MMS	WHMI/PCM600
Off	No access	No access
Maintenance	Command originator category mainte-nance	No access
All levels	All originator categories	Yes

3.7.7 LHMI indications

The yellow Start LED flashes when the relay is in “IED blocked” or “IED test and blocked” mode. The green Ready LED flashes to indicate that the “IED test and blocked” mode or "IED test" mode is activated.

3.7.8 Signals

Table 39: PROTECTION input signals

Name	Type	Default	Description
BI_SG_2	BOOLEAN	0	Setting group 2 is active
BI_SG_3	BOOLEAN	0	Setting group 3 is active
BI_SG_4	BOOLEAN	0	Setting group 4 is active
BI_SG_5	BOOLEAN	0	Setting group 5 is active
BI_SG_6	BOOLEAN	0	Setting group 6 is active

Table 40: CONTROL input signals

Name	Type	Default	Description
CTRL_OFF	BOOLEAN	0	Control OFF
CTRL_LOC	BOOLEAN	0	Control local
CTRL_STA	BOOLEAN	0	Control station
CTRL_REM	BOOLEAN	0	Control remote
CTRL_ALL	BOOLEAN	0	Control all

Table 41: PROTECTION output signals

Name	Type	Description
SG_LOGIC_SEL	BOOLEAN	Logic selection for setting group
SG_1_ACT	BOOLEAN	Setting group 1 is active
SG_2_ACT	BOOLEAN	Setting group 2 is active
SG_3_ACT	BOOLEAN	Setting group 3 is active
SG_4_ACT	BOOLEAN	Setting group 4 is active
SG_5_ACT	BOOLEAN	Setting group 5 is active
SG_6_ACT	BOOLEAN	Setting group 6 is active
BEH_BLK	BOOLEAN	Logical device LD0 block status

Table continues on the next page

Name	Type	Description
BEH_TST	BOOLEAN	Logical device LD0 test status
FRQ_ADP_FAIL	BOOLEAN	Frequency adaptivity status fail

Table 42: CONTROL output signals

Name	Type	Description
OFF	BOOLEAN	Control OFF
LOCAL	BOOLEAN	Control local
STATION	BOOLEAN	Control station
REMOTE	BOOLEAN	Control remote
ALL	BOOLEAN	Control all
BEH_BLK	BOOLEAN	Logical device LD0 block status
BEH_TST	BOOLEAN	Logical device LD0 test status

3.8 Fault recorder FLTRFRC

3.8.1 Function block

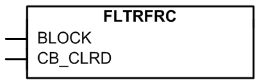


Figure 32: Function block

3.8.2 Functionality

The protection relay has the capacity to store the records of 128 latest fault events. Fault records include fundamental or RMS current values. The records enable the user to analyze recent power system events. Each fault record (FLTRFRC) is marked with an up-counting fault number and a time stamp that is taken from the beginning of the fault.

The fault recording period begins from the start event of any protection function and ends if any protection function trips or the start is restored before the operate event. If a start is restored without an operate event, the start duration shows the protection function that has started first.

Start duration that has the value of 100% indicates that a protection function has operated during the fault and if none of the protection functions has been operated, Start duration shows always values less than 100%.

The Fault recorded data Protection and Start duration is from the same protection function. The Fault recorded data operate time shows the time of the actual fault period. This value is the time difference between the activation of the internal start and operate signals. The actual operate time also includes the starting time and the delay of the output relay. The Fault recorded data *Breaker clear time* is the time difference between internal operate signal and activation of `CB_CLRD` input.

If some functions in relay application are sensitive to start frequently it might be advisable to set the setting parameter *Trig mode* to “From operate”. Then only faults that cause an operate event trigger a new fault recording.

The fault-related current, voltage, frequency, angle values, shot pointer and the active setting group number are taken from the moment of the operate event, or from the beginning of the fault if only a start event occurs during the fault. The maximum current value collects the maximum fault currents during the fault. In case frequency cannot be measured, nominal frequency is used for frequency and zero for Frequency gradient and validity is set accordingly.

Measuring mode for phase current and residual current values can be selected with the *Measurement mode* setting parameter.

3.8.3 Settings

Table 43: FLTRFRC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Trig mode	0=From all faults 1=From operate 2=From only start			0=From all faults	Triggering mode

Table 44: FLTRFRC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
A measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode phase currents and residual current

3.8.4 Monitored data

Table 45: FLTRFRC Monitored data

Name	Type	Values (Range)	Unit	Description
Fault number	INT32	0...999999		Fault record number
Time and date	Timestamp			Fault record time stamp
Protection	Enum	0=Unknown [1] 1=PHLPTOC1		Protection function

Table continues on the next page

[1] When TRPPTRC is triggered by any signal which does not light up the START or TRIP LEDs

Name	Type	Values (Range)	Unit	Description
		2=PHLPTOC2 6=PHHPTOC1 7=PHHPTOC2 8=PHHPTOC3 9=PHHPTOC4 12=PHIPTOC1 13=PHIPTOC2 17=EFLPTOC1 18=EFLPTOC2 19=EFLPTOC3 22=EFHPTOC1 23=EFHPTOC2 24=EFHPTOC3 25=EFHPTOC4 30=EFIPTOC1 31=EFIPTOC2 32=EFIPTOC3 35=NSPTOC1 36=NSPTOC2 -7=INTRPTEF1 -5=STTPMSU1 -3=JAMPTOC1		
		41=PDNSPTOC1 44=T1PTTR1 46=T2PTTR1 48=MPTTR1 50=DEFLPDEF1 51=DEFLPDEF2 53=DEFHPDEF1 56=EFPADM1 57=EFPADM2 58=EFPADM3 59=FRPFRQ1 60=FRPFRQ2 61=FRPFRQ3 62=FRPFRQ4 63=FRPFRQ5 64=FRPFRQ6 65=LSHDPFRQ1 66=LSHDPFRQ2 67=LSHDPFRQ3 68=LSHDPFRQ4 69=LSHDPFRQ5 71=DPHLPDOC1 72=DPHLPDOC2 74=DPHHPDOC1 77=MAPGAPC1 78=MAPGAPC2 79=MAPGAPC3		

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		85=MNSPTOC1 86=MNSPTOC2 88=LOFLPTUC1 90=TR2PTDF1 91=LNPLDF1 92=LREFPNDF1 94=MPDIF1 96=HREFPDIF1		
		100=ROVPTOV1 101=ROVPTOV2 102=ROVPTOV3 104=PHPTOV1 105=PHPTOV2 106=PHPTOV3 108=PHPTUV1 109=PHPTUV2 110=PHPTUV3 112=NSPTOV1 113=NSPTOV2 116=PSPTUV1 118=ARCSARC1 119=ARCSARC2 120=ARCSARC3 -96=SPHIPTOC1 -93=SPHLPTOC2 -92=SPHLPTOC1 -89=SPHHPTOC2 -88=SPHHPTOC1 -87=SPHPTUV4 -86=SPHPTUV3 -85=SPHPTUV2 -84=SPHPTUV1 -83=SPHPTOV4 -82=SPHPTOV3 -81=SPHPTOV2 -80=SPHPTOV1 -25=OEPVPH4 -24=OEPVPH3 -23=OEPVPH2 -22=OEPVPH1 -19=PSPTOV2 -18=PSPTOV1 -15=PREVPTOC1		
		-12=PHPTUC2 -11=PHPTUC1 -9=PHIZ1 5=PHLTPTOC1 20=EFLPTOC4 26=EFHPTOC5		

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		27=EFHPTOC6 37=NSPTOC3 38=NSPTOC4 45=T1PTTR2 54=DEFHPDEF2 75=DPHHPDOC2 89=LOFLPTUC2 103=ROVPTOV4 117=PSPTUV2 -13=PHPTUC3 3=PHLPTOC3 10=PHHPTOC5 11=PHHPTOC6 28=EFHPTOC7 29=EFHPTOC8 107=PHPTOV4 111=PHPTUV4 114=NSPTOV3 115=NSPTOV4 -30=PHDSTPDIS1 -29=TR3PTDF1 -28=HICPDIF1 -27=HIBPDIF1 -26=HIAPDIF1 -32=LSHDPFRQ8 -31=LSHDPFRQ7 70=LSHDPFRQ6 80=MAPGAPC4 81=MAPGAPC5 82=MAPGAPC6 83=MAPGAPC7		
		-102=MAPGAPC12 -101=MAPGAPC11 -100=MAPGAPC10 -99=MAPGAPC9 -98=RESCPSCH1 -57=FDEFLPDEF2 -56=FDEFLPDEF1 -54=FEFLPTOC1 -53=FDPHLPDOC2 -52=FDPHLPDOC1 -50=FPHLPTOC1 -47=MAP12GAPC8 -46=MAP12GAPC7 -45=MAP12GAPC6 -44=MAP12GAPC5 -43=MAP12GAPC4 -42=MAP12GAPC3 -41=MAP12GAPC2		

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		-40=MAP12GAPC1 -37=HAEFPTOC1 -35=WPWDE3 -34=WPWDE2 -33=WPWDE1 52=DEFLPDEF3 84=MAPGAPC8 93=LREFPNDF2 97=HREFPDIF2 -117=XDEFLPDEF2 -116=XDEFLPDEF1 -115=SDPHLPDOC2 -114=SDPHLPDOC1 -113=XNSPTOC2 -112=XNSPTOC1 -111=XEFIPTOC2 -110=XEFHPTOC4 -109=XEFHPTOC3 -108=XEFLPTOC3 -107=XEFLPTOC2 -66=DQPTUV1 -65=VVSPPAM1 -64=PHPVOC1 -63=H3EFPSEF1 -60=HCUBPTOC1 -59=CUBPTOC1 -72=DOPPDPR1 -69=DUPPDPR1 -61=COLPTOC1 -106=MAPGAPC16 -105=MAPGAPC15 -104=MAPGAPC14 -103=MAPGAPC13 -76=MAPGAPC18 -75=MAPGAPC17 -62=SRCPTOC1 -74=DOPPDPR3 -73=DOPPDPR2 -70=DUPPDPR2 -58=UZPDIS1 -36=UEXPDIS1 14=MFADPSDE1 -10=LVRTPTUV1 -8=LVRTPTUV2 -6=LVRTPTUV3 -122=DPH3LPDOC1 -121=DPH3HPDOC2 -120=DPH3HPDOC1 -119=PH3LPTOC2 -118=PH3LPTOC1		

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		-79=PH3HPTOC2 -78=PH3HPTOC1 -77=PH3IPTOC1 -127=PHAPTUV1 -124=PHAPTOV1 -123=DPH3LPDOC2 -68=PHPVOC2 -67=DQPTUV2 -39=UEXPDIS2 98=MHZPDIF1 -4=MREFPTOC1		
Start duration	FLOAT32	0.00...100.00	%	Maximum start duration of all stages during the fault
Operate time	FLOAT32	0.000...999999.999	s	Operate time
Breaker clear time	FLOAT32	0.000...3.000	s	Breaker clear time
Fault distance	FLOAT32	0.00...3000.00	pu	Distance to fault measured in pu
Fault resistance	FLOAT32	0.00...1000000.00	ohm	Fault resistance
Active group	INT32	1...6		Active setting group
Shot pointer	INT32	1...7		Autoreclosing shot pointer value
Max diff current IL1	FLOAT32	0.000...80.000	pu	Maximum phase A differential current
Max diff current IL2	FLOAT32	0.000...80.000	pu	Maximum phase B differential current
Max diff current IL3	FLOAT32	0.000...80.000	pu	Maximum phase C differential current
Diff current IL1	FLOAT32	0.000...80.000	pu	Differential current phase A
Diff current IL2	FLOAT32	0.000...80.000	pu	Differential current phase B
Diff current IL3	FLOAT32	0.000...80.000	pu	Differential current phase C
Max bias current IL1	FLOAT32	0.000...50.000	pu	Maximum phase A bias current
Max bias current IL2	FLOAT32	0.000...50.000	pu	Maximum phase B bias current
Max bias current IL3	FLOAT32	0.000...50.000	pu	Maximum phase C bias current
Bias current IL1	FLOAT32	0.000...50.000	pu	Bias current phase A
Bias current IL2	FLOAT32	0.000...50.000	pu	Bias current phase B
Bias current IL3	FLOAT32	0.000...50.000	pu	Bias current phase C
Diff current Io	FLOAT32	0.000...80.000	pu	Differential current residual
Bias current Io	FLOAT32	0.000...50.000	pu	Bias current residual
Max current IL1	FLOAT32	0.000...50.000	xIn	Maximum phase A current
Max current IL2	FLOAT32	0.000...50.000	xIn	Maximum phase B current
Max current IL3	FLOAT32	0.000...50.000	xIn	Maximum phase C current
Max current Io	FLOAT32	0.000...50.000	xIn	Maximum residual current
Current IL1	FLOAT32	0.000...50.000	xIn	Phase A current
Current IL2	FLOAT32	0.000...50.000	xIn	Phase B current
Current IL3	FLOAT32	0.000...50.000	xIn	Phase C current

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Current Io	FLOAT32	0.000...50.000	xIn	Residual current
Current Io-Calc	FLOAT32	0.000...50.000	xIn	Calculated residual current
Current Ps-Seq	FLOAT32	0.000...50.000	xIn	Positive sequence current
Current Ng-Seq	FLOAT32	0.000...50.000	xIn	Negative sequence current
Max current IL1B	FLOAT32	0.000...50.000	xIn	Maximum phase A current (b)
Max current IL2B	FLOAT32	0.000...50.000	xIn	Maximum phase B current (b)
Max current IL3B	FLOAT32	0.000...50.000	xIn	Maximum phase C current (b)
Max current IoB	FLOAT32	0.000...50.000	xIn	Maximum residual current (b)
Current IL1B	FLOAT32	0.000...50.000	xIn	Phase A current (b)
Current IL2B	FLOAT32	0.000...50.000	xIn	Phase B current (b)
Current IL3B	FLOAT32	0.000...50.000	xIn	Phase C current (b)
Current IoB	FLOAT32	0.000...50.000	xIn	Residual current (b)
Current Io-CalcB	FLOAT32	0.000...50.000	xIn	Calculated residual current (b)
Current Ps-SeqB	FLOAT32	0.000...50.000	xIn	Positive sequence current (b)
Current Ng-SeqB	FLOAT32	0.000...50.000	xIn	Negative sequence current (b)
Max current IL1C	FLOAT32	0.000...50.000	xIn	Maximum phase A current (c)
Max current IL2C	FLOAT32	0.000...50.000	xIn	Maximum phase B current (c)
Max current IL3C	FLOAT32	0.000...50.000	xIn	Maximum phase C current (c)
Max current IoC	FLOAT32	0.000...50.000	xIn	Maximum residual current (c)
Current IL1C	FLOAT32	0.000...50.000	xIn	Phase A current (c)
Current IL2C	FLOAT32	0.000...50.000	xIn	Phase B current (c)
Current IL3C	FLOAT32	0.000...50.000	xIn	Phase C current (c)
Current IoC	FLOAT32	0.000...50.000	xIn	Residual current (c)
Current Io-CalcC	FLOAT32	0.000...50.000	xIn	Calculated residual current (c)
Current Ps-SeqC	FLOAT32	0.000...50.000	xIn	Positive sequence current (c)
Current Ng-SeqC	FLOAT32	0.000...50.000	xIn	Negative sequence current (c)
Voltage UL1	FLOAT32	0.000...4.000	xUn	Phase A voltage
Voltage UL2	FLOAT32	0.000...4.000	xUn	Phase B voltage
Voltage UL3	FLOAT32	0.000...4.000	xUn	Phase C voltage
Voltage U12	FLOAT32	0.000...4.000	xUn	Phase A to phase B voltage
Voltage U23	FLOAT32	0.000...4.000	xUn	Phase B to phase C voltage
Voltage U31	FLOAT32	0.000...4.000	xUn	Phase C to phase A voltage
Voltage Uo	FLOAT32	0.000...4.000	xUn	Residual voltage
Voltage Zro-Seq	FLOAT32	0.000...4.000	xUn	Zero sequence voltage
Voltage Ps-Seq	FLOAT32	0.000...4.000	xUn	Positive sequence voltage
Voltage Ng-Seq	FLOAT32	0.000...4.000	xUn	Negative sequence voltage
Voltage UL1B	FLOAT32	0.000...4.000	xUn	Phase A voltage (b)

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Voltage UL2B	FLOAT32	0.000...4.000	xUn	Phase B voltage (b)
Voltage UL3B	FLOAT32	0.000...4.000	xUn	Phase B voltage (b)
Voltage U12B	FLOAT32	0.000...4.000	xUn	Phase A to phase B voltage (b)
Voltage U23B	FLOAT32	0.000...4.000	xUn	Phase B to phase C voltage (b)
Voltage U31B	FLOAT32	0.000...4.000	xUn	Phase C to phase A voltage (b)
Voltage UoB	FLOAT32	0.000...4.000	xUn	Residual voltage (b)
Voltage Zro-SeqB	FLOAT32	0.000...4.000	xUn	Zero sequence voltage (b)
Voltage Ps-SeqB	FLOAT32	0.000...4.000	xUn	Positive sequence voltage (b)
Voltage Ng-SeqB	FLOAT32	0.000...4.000	xUn	Negative sequence voltage (b)
PTTR thermal level	FLOAT32	0.00...99.99		PTTR calculated temperature of the protected object relative to the operate level
PDNSPTOC1 rat. I2/I1	FLOAT32	0.00...999.99	%	PDNSPTOC1 ratio I2/I1
Frequency	FLOAT32	30.00...80.00	Hz	Frequency
Frequency gradient	FLOAT32	-10.00...10.00	Hz/s	Frequency gradient
Conductance Yo	FLOAT32	-1000.00...1000.00	mS	Conductance Yo
Susceptance Yo	FLOAT32	-1000.00...1000.00	mS	Susceptance Yo
Angle Uo - Io	FLOAT32	-180.00...180.00	deg	Angle residual voltage - residual current
Angle U23 - IL1	FLOAT32	-180.00...180.00	deg	Angle phase B to phase C voltage - phase A current
Angle U31 - IL2	FLOAT32	-180.00...180.00	deg	Angle phase C to phase A voltage - phase B current
Angle U12 - IL3	FLOAT32	-180.00...180.00	deg	Angle phase A to phase B voltage - phase C current
Angle UoB - IoB	FLOAT32	-180.00...180.00	deg	Angle residual voltage - residual current (b)
Angle U23B - IL1B	FLOAT32	-180.00...180.00	deg	Angle phase B to phase C voltage - phase A current (b)
Angle U31B - IL2B	FLOAT32	-180.00...180.00	deg	Angle phase C to phase A voltage - phase B current (b)
Angle U12B - IL3B	FLOAT32	-180.00...180.00	deg	Angle phase A to phase B voltage - phase C current (b)

3.9 Nonvolatile memory

In addition to the setting values, the protection relay can store some data in the nonvolatile memory.

- Up to 1024 events are stored. The stored events are visible in LHMI, WHMI and Event viewer tool in PCM600.
- Recorded data
  - Fault records (up to 128)
  - Maximum demands
- Circuit breaker condition monitoring

- Latched alarm and trip LEDs' statuses
- Trip circuit lockout
- Counter values

3.10 Sensor inputs for currents and voltages

This chapter gives short examples on how to define the correct parameters for sensor measurement interfaces.

Sensors can have correction factors, measured and verified by the sensor manufacturer, to increase the measurement accuracy. Correction factors are recommended to be set to the relay. Two types of correction factors are available for voltage and current (Rogowski) sensors. The Amplitude correction factor is named *Amplitude corr. A(B/C)* and Angle correction factor is named *Angle corr A(B/C)*. These correction factors can be found on the Sensor's rating plate and/or sensor routine test protocol. If the correction factors are not available, contact the sensor manufacturer for more information.

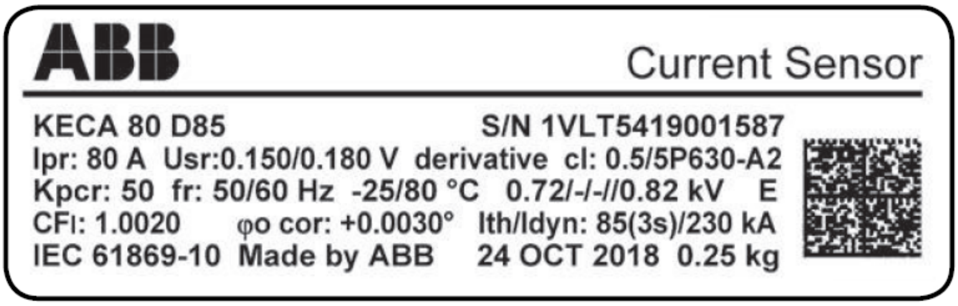


Figure 33: Example of ABB Rogowski current sensor KECA 80 D85 rating plate

Current (Rogowski) sensor setting example

In this example, an 80 A/0.150 V at 50 Hz (0.180 V at 60 Hz) sensor, such as the example shown in *Figure 33*, is used in a 50 Hz electrical network. The application has a 150 A nominal current (In) corresponding to the protected object's nominal current. The application nominal current is set to Rogowski sensor setting *Primary current*. Taken from the sensor's technical data, this example sensor can be used with up to 4000 A application nominal current. As the Rogowski sensor is linear and does not saturate, the 80 A/0.150 V at 50 Hz sensor also works as a 150 A/0.28125 V at 50 Hz sensor. When defining another primary value for the sensor, also the nominal voltage has to be redefined to maintain the same transformation ratio. However, the setting in the protection relay (*Rated Secondary Value*) is not in V but in mV/Hz, which makes the same setting *Rated Secondary Value* valid for both 50 and 60 Hz nominal frequency.

$$RSV = \frac{\frac{I_n}{I_{pr}} \times K_r}{f_n}$$

(Equation 1)

RSV	*Rated Secondary Value* in mV/Hz
I_n	Application nominal current
I_{pr}	Sensor-rated primary current
f_n	Network nominal frequency
K_r	Sensor-rated voltage at the rated current in mV

In this example, the value is as calculated using the equation.

$$\frac{\frac{150A}{80A} \times 150mV}{50Hz} = 5.625\frac{mV}{Hz}$$

(Equation 2)

With this information, the protection relay's current (Rogowski) sensor settings can be set.

Table 46: Example setting values for current (Rogowski) sensor

Setting	Value
Primary current	150 A
Rated secondary value	5.625 mV/Hz

When considering setting values for current sensor interfaces and for protection functions utilizing these measurements, it should be noted that the sensor measurement inputs in the relay have limits for linear behavior. When this limit is exceeded, the input starts to saturate. The saturation is reflected to the protection functions connected to the sensor inputs. To ensure that the related protection functions operate correctly, the start value setting for protection functions utilizing either instantaneous or definite minimum time characteristics must not exceed the linear measurement range. Furthermore, the effect on protection functions utilizing inverse time characteristics should be considered. The upper limit of the linear measurement range depends on the selected application nominal current and the type of the current sensor used. *Table 47* shows the limits for an 80A/150mV 50Hz sensor.

Table 47: Application nominal current relation to the upper limit of linear measurement range

Application nominal current (In)	Rated secondary value with 80A / 0.150 V at 50 Hz (0.180 V at 60 Hz)	Upper limit of linear measurement range
40...800 A	1.500...30.000 mV/Hz	60 × I_n
800...1250 A	30.000...46.875 mV/Hz	60...40 × I_n
1250...2500 A	46.875...93.750 mV/Hz	40...20 × I_n
2500...4000 A	93.750...150.000 mV/Hz	20...12.5 × I_n

Table 47 shows the upper limits of the linear measurement range based on a certain range in application nominal current. The linear measurement limit for a given application nominal current can be derived from the values stated in the table with a simple proportion equation. For example, the upper limit for linear measurement for 3000 A application nominal current would be 17.5 xIn.

It can also be calculated from *Table 47* that with the stated sensor the relay input can linearly measure up to 50 kA (RMS) short circuit currents.

Rogowski sensor and overcurrent protection setting evaluation example

A 20 kV utility substation with a single busbar switchgear rated up to 40 kA shortcircuit currents has one incomer and 20 outgoing feeder relays using 80 A/0.150 V at 50 Hz Rogowski current sensors with rating plate values similar to *Figure 33*. For the incomer panel, electrical system designer has evaluated the application nominal current to be 1250 A. Customer specification for these protection relays defines normal instantaneous and time-delayed overcurrent and earth-fault protection functions. Overcurrent protection requires functions to be settable up to 20 xIn.

The sensor setting *Primary current* is set to be the same as the evaluated application nominal current 1250 A. According to the sensor's technical data, the application nominal current matches the sensor's capability which is up to 4000 A.

The setting *Rated secondary value* is calculated by using *Equation 1*.

$$\frac{\frac{1250A}{80A} \cdot 150mV}{50Hz} = 46.875 \frac{mV}{Hz}$$

(Equation 3)

From *Table 47* it is seen that with the 1250 A application nominal current value, the maximum setting for overcurrent protection is 40 xIn. This covers the customer specification requirements for overcurrent settings of up to 20 xIn.

Voltage sensor setting example

The voltage sensor is based on the resistive divider or capacitive divider principle. Therefore, the voltage is linear throughout the whole measuring range. The output signal is a voltage, directly proportional to the primary voltage. For the voltage sensor, all parameters are readable directly from its rating plate and/or sensor routine test protocol, and conversions are not needed.

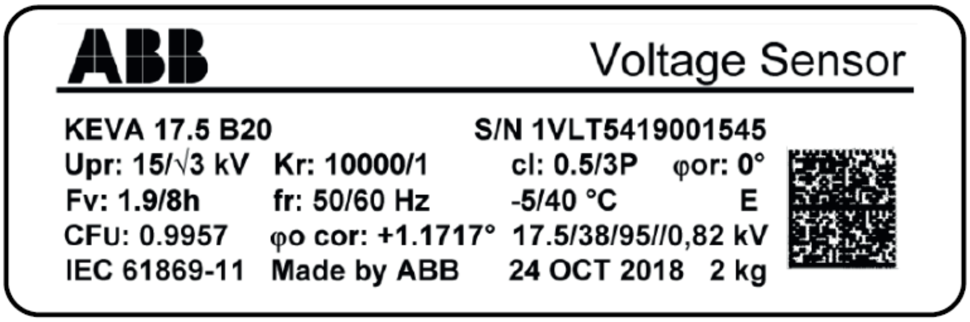


Figure 34: Example of ABB voltage sensor KEVA 17.5 B21 rating plate

In this example the system phase-to-phase voltage rating is 10 kV. Thus, the *Primary voltage* parameter is set to 10 kV. For protection relays with sensor measurement support, the *Voltage input type* is set to "Voltage sensor". The VT connection parameter is set to the "WYE" type. The division ratio for ABB voltage sensors is most often 10000:1. Thus, the *Division ratio* parameter is usually set to "10000". The primary voltage is proportionally divided by this division ratio.

Table 48: Example setting values for voltage sensor

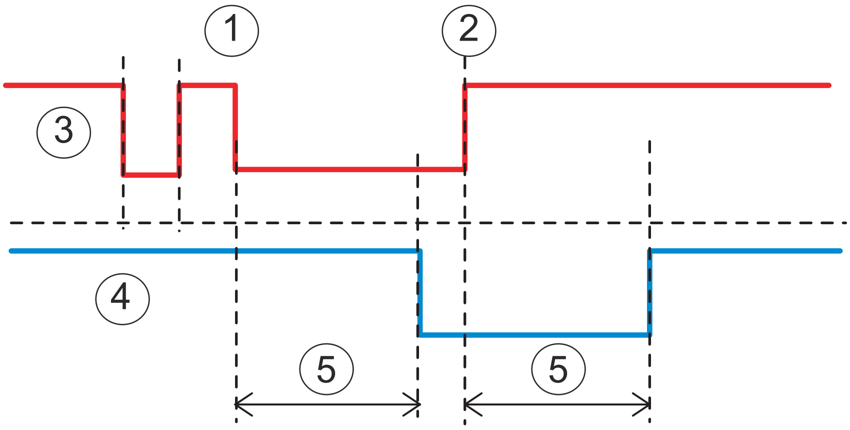
Setting	Value
Primary voltage	10 kV
VT connection	Wye
Voltage input type	3=Voltage sensor
Division ratio	10000

3.11 Binary inputs

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

3.11.1 Binary input filter time

The filter time eliminates debounces and short disturbances on a binary input. The filter time is set for each binary input of the protection relay.



1 t_0
2 t_1
3 Input signal
4 Filtered input signal
5 Filter time

Figure 35: Binary input filtering

At the beginning, the input signal is at the high state, the short low state is filtered and no input state change is detected. The low state starting from the time t_0 exceeds the filter time, which means that the change in the input state is detected and the time tag attached to the input change is t_0. The high state starting from t_1 is detected and the time tag t_1 is attached.

Each binary input has a filter time parameter *"Input # filter"*, where # is the number of the binary input of the module in question (for example *"Input 1 filter"*).

Table 49: Input filter parameter values

Parameter	Values	Default
Input # filter time	5...1000 ms	5 ms

3.11.2 Binary input inversion

The parameter *Input # invert* is used to invert a binary input.

Table 50: Binary input states

Control voltage	Input # invert	State of binary input
No	0	FALSE (0)
Yes	0	TRUE (1)
No	1	TRUE (1)
Yes	1	FALSE (0)

When a binary input is inverted, the state of the input is TRUE (1) when no control voltage is applied to its terminals. Accordingly, the input state is FALSE (0) when a control voltage is applied to the terminals of the binary input.

3.11.3 Oscillation suppression

Oscillation suppression is used to reduce the load from the system when a binary input starts oscillating. A binary input is regarded as oscillating if the number of valid state changes (= number of events after filtering) during one second is equal to or greater than the set oscillation level value. During oscillation, the binary input is blocked (the status is invalid) and an event is generated. The state of the input will not change when it is blocked, that is, its state depends on the condition before blocking.

The binary input is regarded as non-oscillating if the number of valid state changes during one second is less than the set oscillation level value minus the set oscillation hysteresis value. Note that the oscillation hysteresis must be set lower than the oscillation level to enable the input to be restored from oscillation. When the input returns to a non-oscillating state, the binary input is deblocked (the status is valid) and an event is generated.

Table 51: Oscillation parameters

Parameter	Value	Default
Input osc. level	2...50 events/s	30 events/s
Input osc. hyst	2...50 events/s	10 events/s

3.12 Binary outputs

The protection relay provides a number of binary outputs used for tripping, executing local or remote control actions of a breaker or a disconnector, and for connecting the protection relay to external annunciation equipment for indicating, signalling and recording.

Power output contacts are used when the current rating requirements of the contacts are high, for example, for controlling a breaker, such as energizing the breaker trip and closing coils.

The contacts used for external signalling, recording and indicating, the signal outputs, need to adjust to smaller currents, but they can require a minimum current (burden) to ensure a guaranteed operation.

The protection relay provides both power output and signal output contacts. To guarantee proper operation, the type of the contacts used are chosen based on the operating and reset time, continuous current rating, make and carry for short time, breaking rate and minimum connected burden. A combination of series or parallel contacts can also be used for special applications. When appropriate, a signal output can also be used to energize an external trip relay, which in turn can be confiugred to energize the breaker trip or close coils.

Using an external trip relay can require an external trip circuit supervision relay. It can also require wiring a separate trip relay contact back to the protection relay for breaker failure protection function.

All contacts are freely programmable, except the internal fault output IRF.

3.12.1 Power output contacts

Power output contacts are normally used for energizing the breaker closing coil and trip coil, external high burden lockout or trip relays.

3.12.1.1 Dual single-pole power outputs PO1 and PO2

Dual (series-connected) single-pole (normally open/form A) power output contacts PO1 and PO2 are rated for continuous current of 8 A. The contacts are normally used for closing circuit breakers and energizing high burden trip relays. They can be arranged to trip the circuit breakers when the trip circuit supervision is not available or when external trip circuit supervision relay is provided.

The power outputs are included in slot X100 of the power supply module.

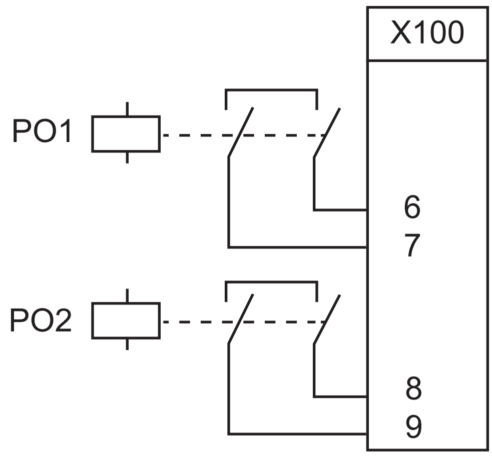


Figure 36: Dual single-pole power output contacts PO1 and PO2

3.12.1.2 Double-pole power outputs PO3 and PO4 with trip circuit supervision

The power outputs PO3 and PO4 are double-pole normally open/form A power outputs with trip circuit supervision.

When the two poles of the contacts are connected in series, they have the same technical specification as PO1 for breaking duty. The trip circuit supervision hardware and associated functionality which can supervise the breaker coil both during closing and opening condition are also provided. Contacts PO3 and PO4 are almost always used for energizing the breaker trip coils.

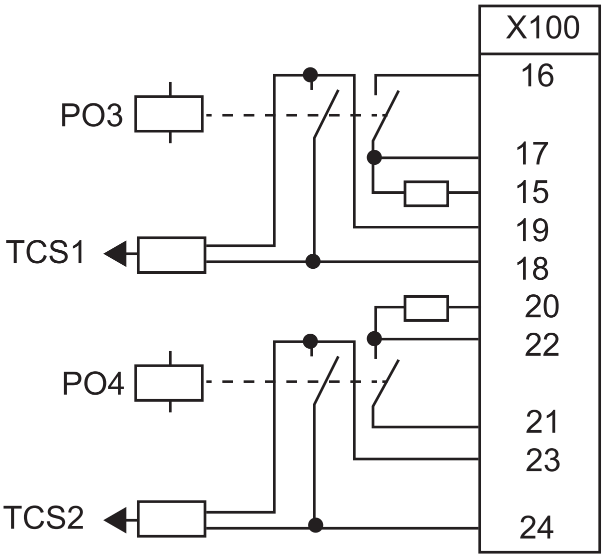


Figure 37: Double-pole power outputs PO3 and PO4 with trip circuit supervision

Power outputs PO3 and PO4 are included in the power supply module located in slot X100 of the protection relay.

3.12.1.3 Dual single-pole signal/trip output contact SO3

The dual parallel-connected, single-pole, normally open/form A output contact SO3 has a continuous rating of 5 A but has a lower breaking capacity than the other POs. When used in breaker tripping applications, an external contact, such as breaker auxiliary contact, is recommended to break the circuit. When the application requires, an optional BIO card with HSO contact can be ordered with the protection relay.

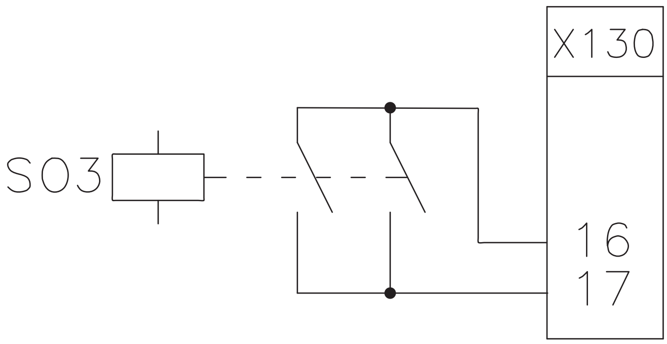


Figure 38: Signal/trip output contact SO3

The signal/trip output contact is included in the module RTD0002 located in slot X130 of the protection relay.

3.12.1.4 Dual single-pole high-speed power outputs HSO1, HSO2 and HSO3

HSO1, HSO2 and HSO3 are dual parallel connected, single-pole, normally open/form A high-speed power outputs. The high-speed power output is a hybrid discrete and electromechanical output that is rated as a power output.

The outputs are normally used in applications that require fast relay output contact activation time to achieve fast opening of a breaker, such as, arc-protection or breaker failure protection, where fast operation is required either to minimize fault effects to the equipment or to avoid a fault to expand to a larger area. With the high-speed outputs, the total time from the application to the relay output contact activation is 5...6 ms shorter than when using output contacts with conventional mechanical output relays. The high-speed power outputs have a continuous rating of 6 A. When two of HSO contacts are connected in series, the breaking rate is equal to that of output contact PO1.

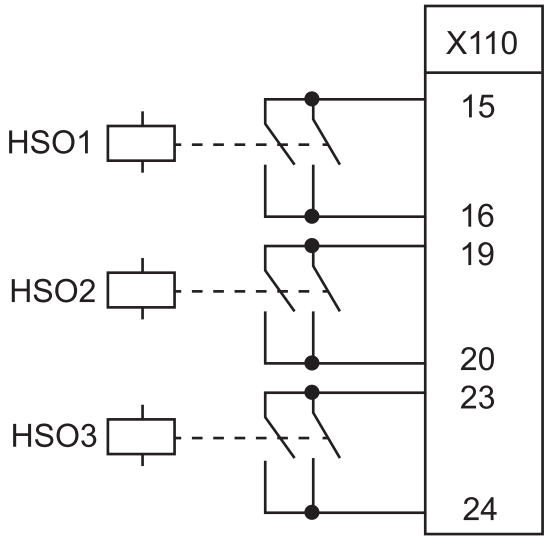


Figure 39: High-speed power outputs HSO1, HSO2 and HSO3

The reset time of the high-speed output contacts is longer than that of the conventional output contacts.

High-speed power contacts are part of the card BIO0007 with eight binary inputs and three HSOs. They are optional alternatives to conventional BIO cards of the protection relay.

3.12.2 Signal output contacts

Signal output contacts are single-pole, single (normally open/form A or change-over/form C) signal output contacts (SO1, SO2,...) or parallel connected dual contacts.

The signal output contacts are used for energizing, for example, external low burden trip relays, auxiliary relays, annunciators and LEDs.

A single signal contact is rated for a continuous current of 5 A. It has a make and carry for 0.5 seconds at 15 A.

When two contacts are connected in parallel, the relay is of a different design. It has the make and carry rating of 30 A for 0.5 seconds. This can be applied for energizing breaker close coil and tripping coil. Due to the limited breaking capacity, a breaker auxiliary contact can be required to break the circuit.

When the application requires high making and breaking duty, it is possible to use HSO contacts in the protection relay or an external interposing auxiliary relay.

3.12.2.1 Internal fault signal output IRF

The internal fault signal output (change-over/form C) IRF is a single contact included in the power supply module of the protection relay.

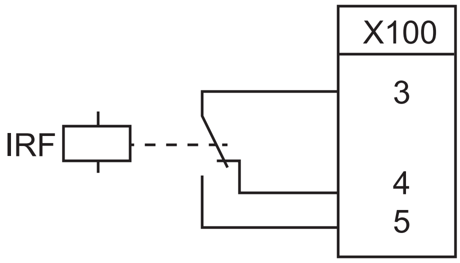


Figure 40: Internal fault signal output IRF

3.12.2.2 Signal outputs SO1 and SO2 in power supply module

Signal outputs (normally open/form A or change-over/form C) SO1 (dual parallel form C) and SO2 (single contact/form A) are part of the power supply module of the protection relay.

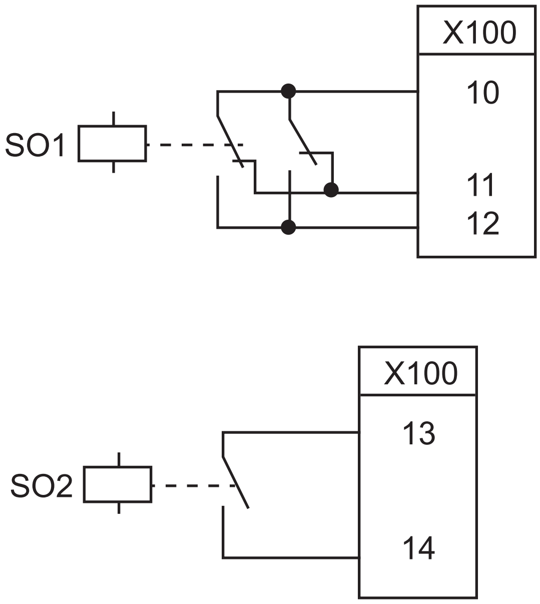


Figure 41: Signal outputs SO1 and SO2 in power supply module

3.12.2.3 Signal outputs SO1 and SO2 in RTD0002

The signal ouputs SO1 and SO2 (single contact/change-over /form C) are included in the RTD0002 module.

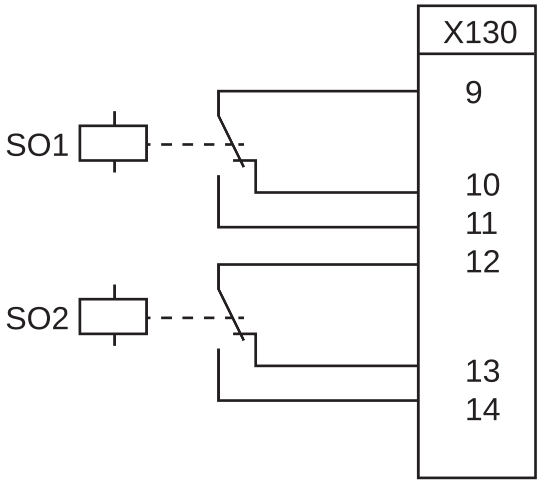


Figure 42: Signal output in RTD0002

3.12.2.4 Signal outputs SO1, SO2, SO3 and SO4 in BIO0005

The optional card BIO0005 provides the signal outputs SO1, SO2 SO3 and SO4. Signal outputs SO1 and SO2 are dual, parallel form C contacts; SO3 is a single form C contact, and SO4 is a single form A contact.

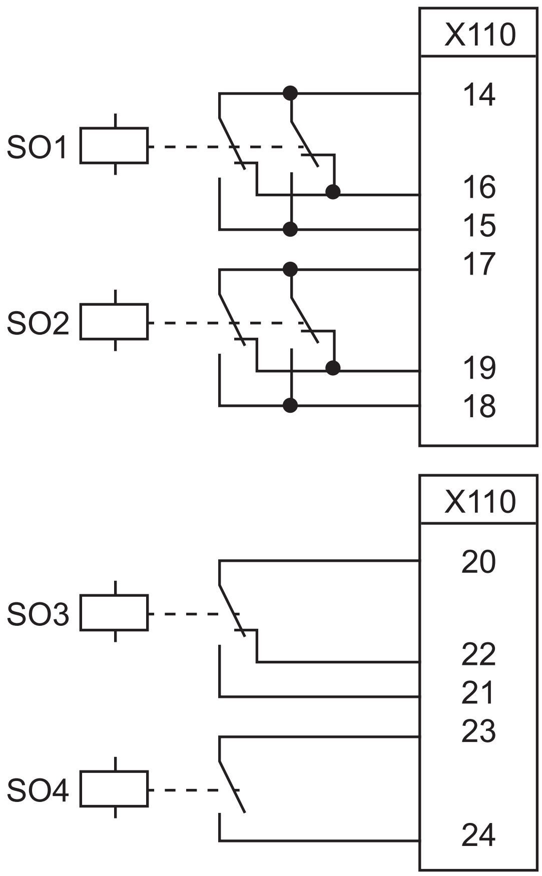


Figure 43: Signal output in BIO0005

3.13 RTD/mA inputs

3.13.1 Functionality

The RTD and mA analog input module is used for monitoring and metering current (mA), temperature (°C) and resistance (Ω). Each input can be linearly scaled for various applications, for example, transformer's tap changer position indication. Each input has independent limit value supervision and deadband supervision functions, including warning and alarm signals.

3.13.2 Operation principle

All the inputs of the module are independent RTD and mA channels with individual protection, reference and optical isolation for each input, making them galvanically isolated from each other and from the rest of the module. However, the RTD inputs share a common ground.

3.13.2.1 Selection of input signal type

The function module inputs accept current or resistance type signals. The inputs are configured for a particular type of input type by the channel-specific *Input mode* setting. The default value for all inputs is “Not in use”, which means that the channel is not sampled at all, and the output value quality is set accordingly.

Table 52: Limits for the RTD/mA inputs

Input mode	Description
Not in use	Default selection. Used when the corresponding input is not used.
0...20 mA	Selection for analog DC milliampere current inputs in the input range of 0...20 mA.
Resistance	Selection for RTD inputs in the input range of 0...2000 Ω.
Pt100 Pt250 Ni100 Ni120 Ni250 Cu10	Selection for RTD inputs, when temperature sensor is used. All the selectable sensor types have their resistance vs. temperature characteristics stored in the module; default measuring range is -40...200°C.

3.13.2.2 Selection of output value format

Each input has independent *Value unit* settings that are used to select the unit for the channel output. The default value for the *Value unit* setting is “Dimensionless”. *Input minimum* and *Input maximum*, and *Value maximum* and *Value minimum* settings have to be adjusted according to the input channel. The default values for these settings are set to their maximum and minimum setting values.

When the channel is used for temperature sensor type, set the *Value unit* setting to “Degrees celsius”. When *Value unit* is set to “Degrees celsius”, the linear scaling is not possible, but the default range (-40…200 °C) can be set smaller with the *Value maximum* and *Value minimum* settings.

When the channel is used for DC milliampere signal and the application requires a linear scaling of the input range, the *Value unit* setting value has to be "Dimensionless”, where the input range can be linearly scaled with settings *Input minimum* and *Input maximum* to *Value minimum* and *Value maximum*. When milliampere is used as an output unit, *Value unit* has to be "Ampere”. When *Value unit* is set to “Ampere”, the linear scaling is not possible, but the default range (0…20 mA) can be set smaller with the *Value maximum* and *Value minimum* settings.

When the channel is used for resistance type signals and the application requires a linear scaling of the input range, the *Value unit* setting value has to be "Dimensionless”, where the input range can be linearly scaled with the setting *Input minimum* and *Input maximum* to *Value minimum* and *Value maximum*. When resistance is used as an output unit, *Value unit* has to be "Ohm". When *Value unit* is set to “Ohm”, the linear scaling is not possible, but the default range (0…2000 Ω) can be set smaller with the *Value maximum* and *Value minimum* settings.

3.13.2.3 Input linear scaling

Each RTD/mA input can be scaled linearly by the construction of a linear output function in respect to the input. The curve consists of two points, where the y-axis (*Input minimum* and *Input maximum*) defines the input range and the x-axis (*Value minimum* and *Value maximum*) is the range of the scaled value of the input.

The input scaling can be bypassed by selecting *Value unit* = "Ohm" when *Input mode* = "Resistance" is used and by selecting *Value unit* = "Ampere" when *Input mode* = "0...20 mA" is used.

Example for linear scaling

Milliampere input is used as tap changer position information. The sensor information is from 4 mA to 20 mA that is equivalent to the tap changer position from -36 to 36, respectively.

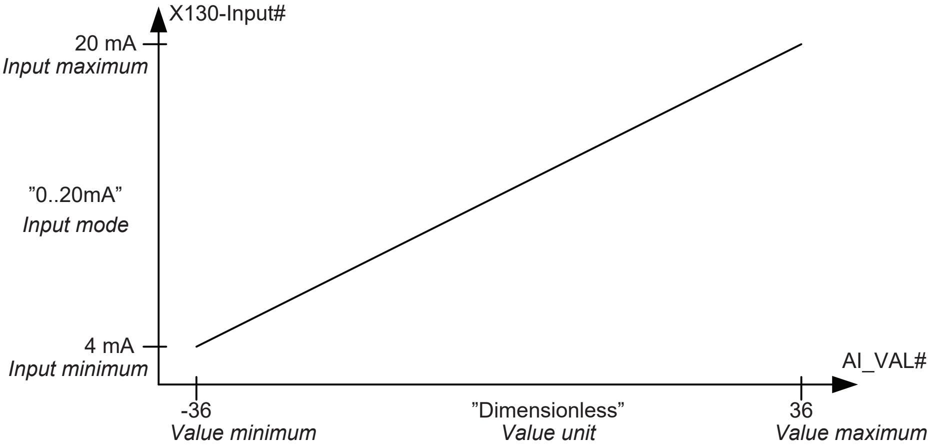


Figure 44: Milliampere input scaled to tap changer position information

3.13.2.4 Measurement chain supervision

Each input contains a functionality to monitor the input measurement chain. The circuitry monitors the RTD channels continuously and reports a circuitry break of any enabled input channel. If the measured input value is outside the limits, minimum/maximum value is shown in the corresponding output. The quality of the corresponding output is set accordingly to indicate misbehavior in the RTD/mA input.

Table 53: Function identification, limits for the RTD/mA inputs

Input	Limit value
RTD temperature, high	> 200 °C
RTD temperature, low	< -40 °C
mA current, high	> 23 mA
Resistance, high	> 2000 Ω

3.13.2.5 Self-supervision

Each input sample is validated before it is fed into the filter algorithm. The samples are validated by measuring an internally set reference current immediately after the inputs are sampled. Each RTD sensor type has expected current based on the sensor type. If the measured offset current deviates from the reference current more than 20%, the sample is discarded and the output is set to invalid. The invalid measure status deactivates as soon as the measured input signal is within the measurement offset.

3.13.2.6 Calibration

RTD and mA inputs are calibrated at the factory. The calibration circuitry monitors the RTD channels continuously and reports a circuitry break of any channel.

3.13.2.7 Limit value supervision

The limit value supervision function indicates whether the measured value of AI_INST# exceeds or falls below the set limits. All the measuring channels have an individual limit value supervision function. The measured value contains the corresponding range information AI_RANGE# and has a value in the range of 0 to 4:

- 0: “normal”
- 1: “high”
- 2: “low”
- 3: “high-high”
- 4: “low-low”

The range information changes and the new values are reported.

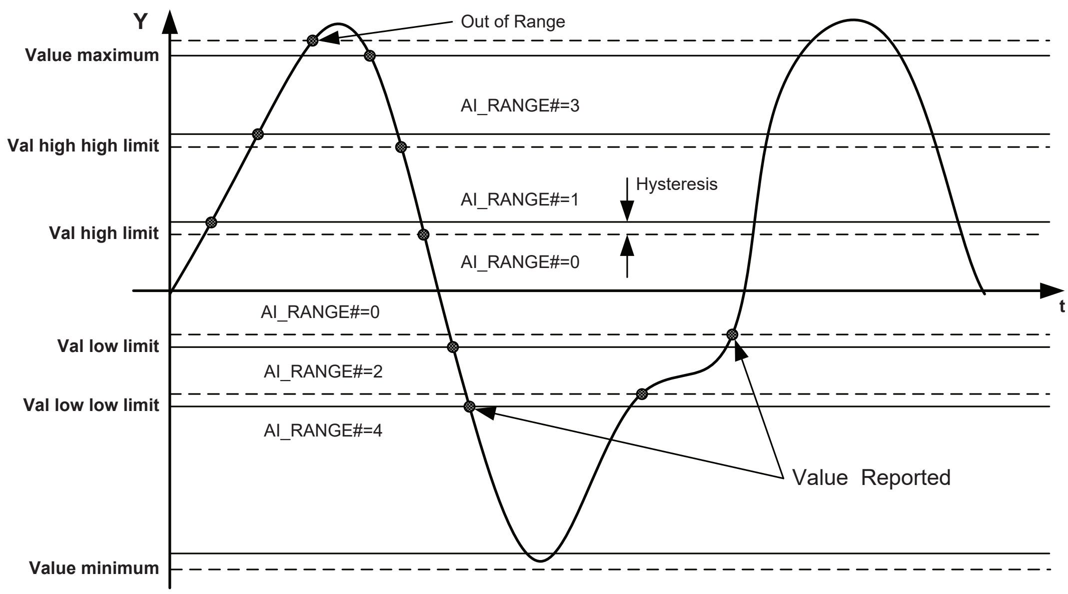


Figure 45: Limit value supervision for RTD

The range information of “High-high limit” and “Low-low limit” is combined from all measurement channels to the Boolean ALARM output. The range information of “High limit” and “Low limit” is combined from all measurement channels to the Boolean WARNING output.

Table 54: Settings for RTD analog input limit value supervision

Function	Settings for limit value supervision	
RTD analog input	Out of range	Value maximum
	High-high limit	Val high high limit
	High limit	Val high limit
	Low limit	Val low limit
	Low-low limit	Val low low limit
	Out of range	Value minimum

When the measured value exceeds either the *Value maximum* setting or the *Value minimum* setting, the corresponding quality is set to out of range and a maximum or minimum value is shown when the measured value exceeds the added hysteresis, respectively. The hysteresis is added to the extreme value of the range limit to allow the measurement slightly to exceed the limit value before it is considered out of range.

3.13.2.8 Deadband supervision

Each input has an independent deadband supervision. The deadband supervision function reports the measured value according to integrated changes over a time period.

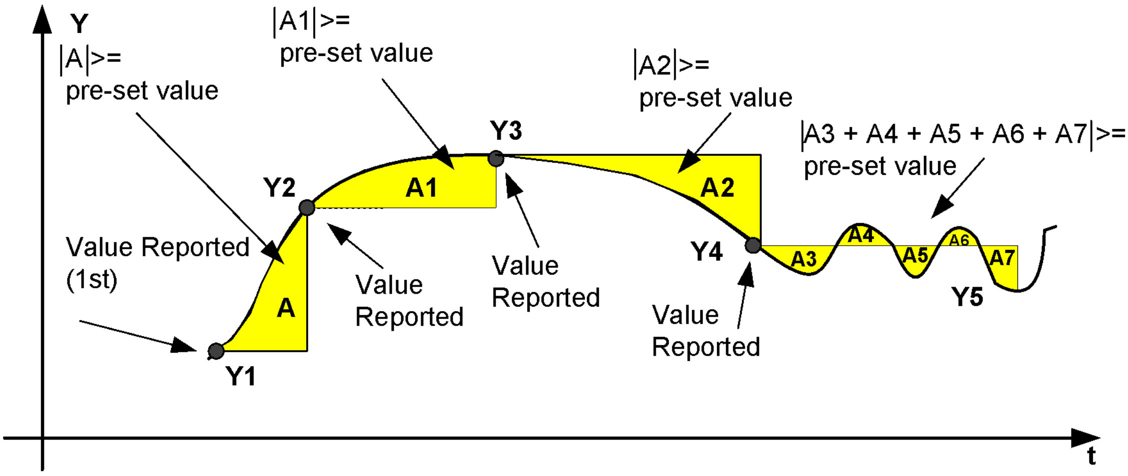


Figure 46: Integral deadband supervision

The deadband value used in the integral calculation is configured with the *Value deadband* setting. The value represents the percentage of the difference between the maximum and minimum limits in the units of 0.001 percent * seconds. The reporting delay of the integral algorithms in seconds is calculated with the formula:

$$t(s) = \frac{(Value\ maximum - Value\ minimum) \cdot \frac{deadband}{100000} s}{\Delta Y}$$

(Equation 4)

Example of RTD analog input deadband supervision

Temperature sensor Pt100 is used in the temperature range of 15...180 °C. *Value unit* “Degrees Celsius” is used and the set values *Value minimum* and *Value maximum* are set to 15 and 180, respectively.

Value deadband = 7500 (7.5% of the total measuring range 165)

AI_VAL# = AI_DB# = 85

If AI_VAL# changes to 90, the reporting delay is:

$$t(s) = \frac{(180°C - 15°C) \cdot \frac{7500\%s}{100000} s}{90°C - 85°C} \approx 2.5s$$

(Equation 5)

Table 55: Settings for RTD analog input deadband supervision

Funtion	Setting	Maximum/minimum (=range)
RTD analog input	Value deadband	Value maximum / Value minimum (=20000)

Since the function can be utilized in various measurement modes, the default values are set to the extremes; thus, it is very important to set correct limit values to suit the application before the deadband supervision works properly.

3.13.2.9 RTD temperature vs. resistance

Table 56: Temperature vs. resistance

Temp °C	Platinum TCR 0.00385		Nickel TCR 0.00618			Copper TCR 0.00427
	Pt 100	Pt 250	Ni 100	Ni 120	Ni 250	Cu 10
-40	84.27	210.675	79.1	94.92	197.75	7.49
-30	88.22	220.55	84.1	100.92	210.25	-
-20	92.16	230.4	89.3	107.16	223.25	8.263
-10	96.09	240.225	94.6	113.52	236.5	-
0	100	250	100	120	250	9.035
10	103.9	259.75	105.6	126.72	264	-
20	107.79	269.475	111.2	133.44	278	9.807
30	111.67	279.175	117.1	140.52	292.75	-
40	115.54	288.85	123	147.6	307.5	10.58
50	119.4	298.5	129.1	154.92	322.75	-

Table continues on the next page

Temp °C	Platinum TCR 0.00385		Nickel TCR 0.00618			Copper TCR 0.00427
	Pt 100	Pt 250	Ni 100	Ni 120	Ni 250	Cu 10
60	123.24	308.1	135.3	162.36	338.25	11.352
70	127.07	317.675	141.7	170.04	354.25	-
80	130.89	327.225	148.3	177.96	370.75	12.124
90	134.7	336.75	154.9	185.88	387.25	-
100	138.5	346.25	161.8	194.16	404.5	12.897
120	146.06	365.15	176	211.2	440	13.669
140	153.58	383.95	190.9	229.08	477.25	14.442
150	-	-	198.6	238.32	496.5	-
160	161.04	402.6	206.6	247.92	516.5	15.217
180	168.46	421.15	223.2	267.84	558	-
200	175.84	439.6	240.7	288.84	601.75	-

3.13.2.10 RTD/mA input connection

RTD inputs can be used with a 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 the same type and length. Thus the wire resistance is automatically compensated.

In the 2-wire connection, the lead resistance is not compensated. This scheme may be adopted when the lead resistance is negligible when compared to the RTD resistance or when the error so introduced is acceptable for the application in which it is used.

3.13.2.11 RTD/mA card variants

The available variants of RTD cards are 6RTD/2mA and 2RTD/1mA. The features are similar in both cards.

The available variants of RTD cards are 6RTD/2mA and 2RTD/1mA/3SO with an RTD capability. The features are similar in both cards.

6RTD/2mA card

This card accepts two milliampere inputs and six inputs from the RTD sensors. The inputs `1` and `2` are used for current measurement, whereas inputs from `3` to `8` are used for resistance type of measurements.

RTD/mA input connection

Resistance and temperature sensors can be connected to the 6RTD/2mA board with 3-wire and 2-wire connections.

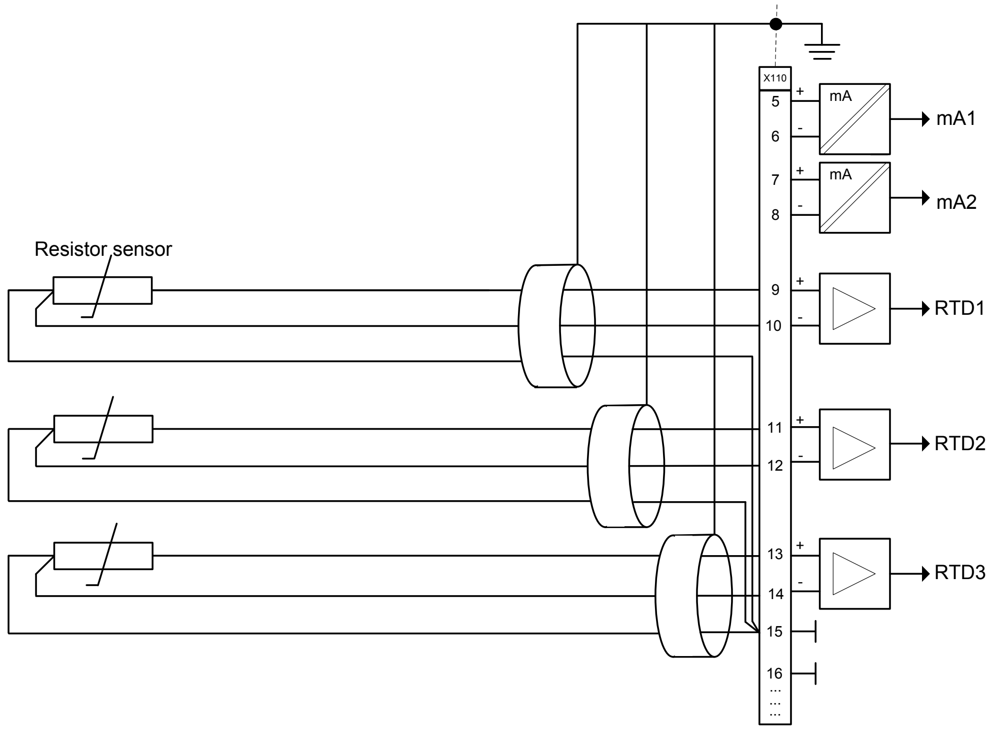


Figure 47: Three RTD sensors and two resistance sensors connected according to the 3-wire connection for 6RTD/2mA card

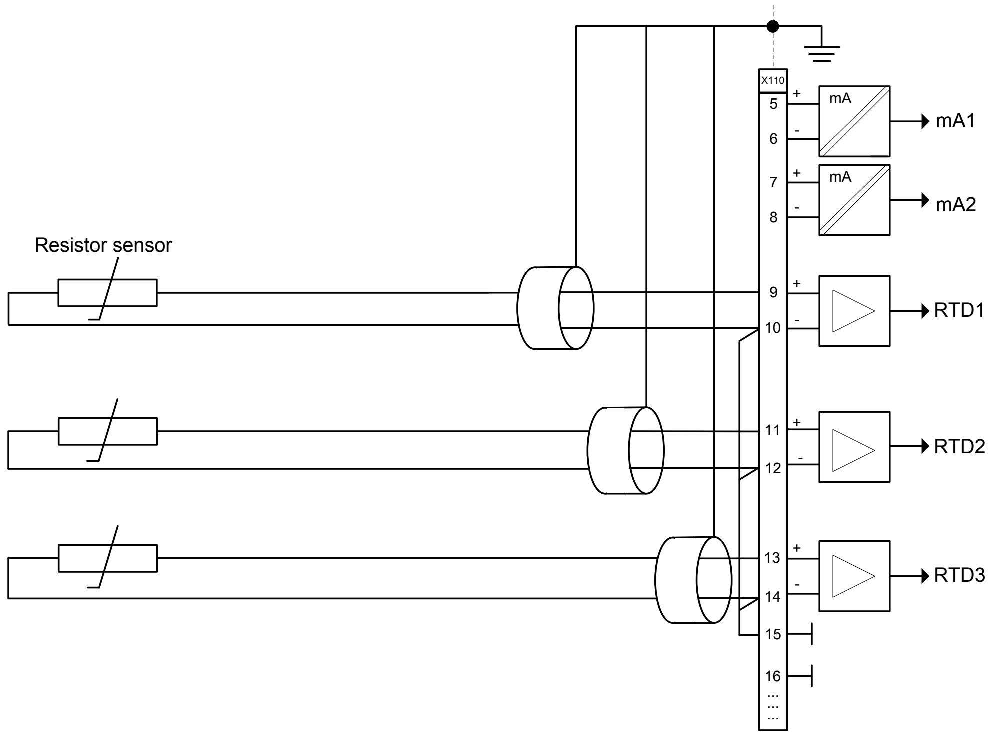


Figure 48: Three RTD sensors and two resistance sensors connected according to the 2-wire connection for 6RTD/2mA card

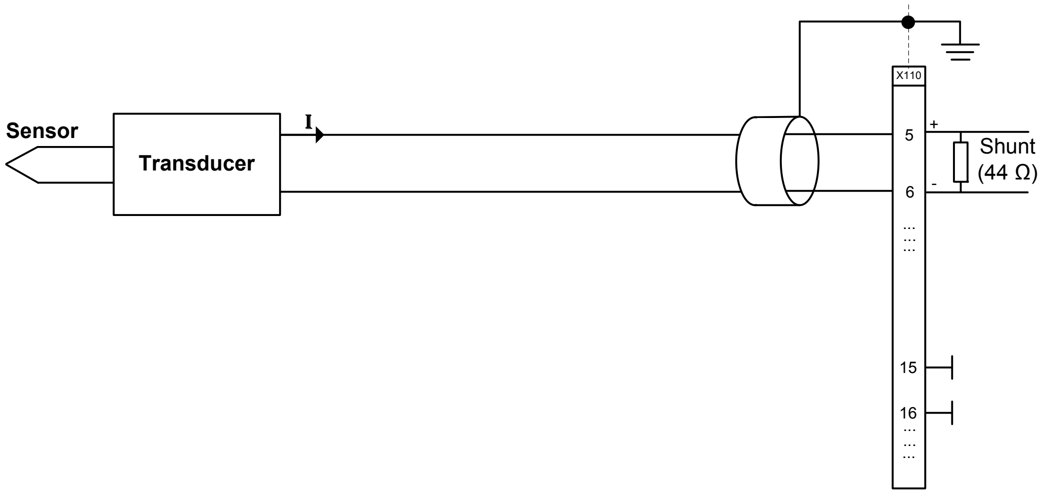


Figure 49: mA wiring connection for 6RTD/2mA card

2RTD/1mA card

This type of card accepts one milliampere input, two inputs from RTD sensors and five inputs from VTs. The Input 1 is assigned for current measurements, inputs 2 and 3 are for RTD sensors and inputs 4 to 8 are used for measuring input data from VT.

2RTD/1mA/3SO card has one milliampere input, two inputs from RTD sensors and three signal outputs. The Input 1 is assigned for current measurements, inputs 2 and 3 are for RTD sensors and outputs 4,5,6 are used signal outputs.

RTD/mA input connections

The examples of 3-wire and 2-wire connections of resistance and temperature sensors to the 2RTD/1mA board are as shown:

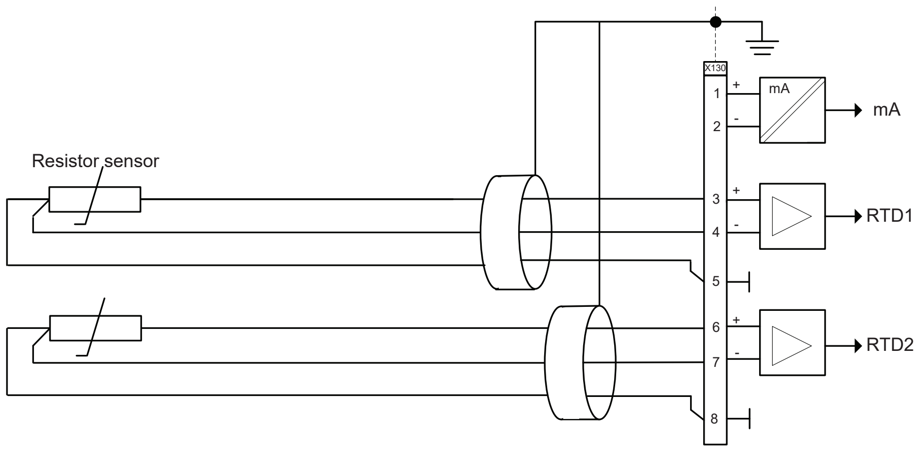


Figure 50: Two RTD and resistance sensors connected according to the 3-wire connection for RTD/mA card

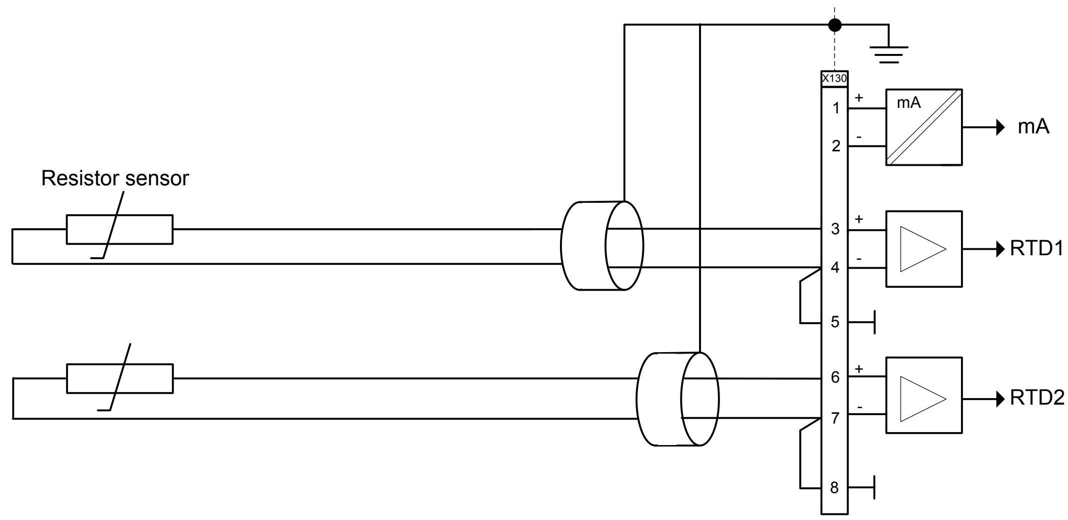


Figure 51: Two RTD and resistance sensors connected according to the 2-wire connection for RTD/mA card

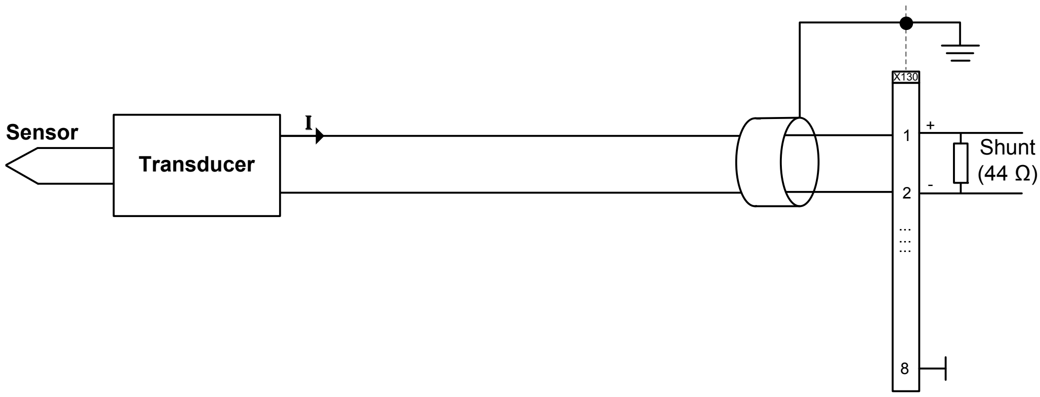


Figure 52: mA wiring connection for RTD/mA card

3.13.3 Signals

Table 57: 6RTD/2mA analog output signals

Name	Type	Description
ALARM	BOOLEAN	General alarm
WARNING	BOOLEAN	General warning
AI_VAL1	FLOAT32	mA input, Connectors 1-2, instantaneous value
AI_VAL2	FLOAT32	mA input, Connectors 3-4, instantaneous value

Table continues on the next page

Name	Type	Description
AI_VAL3	FLOAT32	RTD input, Connectors 5-6-11c, instantaneous value
AI_VAL4	FLOAT32	RTD input, Connectors 7-8-11c, instantaneous value
AI_VAL5	FLOAT32	RTD input, Connectors 9-10-11c, instantaneous value
AI_VAL6	FLOAT32	RTD input, Connectors 13-14-12c, instantaneous value
AI_VAL7	FLOAT32	RTD input, Connectors 15-16-12c, instantaneous value
AI_VAL8	FLOAT32	RTD input, Connectors 17-18-12c, instantaneous value

Table 58: 2RTD/1mA analog output signals

Name	Type	Description
ALARM	BOOLEAN	General alarm
WARNING	BOOLEAN	General warning
AI_VAL1	FLOAT32	mA input, Connectors 1-2, instantaneous value
AI_VAL2	FLOAT32	RTD input, Connectors 3-5, instantaneous value
AI_VAL3	FLOAT32	RTD input, Connectors 6-8, instantaneous value

3.13.4 RTD input settings

Table 59: RTD input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Input mode	1=Not in use 2=Resistance 10=Pt100 11=Pt250 20=Ni100 21=Ni120 22=Ni250 30=Cu10			1=Not in use	Analogue input mode
Input maximum	0...2000	Ω	1	2000	Maximum analogue input value for mA or resistance scaling
Input minimum	0...2000	Ω	1	0	Minimum analogue input value for mA or resistance scaling
Value unit	1=Dimensionless 5=Ampere			1=Dimensionless	Selected unit for output value format

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	23=Degrees celsius 30=Ohm				
Value maximum	-10000.0...10000.0		1	10000.0	Maximum output value for scaling and supervision
Value minimum	-10000.0...10000.0		1	-10000.0	Minimum output value for scaling and supervision
Val high high limit	-10000.0...10000.0		1	10000.0	Output value high alarm limit for supervision
Value high limit	-10000.0...10000.0		1	10000.0	Output value high warning limit for supervision
Value low limit	-10000.0...10000.0		1	-10000.0	Output value low warning limit for supervision
Value low low limit	-10000.0...10000.0		1	-10000.0	Output value low alarm limit for supervision
Value deadband	100...100000		1	1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 60: mA input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Input mode	1=Not in use 5=0..20mA			1=Not in use	Analogue input mode
Input maximum	0...20	mA	1	20	Maximum analogue input value for mA or resistance scaling
Input minimum	0...20	mA	1	0	Minimum analogue input value for mA or resistance scaling
Value unit	1=Dimensionless 5=Ampere 23=Degrees celsius 30=Ohm			1=Dimensionless	Selected unit for output value format
Value maximum	-10000.0...10000.0		1	10000.0	Maximum output value for scaling and supervision
Value minimum	-10000.0...10000.0		1	-10000.0	Minimum output value for scaling and supervision
Val high high limit	-10000.0...10000.0		1	10000.0	Output value high alarm limit for supervision
Value high limit	-10000.0...10000.0		1	10000.0	Output value high warning limit for supervision
Value low limit	-10000.0...10000.0		1	-10000.0	Output value low warning limit for supervision
Value low low limit	-10000.0...10000.0		1	-10000.0	Output value low alarm limit for supervision
Value deadband	100...100000		1	1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

3.13.5 Monitored data

Table 61: 6RTD/2mA monitored data

Name	Type	Values (Range)	Unit	Description
AI_DB1	FLOAT32	-10000.0...10000.0		mA input, Connectors 1-2, reported value
AI_RANGE1	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		mA input, Connectors 1-2, range
AI_DB2	FLOAT32	-10000.0...10000.0		mA input, Connectors 3-4, reported value
AI_RANGE2	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		mA input, Connectors 3-4, range
AI_DB3	FLOAT32	-10000.0...10000.0		RTD input, Connectors 5-6-11c, reported value
AI_RANGE3	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 5-6-11c, range
AI_DB4	FLOAT32	-10000.0...10000.0		RTD input, Connectors 7-8-11c, reported value
AI_RANGE4	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 7-8-11c, range
AI_DB5	FLOAT32	-10000.0...10000.0		RTD input, Connectors 9-10-11c, reported value
AI_RANGE5	Enum	0=normal 1=high 2=low		RTD input, Connectors 9-10-11c, range

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		3=high-high 4=low-low		
AI_DB6	FLOAT32	-10000.0...10000.0		RTD input, Connectors 13-14-12c, reported value
AI_RANGE6	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 13-14-12c, range
AI_DB7	FLOAT32	-10000.0...10000.0		RTD input, Connectors 15-16-12c, reported value
AI_RANGE7	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 15-16-12c, range
AI_DB8	FLOAT32	-10000.0...10000.0		RTD input, Connectors 17-18-12c, reported value
AI_RANGE8	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 17-18-12c, range

Table 62: 2RTD/1mA monitored data

Name	Type	Values (Range)	Unit	Description
AI_DB1	FLOAT32	-10000.0...10000.0		mA input, Connectors 1-2, reported value
AI_RANGE1	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		mA input, Connectors 1-2, range

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
AI_DB2	FLOAT32	-10000.0...10000.0		RTD input, Connectors 3-5, reported value
AI_RANGE2	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 3-5, range
AI_DB3	FLOAT32	-10000.0...10000.0		RTD input, Connectors 6-8, reported value
AI_RANGE3	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 6-8, range

3.14 SMV function blocks

SMV function blocks are used in the process bus applications with the sending of the sampled values of analog currents and voltages and with the receiving of the sampled values of voltages.

3.14.1 IEC 61850-9-2 LE sampled values sending SMVSENDER

3.14.1.1 Functionality

The SMVSENDER function block is used for activating the SMV sending functionality. It adds/removes the sampled value control block and the related data set into/from the sending device's configuration. It has no input or output signals.

SMVSENDER can be disabled with the *Operation* setting value “off”. If the SMVSENDER is disabled from the LHMI, it can only be enabled from the LHMI. When disabled, the sending of the samples values is disabled.

3.14.1.2 Settings

Table 63: SMVSENDER Settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation

3.14.2 IEC 61850-9-2 LE sampled values receiving SMVRCV

3.14.2.1 Function block

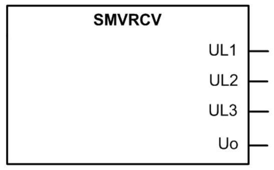


Figure 53: Function block

3.14.2.2 Functionality

The SMVRCV function block is used for activating the SMV receiving functionality.

3.14.2.3 Signals

Table 64: SMVRCV Output signals

Name	Type	Description
UL1	INT32-UL1	IEC61850-9-2 phase 1 voltage
UL2	INT32-UL2	IEC61850-9-2 phase 2 voltage
UL3	INT32-UL3	IEC61850-9-2 phase 3 voltage
U0	INT32-Uo	IEC61850-9-2 residual voltage

3.14.3 ULTVTR function block

3.14.3.1 Function block

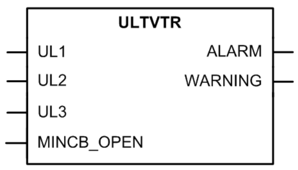


Figure 54: Function block

3.14.3.2 Functionality

The ULTVTR function is used in the receiver application to perform the supervision for the sampled values and to connect the received analog phase voltage inputs to the application. Synchronization accuracy, sampled value frame transfer delays and missing frames are being supervised.

The typical additional operate time increase is +2 ms for all the receiver application functions (using either local or remote samples) when SMV is used.

3.14.3.3 Operation principle

The ALARM in the receiver is activated if the synchronization accuracy of the sender or the receiver is either unknown or worse than 8 ms. The output is held on for 10 seconds after the synchronization accuracy returns within limits.

ALARM is activated when two or more consecutive SMV frames are lost or late. A single loss of frame is corrected with a zero-order hold scheme. In this case the effect on protection is considered negligible and the WARNING or ALARM outputs are not activated. The output is held on for 10 seconds after the conditions return to normal.

The *SMV Max Delay* parameter defines how long the receiver waits for the SMV frames before activating the ALARM output. This parameter can be accessed via **Configuration** > **System** > **Common**. Waiting of the SMV frames also delays the local measurements of the receiver to keep them correctly time aligned. The *SMV Max Delay* values include sampling, processing and network delay.

The MINCB_OPEN input signal is supposed to be connected through a protection relay's binary input to the NC auxiliary contact of the miniature circuit breaker protecting the VT secondary circuit. The MINCB_OPEN signal sets the FUSEF_U output signal to block all the voltage-related functions when MCB is in the open state.

The WARNING output in the receiver is activated if the synchronization accuracy of the sender or the receiver is worse than 4 μs. The output is held on for 10 seconds after the synchronization accuracy returns within limits.

The WARNING output is always internally active whenever the ALARM output is active.

The receiver activates the WARNING and ALARM outputs if any of the quality bits, except for the derived bit, is activated. When the receiver is in the test mode, it accepts SMV frames with test bit without activating the WARNING and ALARM outputs.

3.14.3.4 Signals

Table 65: ULTVTR Input signals

Name	Type	Default	Description
UL1	INT32-UL1	0	IEC61850-9-2 phase 1 voltage
UL2	INT32-UL2	0	IEC61850-9-2 phase 2 voltage
UL3	INT32-UL3	0	IEC61850-9-2 phase 3 voltage
MINCB_OPEN	BOOLEAN	0	Active when external MCB opens protected voltage circuit

Table 66: ULTVTR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm
WARNING	BOOLEAN	Warning

3.14.3.5 Settings

Table 67: ULTVTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Primary voltage	0.100...440.000	kV	0.001	20.000	Primary rated voltage
Secondary voltage	60...210	V	1	100	Secondary rated voltage
VT connection	1=Wye 2=Delta 3=U12 4=UL1			2=Delta	Voltage transducer measurement connection
Amplitude Corr A	0.9000...1.1000		0.0001	1.0000	Phase A Voltage phasor magnitude correction of an external voltage transformer
Amplitude Corr B	0.9000...1.1000		0.0001	1.0000	Phase B Voltage phasor magnitude correction of an external voltage transformer
Amplitude Corr C	0.9000...1.1000		0.0001	1.0000	Phase C Voltage phasor magnitude correction of an external voltage transformer
Division ratio	1000...20000		1	10000	Voltage sensor division ratio
Voltage input type	1=Voltage trafo 3=CVD sensor			1=Voltage trafo	Type of the voltage input
Angle Corr A	-8.000 … 8.000	deg	0.0001	0.0000	Phase A Voltage phasor angle correction of an external voltage transformer
Angle Corr B	-8.000 … 8.000	deg	0.0001	0.0000	Phase B Voltage phasor angle correction of an external voltage transformer
Angle Corr C	-8.000 … 8.000	deg	0.0001	0.0000	Phase C Voltage phasor angle correction of an external voltage transformer

3.14.3.6 Monitored data

Monitored data is available in three locations.

- **Monitoring** > **I/O status** > **Analog inputs**
- **Monitoring** > **IED status** > **SMV traffic**
- **Monitoring** > **IED status** > **SMV accuracy**

3.14.4 RESTVTR function block

3.14.4.1 Function block

Figure 55: Function block

3.14.4.2 Functionality

The RESTVTR function is used in the receiver application to perform the supervision for the sampled values of analog residual voltage and to connect the received analog residual voltage input to the application. Synchronization accuracy, sampled value frame transfer delays and missing frames are being supervised.

The typical additional operate time increase is +2 ms for all the receiver application functions (using either local or remote samples) when SMV is used.

3.14.4.3 Operation principle

The `ALARM` in the receiver is activated if the synchronization accuracy of the sender or the receiver is either unknown or worse than 8 ms. The output is held on for 10 seconds after the synchronization accuracy returns within limits.

`ALARM` is activated when two or more consecutive SMV frames are lost or late. A single loss of frame is corrected with a zero-order hold scheme. In this case, the effect on protection is considered negligible and the `WARNING` or `ALARM` outputs are not activated. The output is held on for 10 seconds after the conditions return to normal.

The *SMV Max Delay* parameter defines how long the receiver waits for the SMV frames before activating the `ALARM` output. This parameter can be accessed via **Configuration/System/Common.** Waiting of the SMV frames also delays the local measurements of the receiver to keep them correctly time aligned. The *SMV Max Delay* values include sampling, processing and network delay.

The `WARNING` output in the receiver is activated if the synchronization accuracy of the sender or the receiver is worse than 4 μs. The output is held on for 10 seconds after the synchronization accuracy returns within limits.

The `WARNING` output is always internally active whenever the `ALARM` output is active.

3.14.4.4 Signals

Table 68: RESTVTR Input signals

Name	Type	Default	Description
Uo	INT32-UL0	0	IEC61850-9-2 residual voltage

Table 69: RESTVTR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm
WARNING	BOOLEAN	Warning

3.14.4.5 Settings

Table 70: RESTVTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Primary voltage	0.100...440.000	kV	0.001	11.547	Primary voltage
Secondary voltage	60...210	V	1	100	Secondary voltage
Amplitude Corr	0.9000...1.1000		0.0001	1.0000	Amplitude correction
Angle correction	-20.0000...20.0000	deg	0.0001	0.0000	Angle correction factor

3.14.4.6 Monitored data

Monitored data is available in three locations.

- **Monitoring** > **I/O status** > **Analog inputs**
- **Monitoring** > **IED status** > **SMV traffic**
- **Monitoring** > **IED status** > **SMV accuracy**

3.15 GOOSE function blocks

GOOSE function blocks are used for connecting incoming GOOSE data to application. They support BOOLEAN, Dbpos, Enum, FLOAT32, INT8 and INT32 data types.

Common signals

The VALID output indicates the validity of received GOOSE data, which means in case of valid, that the GOOSE communication is working and received data quality bits (if configured) indicate good process data. Invalid status is caused either by bad data quality bits or GOOSE communication failure. See IEC 61850 engineering guide for details.

The OUT output passes the received GOOSE value for the application. Default value (0) is used if VALID output indicates invalid status. The IN input is defined in the GOOSE configuration and can always be seen in SMT sheet.

Settings

The GOOSE function blocks do not have any parameters available in LHMI or PCM600.

3.15.1 GOOSERCV_BIN function block

3.15.1.1 Function block

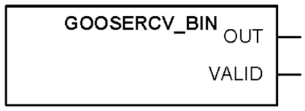


Figure 56: Function block

3.15.1.2 Functionality

The GOOSERCV_BIN function is used to connect the GOOSE binary inputs to the application.

3.15.1.3 Signals

Table 71: GOOSERCV_BIN Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
VALID	BOOLEAN	Output signal

3.15.2 GOOSERCV_DP function block

3.15.2.1 Function block

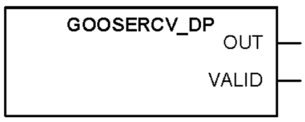


Figure 57: Function block

3.15.2.2 Functionality

The GOOSERCV_DP function is used to connect the GOOSE double binary inputs to the application.

3.15.2.3 Signals

Table 72: GOOSERCV_DP Output signals

Name	Type	Description
OUT	Dbpos	Output signal
VALID	BOOLEAN	Output signal

3.15.3 GOOSERCV_MV function block

3.15.3.1 Function block

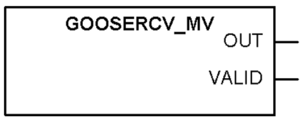


Figure 58: Function block

3.15.3.2 Functionality

The GOOSERCV_MV function is used to connect the GOOSE measured value inputs to the application.

3.15.3.3 Signals

Table 73: GOOSERCV_MV Output signals

Name	Type	Description
OUT	FLOAT32	Output signal
VALID	BOOLEAN	Output signal

3.15.4 GOOSERCV_INT8 function block

3.15.4.1 Function block

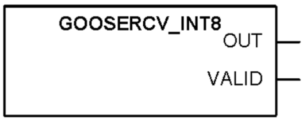


Figure 59: Function block

3.15.4.2 Functionality

The GOOSERCV_INT8 function is used to connect the GOOSE 8 bit integer inputs to the application.

3.15.4.3 Signals

Table 74: GOOSERCV_INT8 Output signals

Name	Type	Description
OUT	INT8	Output signal
VALID	BOOLEAN	Output signal

3.15.5 GOOSERCV_INTL function block

3.15.5.1 Function block

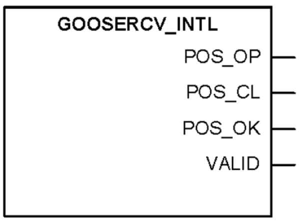


Figure 60: Function block

3.15.5.2 Functionality

The received GOOSE interlocking information function GOOSERCV_INTL is used to connect the GOOSE double binary input to the application and extracting single binary position signals from the double binary position signal.

The `OP` output signal indicates that the position is open. Default value (0) is used if `VALID` output indicates invalid status.

The CL output signal indicates that the position is closed. Default value (0) is used if VALID output indicates invalid status.

The OK output signal indicates that the position is neither in faulty or intermediate state. The default value (0) is used if VALID output indicates invalid status.

3.15.5.3 Signals

Table 75: GOOSERCV_INTL Output signals

Name	Type	Description
POS_OP	BOOLEAN	Position open output signal
POS_CL	BOOLEAN	Position closed output signal
POS_OK	BOOLEAN	Position OK output signal
VALID	BOOLEAN	Output signal

3.15.6 GOOSERCV_CMV function block

3.15.6.1 Function block

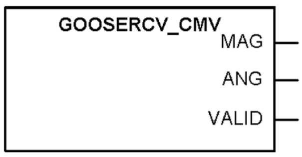


Figure 61: Function block

3.15.6.2 Functionality

The received GOOSE measured value (phasor) information function GOOSERCV_CMV is used to connect GOOSE measured value inputs to the application. The MAG_IN(amplitude) and ANG_IN (angle) inputs are defined in the GOOSE configuration (PCM600).

The MAG output passes the received GOOSE amplitude and ANG the received angle value for the application.

3.15.6.3 Signals

Table 76: GOOSERCV_CMV Output signals

Name	Type	Description
MAG	FLOAT32	Output signal (amplitude)
ANG	FLOAT32	Output signal (angle)
VALID	BOOLEAN	Output signal

3.15.7 GOOSERCV_ENUM function block

3.15.7.1 Function block

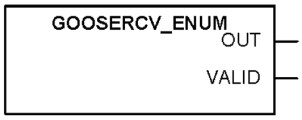


Figure 62: Function block

3.15.7.2 Functionality

The GOOSERCV_ENUM function block is used to connect GOOSE enumerator inputs to the application.

3.15.7.3 Signals

Table 77: GOOSERCV_ENUM Output signals

Name	Type	Description
OUT	Enum	Output signal
VALID	BOOLEAN	Output signal

3.15.8 GOOSERCV_INT32 function block

3.15.8.1 Function block

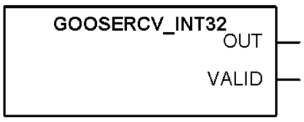


Figure 63: Function block

3.15.8.2 Functionality

The GOOSERCV_INT32 function block is used to connect GOOSE 32 bit integer inputs to the application.

3.15.8.3 Signals

Table 78: GOOSERCV_INT32 Output signals

Name	Type	Description
OUT	INT32	Output signal
VALID	BOOLEAN	Output signal

3.16 Type conversion function blocks

3.16.1 QTY_GOOD function block

3.16.1.1 Function block

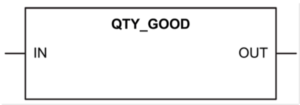


Figure 64: Function block

3.16.1.2 Functionality

The good signal quality function QTY_GOOD evaluates the quality bits of the input signal and passes it as a Boolean signal for the application.

The `IN` input can be connected to any logic application signal (logic function output, binary input, application function output or received GOOSE signal). Due to application logic quality bit propagation, each (simple and even combined) signal has quality which can be evaluated.

The `OUT` output indicates quality good of the input signal. Input signals that have no quality bits set or only test bit is set, will indicate quality good status.

3.16.1.3 Signals

Table 79: QTY_GOOD Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 80: QTY_GOOD Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.16.2 QTY_BAD function block

3.16.2.1 Function block

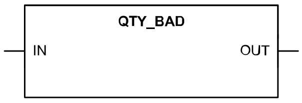


Figure 65: Function block

3.16.2.2 Functionality

The bad signal quality function QTY_BAD evaluates the quality bits of the input signal and passes it as a Boolean signal for the application.

The `IN` input can be connected to any logic application signal (logic function output, binary input, application function output or received GOOSE signal). Due to application logic quality bit propagation, each (simple and even combined) signal has quality which can be evaluated.

The `OUT` output indicates quality bad of the input signal. Input signals that have any other than test bit set, will indicate quality bad status.

3.16.2.3 Signals

Table 81: QTY_BAD Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 82: QTY_BAD Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.16.3 QTY_GOOSE_COMM function block

3.16.3.1 Function block

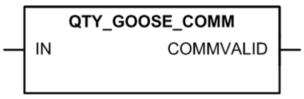


Figure 66: Function block

3.16.3.2 Functionality

The QTY_GOOSE_COMM function block evaluates the peer device communication status from the quality bits of the input signal and passes it as a Boolean signal to the application.

The IN input signal must be connected to the VALID signal of the GOOSE function block.

The OUT output indicates the communication status of the GOOSE function block. When the output is in the true (1) state, the GOOSE communication is active. The value false (0) indicates communication timeout.

3.16.3.3 Signals

Table 83: QTY_GOOSE_COMM Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 84: QTY_GOOSE_COMM Output signals

Name	Type	Description
COMMVALID	BOOLEAN	Output signal

3.16.4 T_HEALTH function block

3.16.4.1 Function block

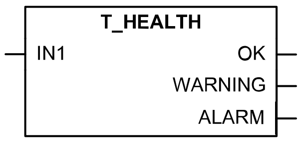


Figure 67: Function block

3.16.4.2 Functionality

The GOOSE data health function T_HEALTH evaluates enumerated data of “Health” data attribute. This function block can only be used with GOOSE.

The IN input can be connected to GOOSERCV_ENUM function block, which is receiving the LD0.LLN0.Health.stVal data attribute sent by another device.

The outputs OK, WARNING and ALARM are extracted from the enumerated input value. Only one of the outputs can be active at a time. In case the GOOSERCV_ENUM function block does not receive the value from the sending device or it is invalid, the default value (0) is used and the ALARM is activated in the T_HEALTH function block.

3.16.4.3 Signals

Table 85: T_HEALTH Input signals

Name	Type	Default	Description
IN1	Any	0	Input signal

Table 86: T_HEALTH Output signals

Name	Type	Description
OK	BOOLEAN	Output signal
WARNING	BOOLEAN	Output signal
ALARM	BOOLEAN	Output signal

3.16.5 T_F32_INT8 function block

3.16.5.1 Function block

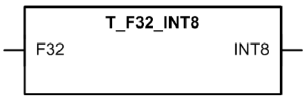


Figure 68: Function block

3.16.5.2 Functionality

The T_F32_INT8 function is used to convert 32-bit floating type values to 8-bit integer type. The rounding operation is included. Output value saturates if the input value is below the minimum or above the maximum value.

3.16.5.3 Signals

Table 87: T_F32_INT8 Input signals

Name	Type	Default	Description
F32	FLOAT32	0.0	Input signal

Table 88: T_F32_INT8 Output signal

Name	Type	Description
INT8	INT8	Output signal

3.16.6 T_DIR function block

3.16.6.1 Function block

Figure 69: Function block

3.16.6.2 Functionality

The T_DIR function evaluates enumerated data of the FAULT_DIR data attribute of the directional functions. T_DIR can only be used with GOOSE. The `DIR` input can be connected to the GOOSERCV_ENUM function block, which is receiving the LD0.<function>.Str.dirGeneral or LD0.<function>.Dir.dirGeneral data attribute sent by another device.

In case the GOOSERCV_ENUM function block does not receive the value from the sending device or it is invalid, the default value (0) is used in function outputs.

The outputs `FWD` and `REV` are extracted from the enumerated input value.

3.16.6.3 Signals

Table 89: T_DIR Input signals

Name	Type	Default	Description
DIR	Enum	0	Input signal

Table 90: T_DIR Output signals

Name	Type	Default	Description
FWD	BOOLEAN	0	Direction forward
REV	BOOLEAN	0	Direction backward

3.16.7 T_TCMD function block

3.16.7.1 Function block

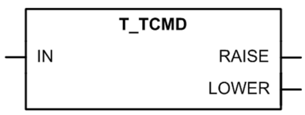


Figure 70: Function block

3.16.7.2 Functionality

The enumerator to boolean conversion function T_TCMD is used to convert enumerated input signals to boolean output signals.

Table 91: Conversion from enumerated to Boolean

IN	RAISE	LOWER
0	FALSE	FALSE
1	FALSE	TRUE
2	TRUE	FALSE
x	FALSE	FALSE

3.16.7.3 Signals

Table 92: T_TCMD input signals

Name	Type	Default	Description
IN	Enum	0	Input signal

Table 93: T_TCMD output signals

Name	Type	Description
RAISE	BOOLEAN	Raise command
LOWER	BOOLEAN	Lower command

3.16.8 T_TCMD_BIN function block

3.16.8.1 Function block

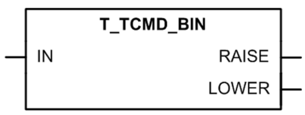


Figure 71: Function block

3.16.8.2 Functionality

The 32-bit integer to binary command conversion function T_TCMD_BIN is used to convert 32 bit integer input signal to boolean output signals.

Table 94: Conversion from integer to Boolean

IN	RAISE	LOWER
0	FALSE	FALSE
1	FALSE	TRUE

Table continues on the next page

IN	RAISE	LOWER
2	TRUE	FALSE
x	FALSE	FALSE

3.16.8.3 Signals

Table 95: T_TCMD_BIN input signals

Name	Type	Default	Description
IN	INT32	0	Input signal

Table 96: T_TCMD_BIN output signals

Name	Type	Description
RAISE	BOOLEAN	Raise command
LOWER	BOOLEAN	Lower command

3.16.9 T_BIN_TCMD function block

3.16.9.1 Function block

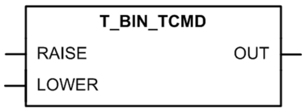


Figure 72: Function block

3.16.9.2 Functionality

The binary command to 32-bit integer conversion function T_BIN_TCMD is used to convert boolean input signals to 32 bit integer output signals.

Table 97: Conversion from Boolean to integer

RAISE	LOWER	OUT
FALSE	FALSE	0
FALSE	TRUE	1
TRUE	FALSE	2

3.16.9.3 Signals

Table 98: T_BIN_TCMD input signals

Name	Type	Default	Description
RAISE	BOOLEAN	0	Raise command
LOWER	BOOLEAN	0	Lower command

Table 99: T_BIN_TCMD output signals

Name	Type	Description
OUT	INT32	Output signal

3.17 Configurable logic blocks

3.17.1 Standard configurable logic blocks

3.17.1.1 OR function block

Functionality

OR, OR6 and OR20 are used to form general combinatory expressions with Boolean variables

The O output is activated when at least one input has the value TRUE. The default value of all inputs is FALSE, which makes it possible to use only the required number of inputs and leave the rest disconnected.

OR has two inputs, OR6 six and OR20 twenty inputs.

Signals

Table 100: OR Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2

Table 101: OR6 Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2
B3	BOOLEAN	0	Input signal 3

Table continues on the next page

Name	Type	Default	Description
B4	BOOLEAN	0	Input signal 4
B5	BOOLEAN	0	Input signal 5
B6	BOOLEAN	0	Input signal 6

Table 102: OR20 Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2
B3	BOOLEAN	0	Input signal 3
B4	BOOLEAN	0	Input signal 4
B5	BOOLEAN	0	Input signal 5
B6	BOOLEAN	0	Input signal 6
B7	BOOLEAN	0	Input signal 7
B8	BOOLEAN	0	Input signal 8
B9	BOOLEAN	0	Input signal 9
B10	BOOLEAN	0	Input signal 10
B11	BOOLEAN	0	Input signal 11
B12	BOOLEAN	0	Input signal 12
B13	BOOLEAN	0	Input signal 13
B14	BOOLEAN	0	Input signal 14
B15	BOOLEAN	0	Input signal 15
B16	BOOLEAN	0	Input signal 16
B17	BOOLEAN	0	Input signal 17
B18	BOOLEAN	0	Input signal 18
B19	BOOLEAN	0	Input signal 19
B20	BOOLEAN	0	Input signal 20

Table 103: OR Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Table 104: OR6 Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Table 105: OR20 Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Settings

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

Function block

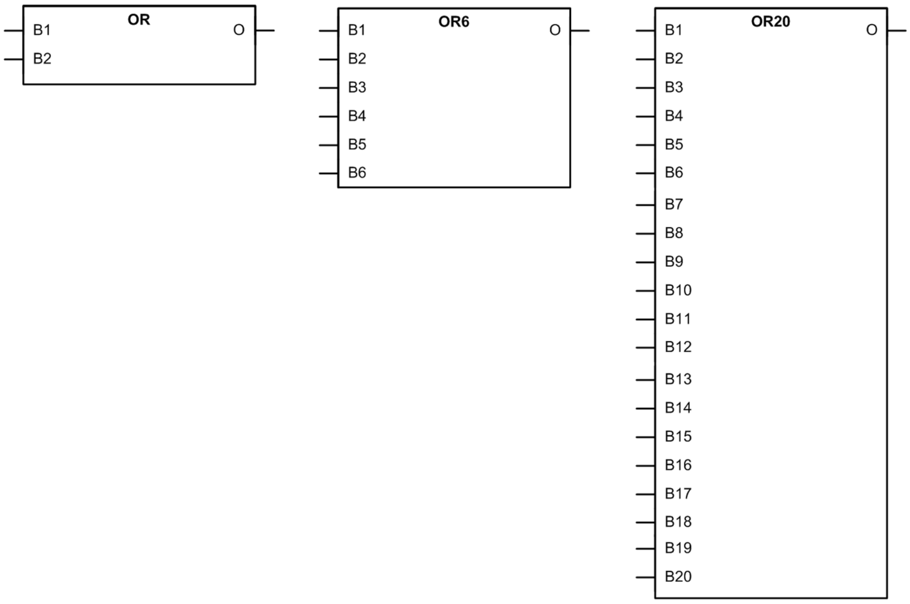


Figure 73: Function blocks

3.17.1.2 AND Function block

AND Function block

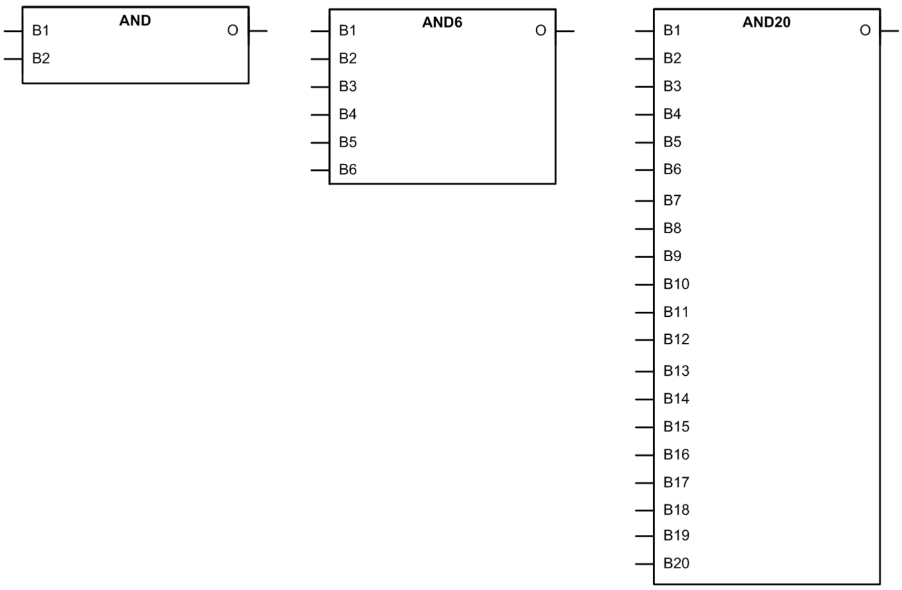


Figure 74: Function blocks

Functionality

AND, AND6 and AND20 are used to form general combinatory expressions with Boolean variables.

The default value in all inputs is logical true, which makes it possible to use only the required number of inputs and leave the rest disconnected.

AND has two inputs, AND6 six inputs and AND20 twenty inputs.

Signals

Table 106: AND Input signals

Name	Type	Default	Description
B1	BOOLEAN	1	Input signal 1
B2	BOOLEAN	1	Input signal 2

Table 107: AND6 Input signals

Name	Type	Default	Description
B1	BOOLEAN	1	Input signal 1
B2	BOOLEAN	1	Input signal 2
B3	BOOLEAN	1	Input signal 3
B4	BOOLEAN	1	Input signal 4
B5	BOOLEAN	1	Input signal 5
B6	BOOLEAN	1	Input signal 6

Table 108: AND20 Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2
B3	BOOLEAN	0	Input signal 3
B4	BOOLEAN	0	Input signal 4
B5	BOOLEAN	0	Input signal 5
B6	BOOLEAN	0	Input signal 6
B7	BOOLEAN	0	Input signal 7
B8	BOOLEAN	0	Input signal 8
B9	BOOLEAN	0	Input signal 9
B10	BOOLEAN	0	Input signal 10
B11	BOOLEAN	0	Input signal 11
B12	BOOLEAN	0	Input signal 12
B13	BOOLEAN	0	Input signal 13
B14	BOOLEAN	0	Input signal 14
B15	BOOLEAN	0	Input signal 15

Table continues on the next page

Name	Type	Default	Description
B16	BOOLEAN	0	Input signal 16
B17	BOOLEAN	0	Input signal 17
B18	BOOLEAN	0	Input signal 18
B19	BOOLEAN	0	Input signal 19
B20	BOOLEAN	0	Input signal 20

Table 109: AND Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Table 110: AND6 Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Table 111: AND20 Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Settings

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

3.17.1.3 XOR function block

Function block

Figure 75: Function block

Functionality

The exclusive OR function XOR is used to generate combinatory expressions with Boolean variables.

The output signal is TRUE if the input signals are different and FALSE if they are equal.

Signals

Table 112: XOR Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2

Table 113: XOR Output signals

Name	Type	Description
O	BOOLEAN	Output signal

Settings

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

3.17.1.4 NOT function block

Function block

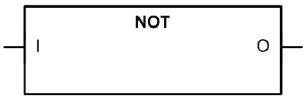


Figure 76: Function block

Functionality

NOT is used to generate combinatory expressions with Boolean variables.

NOT inverts the input signal.

Signals

Table 114: NOT Input signal

Name	Type	Default	Description
1	BOOLEAN	0	Input signal

Table 115: NOT Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Settings

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

3.17.1.5 MAX3 function block

Function block

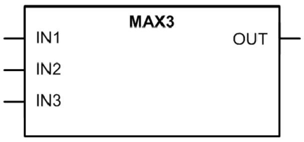


Figure 77: Function block

Functionality

The maximum function MAX3 selects the maximum value from three analog values. Disconnected inputs and inputs whose quality is bad are ignored. If all inputs are disconnected or the quality is bad, MAX3 output value is set to -2^21.

Signals

Table 116: MAX3 Input signals

Name	Type	Default	Description
IN1	FLOAT32	0	Input signal 1
IN2	FLOAT32	0	Input signal 2
IN3	FLOAT32	0	Input signal 3

Table 117: MAX3 Output signal

Name	Type	Description
OUT	FLOAT32	Output signal

Settings

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

3.17.1.6 MIN3 function block

Function block

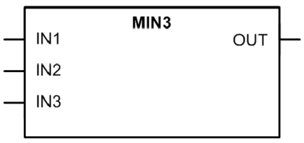


Figure 78: Function block

Functionality

The minimum function MIN3 selects the minimum value from three analog values. Disconnected inputs and inputs whose quality is bad are ignored. If all inputs are disconnected or the quality is bad, MIN3 output value is set to 2^21.

Signals

Table 118: MIN3 Input signals

Name	Type	Default	Description
IN1	FLOAT32	0	Input signal 1
IN2	FLOAT32	0	Input signal 2
IN3	FLOAT32	0	Input signal 3

Table 119: MIN3 Output signal

Name	Type	Description
OUT	FLOAT32	Output signal

Settings

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

3.17.1.7 R_TRIG function block

Function block

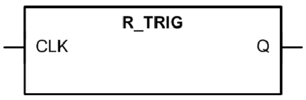


Figure 79: Function block

Functionality

R_TRIG is used as a rising edge detector.

R_TRIG detects the transition from FALSE to TRUE at the `CLK` input. When the rising edge is detected, the element assigns the output to TRUE. At the next execution round, the output is returned to FALSE despite the state of the input.

Signals

Table 120: R_TRIG Input signals

Name	Type	Default	Description
CLK	BOOLEAN	0	Input signal

Table 121: R_TRIG Output signals

Name	Type	Description
Q	BOOLEAN	Output signal

Settings

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

3.17.1.8 F_TRIG function block

Function block

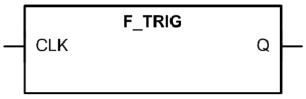


Figure 80: Function block

Functionality

F_TRIG is used as a falling edge detector.

The function detects the transition from TRUE to FALSE at the `CLK` input. When the falling edge is detected, the element assigns the `Q` output to TRUE. At the next execution round, the output is returned to FALSE despite the state of the input.

Signals

Table 122: F_TRIG Input signals

Name	Type	Default	Description
CLK	BOOLEAN	0	Input signal

Table 123: F_TRIG Output signals

Name	Type	Description
Q	BOOLEAN	Output signal

Settings

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

3.17.1.9 T_POS_XX function blocks

Function block

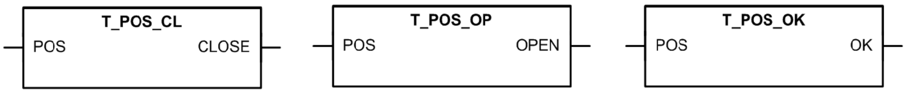


Figure 81: Function blocks

Functionality

The circuit breaker position information can be communicated with the IEC 61850 GOOSE messages. The position information is a double binary data type which is fed to the `POS` input.

T_POS_CL and T_POS_OP are used for extracting the circuit breaker status information. Respectively, T_POS_OK is used to validate the intermediate or faulty breaker position.

Table 124: Cross reference between circuit breaker position and the output of the function block

Circuit breaker position	Output of the function block		
	T_POS_CL	T_POS_OP	T_POS_OK
Intermediate '00'	FALSE	FALSE	FALSE
Close '01'	TRUE	FALSE	TRUE
Open '10'	FALSE	TRUE	TRUE
Faulty '11'	TRUE	TRUE	FALSE

Signals

Table 125: T_POS_CL Input signals

Name	Type	Default	Description
POS	Double binary	0	Input signal

Table 126: T_POS_OP Input signals

Name	Type	Default	Description
POS	Double binary	0	Input signal

Table 127: T_POS_OK Input signals

Name	Type	Default	Description
POS	Double binary	0	Input signal

Table 128: T_POS_CL Output signal

Name	Type	Description
CLOSE	BOOLEAN	Output signal

Table 129: T_POS_OP Output signal

Name	Type	Description
OPEN	BOOLEAN	Output signal

Table 130: T_POS_OK Output signal

Name	Type	Description
OK	BOOLEAN	Output signal

Settings

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

3.17.1.10 SWITCHR function block

Function block

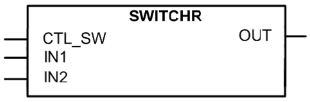


Figure 82: Function block

Functionality

SWITCHR switching block for REAL data type is operated by the `CTL_SW` input, selects the output value `OUT` between the `IN1` and `IN2` inputs.

CTL_SW	OUT
FALSE	IN2
TRUE	IN1

Signals

Table 131: 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 132: SWITCHR Output signals

Name	Type	Description
OUT	REAL	Real switch output

3.17.1.11 SWITCHI32 function block

Function block

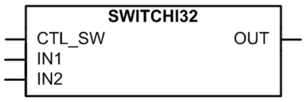


Figure 83: Function block

Functionality

SWITCHI32 switching block for 32-bit integer data type is operated by the CTL_SW input, which selects the output value OUT between the IN1 and IN2 inputs.

Table 133: SWITCHI32

CTL_SW	OUT
FALSE	IN2
TRUE	IN1

Signals

Table 134: SWITCHI32 Input signals

Name	Type	Default	Description
CTL_SW	BOOLEAN	1	Control Switch
IN1	INT32	0	Input signal 1
IN2	INT32	0	Input signal 2

Table 135: SWITCHI32 Output signals

Name	Type	Description
OUT	INT32	Output signal

3.17.1.12 SR function block

Function block

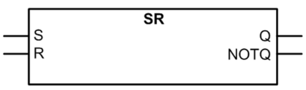


Figure 84: Function block

Functionality

The SR flip-flop output Q can be set or reset from the S or R inputs. S input has a higher priority over the R input. Output NOTQ is the negation of output Q.

The statuses of outputs Q and NOTQ are not retained in the nonvolatile memory.

Table 136: Truth table for SR flip-flop

S	R	Q
0	0	0[1]
0	1	0
1	0	1
1	1	1

Signals

Table 137: SR Input signals

Name	Type	Default	Description
S	BOOLEAN	0=False	Set Q output when set
R	BOOLEAN	0=False	Resets Q output when set

Table 138: SR Output signals

Name	Type	Description
Q	BOOLEAN	Q status
NOTQ	BOOLEAN	NOTQ status

3.17.1.13 RS function block

Function block

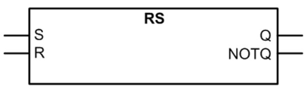


Figure 85: Function block

Functionality

The RS flip-flop output Q can be set or reset from the S or R inputs. R input has a higher priority over the S input. Output NOTQ is the negation of output Q.

The statuses of outputs Q and NOTQ are not retained in the nonvolatile memory.

1 Keep state/no change

Table 139: Truth table for RS flip-flop

S	R	Q
0	0	0 [1]
0	1	0
1	0	1
1	1	0

Signals

Table 140: RS Input signals

Name	Type	Default	Description
S	BOOLEAN	0=False	Set Q output when set
R	BOOLEAN	0=False	Resets Q output when set

Table 141: RS Output signals

Name	Type	Description
Q	BOOLEAN	Q status
NOTQ	BOOLEAN	NOTQ status

Technical revision history

Table 142: RS Technical revision history

Technical revision	Change
L	The name of the function has been changed from SR to RS.

3.17.2 Minimum pulse timer

3.17.2.1 Minimum pulse timer TPGAPC

Function block

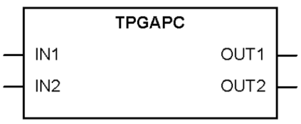


Figure 86: Function block

[1] Keep state/no change

Functionality

The Minimum pulse timer function TPGAPC contains two independent timers. The function has a settable pulse length (in milliseconds). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated, the output is set for a specific duration using the *Pulse time* setting. Both timers use the same setting parameter.

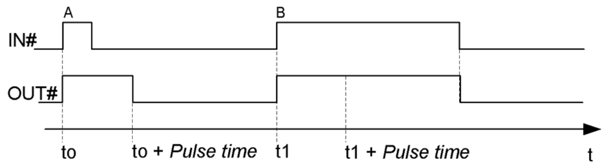


Figure 87: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

Signals

Table 143: TPGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1 status
IN2	BOOLEAN	0=False	Input 2 status

Table 144: TPGAPC Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1 status
OUT2	BOOLEAN	Output 2 status

Settings

Table 145: TPGAPC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time	0...60000	ms	1	150	Minimum pulse time

Technical revision history

Table 146: TPGAPC Technical revision history

Technical revision	Change
B	Outputs now visible in menu
C	Internal improvement

3.17.2.2 Minimum pulse timer TPSGAPC

Function block

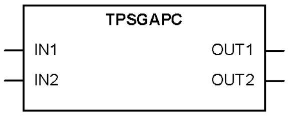


Figure 88: Function block

Functionality

The Minimum second pulse timer function TPSGAPC contains two independent timers. The function has a settable pulse length (in seconds). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated, the output is set for a specific duration using the *Pulse time* setting. Both timers use the same setting parameter.

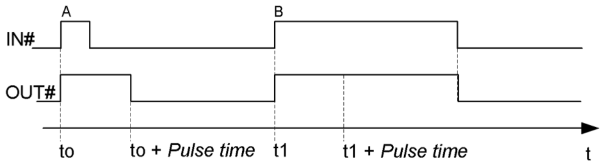


Figure 89: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

Signals

Table 147: TPSGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1
IN2	BOOLEAN	0=False	Input 2

Table 148: TPSGAPC Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1 status
OUT2	BOOLEAN	Output 2 status

Settings

Table 149: TPSGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time	0...300	s	1	0	Minimum pulse time

Technical revision history

Table 150: TPSGAPC Technical revision history

Technical revision	Change
B	Outputs now visible in menu
C	Internal improvement

3.17.2.3 Minimum pulse timer TPMGAPC

Function block

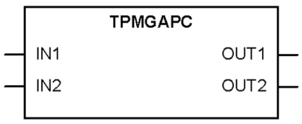


Figure 90: Function block

Functionality

The Minimum minute pulse timer function TPMGAPC contains two independent timers. The function has a settable pulse length (in minutes). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated, the output is set for a specific duration using the *Pulse time* setting. Both timers use the same setting parameter.

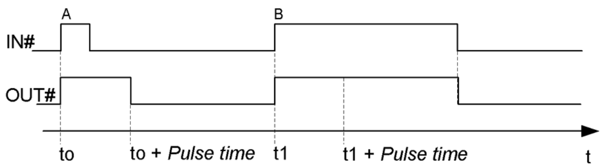


Figure 91: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

Signals

Table 151: TPMGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1
IN2	BOOLEAN	0=False	Input 2

Table 152: TPMGAPC Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1 status
OUT2	BOOLEAN	Output 2 status

Settings

Table 153: TPMGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time	0...300	min	1	0	Minimum pulse time

3.17.3 Pulse timer function block PTGAPC

3.17.3.1 Function block

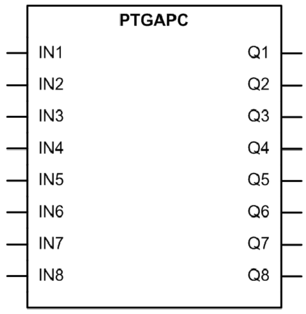


Figure 92: Function block

3.17.3.2 Functionality

The pulse timer function PTGAPC contains eight independent timers. The function has a settable pulse length. Once the input is activated, the output is set for a specific duration using the *Pulse delay time* setting.

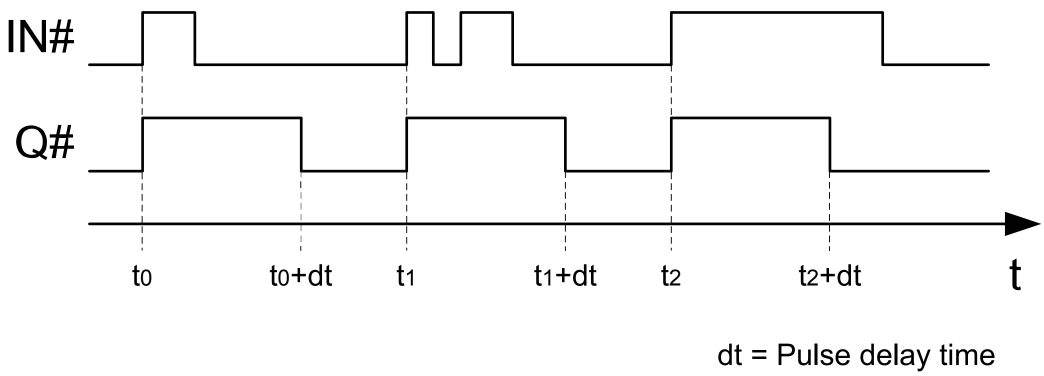


Figure 93: Timer operation

3.17.3.3 Signals

Table 154: PTGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1 status
IN2	BOOLEAN	0=False	Input 2 status
IN3	BOOLEAN	0=False	Input 3 status
IN4	BOOLEAN	0=False	Input 4 status
IN5	BOOLEAN	0=False	Input 5 status
IN6	BOOLEAN	0=False	Input 6 status
IN7	BOOLEAN	0=False	Input 7 status
IN8	BOOLEAN	0=False	Input 8 status

Table 155: PTGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1 status
Q2	BOOLEAN	Output 2 status
Q3	BOOLEAN	Output 3 status
Q4	BOOLEAN	Output 4 status
Q5	BOOLEAN	Output 5 status
Q6	BOOLEAN	Output 6 status
Q7	BOOLEAN	Output 7 status
Q8	BOOLEAN	Output 8 status

3.17.3.4 Settings

Table 156: PTGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time 1	0...3600000	ms	10	0	Pulse time
Pulse time 2	0...3600000	ms	10	0	Pulse time
Pulse time 3	0...3600000	ms	10	0	Pulse time
Pulse time 4	0...3600000	ms	10	0	Pulse time
Pulse time 5	0...3600000	ms	10	0	Pulse time
Pulse time 6	0...3600000	ms	10	0	Pulse time
Pulse time 7	0...3600000	ms	10	0	Pulse time
Pulse time 8	0...3600000	ms	10	0	Pulse time

3.17.3.5 Technical data

Table 157: PTGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

3.17.4 Time delay off (8 pcs) TOFGAPC

3.17.4.1 Function block

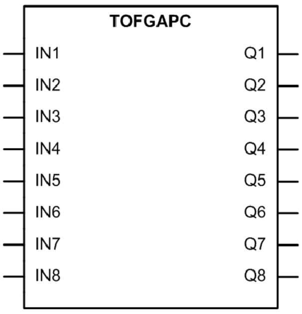


Figure 94: Function block

3.17.4.2 Functionality

The time delay off (8 pcs) function TOFGAPC can be used, for example, for a dropoff-delayed output related to the input signal. The function contains eight independent timers. There is a settable delay in the timer. Once the input is activated, the output is set immediately. When the input is cleared, the output stays on until the time set with the *Off delay time* setting has elapsed.

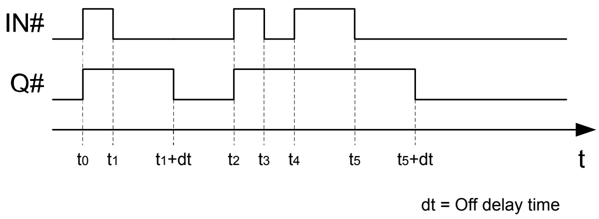


Figure 95: Timer operation

3.17.4.3 Signals

Table 158: TOFGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1 status
IN2	BOOLEAN	0=False	Input 2 status
IN3	BOOLEAN	0=False	Input 3 status
IN4	BOOLEAN	0=False	Input 4 status
IN5	BOOLEAN	0=False	Input 5 status
IN6	BOOLEAN	0=False	Input 6 status
IN7	BOOLEAN	0=False	Input 7 status
IN8	BOOLEAN	0=False	Input 8 status

Table 159: TOFGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1 status
Q2	BOOLEAN	Output 2 status
Q3	BOOLEAN	Output 3 status
Q4	BOOLEAN	Output 4 status
Q5	BOOLEAN	Output 5 status
Q6	BOOLEAN	Output 6 status
Q7	BOOLEAN	Output 7 status
Q8	BOOLEAN	Output 8 status

3.17.4.4 Settings

Table 160: TOFGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Off delay time 1	0...3600000	ms	10	0	Off delay time
Off delay time 2	0...3600000	ms	10	0	Off delay time
Off delay time 3	0...3600000	ms	10	0	Off delay time
Off delay time 4	0...3600000	ms	10	0	Off delay time
Off delay time 5	0...3600000	ms	10	0	Off delay time
Off delay time 6	0...3600000	ms	10	0	Off delay time
Off delay time 7	0...3600000	ms	10	0	Off delay time
Off delay time 8	0...3600000	ms	10	0	Off delay time

3.17.4.5 Technical data

Table 161: TOFGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

3.17.5 Time delay on (8 pcs) TONGAPC

3.17.5.1 Function block

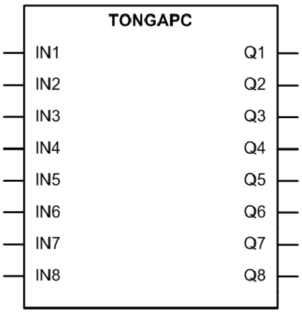


Figure 96: Function block

3.17.5.2 Functionality

The time delay on (8 pcs) function TONGAPC can be used, for example, for time delaying the output related to the input signal. TONGAPC contains eight independent timers. The timer has a settable time delay. Once the input is activated, the output is set after the time set by the *On delay time* setting has elapsed.

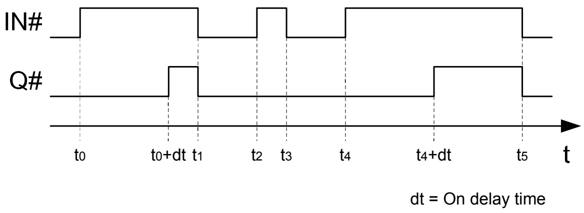


Figure 97: Timer operation

3.17.5.3 Signals

Table 162: TONGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1
IN2	BOOLEAN	0=False	Input 2
IN3	BOOLEAN	0=False	Input 3
IN4	BOOLEAN	0=False	Input 4
IN5	BOOLEAN	0=False	Input 5
IN6	BOOLEAN	0=False	Input 6
IN7	BOOLEAN	0=False	Input 7
IN8	BOOLEAN	0=False	Input 8

Table 163: TONGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1
Q2	BOOLEAN	Output 2
Q3	BOOLEAN	Output 3
Q4	BOOLEAN	Output 4
Q5	BOOLEAN	Output 5
Q6	BOOLEAN	Output 6
Q7	BOOLEAN	Output 7
Q8	BOOLEAN	Output 8

3.17.5.4 Settings

Table 164: TONGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
On delay time 1	0...3600000	ms	10	0	On delay time
On delay time 2	0...3600000	ms	10	0	On delay time
On delay time 3	0...3600000	ms	10	0	On delay time
On delay time 4	0...3600000	ms	10	0	On delay time
On delay time 5	0...3600000	ms	10	0	On delay time
On delay time 6	0...3600000	ms	10	0	On delay time
On delay time 7	0...3600000	ms	10	0	On delay time
On delay time 8	0...3600000	ms	10	0	On delay time

3.17.5.5 Technical data

Table 165: TONGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

3.17.6 Set-reset (8 pcs) SRGAPC

3.17.6.1 Function block

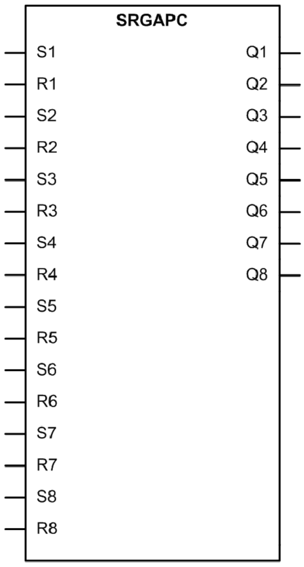


Figure 98: Function block

3.17.6.2 Functionality

The set-reset (8 pcs) function SRGAPC is a simple SR flip-flop with a memory that can be set or that can reset an output from the S# or R# inputs, respectively. The function contains eight independent set-reset flip-flop latches where the SET input has the higher priority over the RESET input. The status of each Q# output is retained in the nonvolatile memory. The individual reset for each Q# output is available on the LHMI or through tool via communication.

Table 166: Truth table for SRGAPC

S#	R#	Q#
0	0	0[1]
0	1	0
1	0	1
1	1	1

3.17.6.3 Signals

Table 167: SRGAPC Input signals

Name	Type	Default	Description
S1	BOOLEAN	0=False	Set Q1 output when set
R1	BOOLEAN	0=False	Resets Q1 output when set

Table continues on the next page

1 Keep state/no change

Name	Type	Default	Description
S2	BOOLEAN	0=False	Set Q2 output when set
R2	BOOLEAN	0=False	Resets Q2 output when set
S3	BOOLEAN	0=False	Set Q3 output when set
R3	BOOLEAN	0=False	Resets Q3 output when set
S4	BOOLEAN	0=False	Set Q4 output when set
R4	BOOLEAN	0=False	Resets Q4 output when set
S5	BOOLEAN	0=False	Set Q5 output when set
R5	BOOLEAN	0=False	Resets Q5 output when set
S6	BOOLEAN	0=False	Set Q6 output when set
R6	BOOLEAN	0=False	Resets Q6 output when set
S7	BOOLEAN	0=False	Set Q7 output when set
R7	BOOLEAN	0=False	Resets Q7 output when set
S8	BOOLEAN	0=False	Set Q8 output when set
R8	BOOLEAN	0=False	Resets Q8 output when set

Table 168: SRGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Q1 status
Q2	BOOLEAN	Q2 status
Q3	BOOLEAN	Q3 status
Q4	BOOLEAN	Q4 status
Q5	BOOLEAN	Q5 status
Q6	BOOLEAN	Q6 status
Q7	BOOLEAN	Q7 status
Q8	BOOLEAN	Q8 status

3.17.6.4 Settings

Table 169: SRGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset Q1	0=Cancel 1=Reset			0=Cancel	Resets Q1 output when set
Reset Q2	0=Cancel 1=Reset			0=Cancel	Resets Q2 output when set
Reset Q3	0=Cancel 1=Reset			0=Cancel	Resets Q3 output when set
Reset Q4	0=Cancel 1=Reset			0=Cancel	Resets Q4 output when set
Reset Q5	0=Cancel 1=Reset			0=Cancel	Resets Q5 output when set
Reset Q6	0=Cancel 1=Reset			0=Cancel	Resets Q6 output when set
Reset Q7	0=Cancel 1=Reset			0=Cancel	Resets Q7 output when set
Reset Q8	0=Cancel 1=Reset			0=Cancel	Resets Q8 output when set

3.17.7 Move (8 pcs) MVGAPC

3.17.7.1 Function block

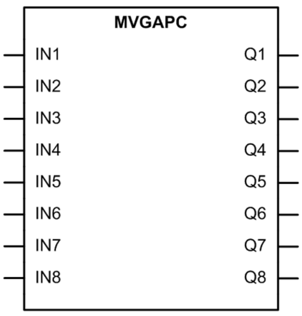


Figure 99: Function block

3.17.7.2 Functionality

The move (8 pcs) function MVGAPC is used for user logic bits. Each input state is directly copied to the output state. This allows the creating of events from advanced logic combinations.

MVGAPC can generate user defined events in LHMI when the output description setting is changed in **Configuration** > **Generic logic** > **MVGAPC1** > **Output x** > **Description**. MVGAPC can also be used to generate events for IEC 61850 client as well as Modbus, DNP3 and IEC 60870-5-103 procotols.

3.17.7.3 Signals

Table 170: MVGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	IN1 status
IN2	BOOLEAN	0=False	IN2 status
IN3	BOOLEAN	0=False	IN3 status
IN4	BOOLEAN	0=False	IN4 status
IN5	BOOLEAN	0=False	IN5 status
IN6	BOOLEAN	0=False	IN6 status
IN7	BOOLEAN	0=False	IN7 status
IN8	BOOLEAN	0=False	IN8 status

Table 171: MVGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Q1 status
Q2	BOOLEAN	Q2 status
Q3	BOOLEAN	Q3 status
Q4	BOOLEAN	Q4 status
Q5	BOOLEAN	Q5 status
Q6	BOOLEAN	Q6 status
Q7	BOOLEAN	Q7 status
Q8	BOOLEAN	Q8 status

3.17.7.4 Settings

Table 172: MVGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Description				MVGAPC1 Q1	Output description
Description				MVGAPC1 Q2	Output description
Description				MVGAPC1 Q3	Output description
Description				MVGAPC1 Q4	Output description
Description				MVGAPC1 Q5	Output description
Description				MVGAPC1 Q6	Output description
Description				MVGAPC1 Q7	Output description
Description				MVGAPC1 Q8	Output description

3.17.8 Integer value move MVI4GAPC

3.17.8.1 Function block

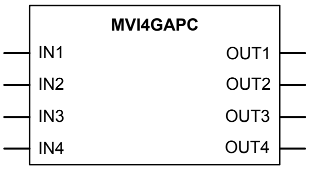


Figure 100: Function block

3.17.8.2 Functionality

The integer value move function MVI4GAPC is used for creation of the events from the integer values. The integer input value is received via `IN1...4` input. The integer output value is available on `OUT1...4` output.

The integer input range is from -2147483648 to 2147483647.

3.17.8.3 Signals

Table 173: MVI4GAPC Input signals

Name	Type	Default	Description
IN1	INT32	0	Integer input value 1
IN2	INT32	0	Integer input value 2
IN3	INT32	0	Integer input value 3
IN4	INT32	0	Integer input value 4

Table 174: MVI4GAPC Output signals

Name	Type	Description
OUT1	INT32	Integer output value 1
OUT2	INT32	Integer output value 2
OUT3	INT32	Integer output value 3
OUT4	INT32	Integer output value 4

3.17.9 Analog value scaling SCA4GAPC

3.17.9.1 Function block

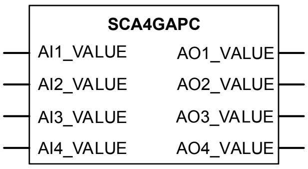


Figure 101: Function block

3.17.9.2 Functionality

The analog value scaling function SCA4GAPC is used for scaling the analog value. It allows creating events from analog values.

The analog value received via the `AIn_VALUE` input is scaled with the *Scale ratio n* setting. The scaled value is available on the `AOn_VALUE` output.

Analog input range is from –10000.0 to 10000.0.

Analog output range is from –2000000.0 to 2000000.0.

If the value of the `AIn_VALUE` input exceeds the analog input range, `AOn_VALUE` is set to 0.0.

If the result of `AIn_VALUE` multiplied by the Scale ratio n setting exceeds the analog output range, `AOn_VALUE` shows the minimum or maximum value, according to analog value range.

3.17.9.3 Signals

Table 175: SCA4GAPC Input signals

Name	Type	Default	Description
AI1_VALUE	FLOAT32	0.0	Analog input value of channel 1
AI2_VALUE	FLOAT32	0.0	Analog input value of channel 2
AI3_VALUE	FLOAT32	0.0	Analog input value of channel 3
AI4_VALUE	FLOAT32	0.0	Analog input value of channel 4

Table 176: SCA4GAPC Output signals

Name	Type	Description
AO1_VALUE	FLOAT32	Analog value 1 after scaling
AO2_VALUE	FLOAT32	Analog value 2 after scaling
AO3_VALUE	FLOAT32	Analog value 3 after scaling
AO4_VALUE	FLOAT32	Analog value 4 after scaling

3.17.9.4 Settings

Table 177: SCA4GAPC settings

Parameter	Values (Range)	Unit	Step	Default	Description
Scale ratio 1	0.001...1000.000		0.001	1.000	Scale ratio for analog value 1
Scale ratio 2	0.001...1000.000		0.001	1.000	Scale ratio for analog value 2
Scale ratio 3	0.001...1000.000		0.001	1.000	Scale ratio for analog value 3
Scale ratio 4	0.001...1000.000		0.001	1.000	Scale ratio for analog value 4

3.17.10 Local/remote control function block CONTROL

3.17.10.1 Function block

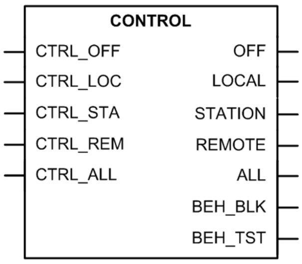


Figure 102: Function block

3.17.10.2 Functionality

Local/Remote control is by default realized through the R/L button on the front panel. The control via binary input can be enabled by setting the value of the *LR control* setting to "Binary input". The binary input control requires that the CONTROL function is instantiated in the product configuration.

Local/Remote control supports multilevel access for control operations in substations according to the IEC 61850 standard. Multilevel control access with separate station control access level is not supported by other protocols than IEC 61850.

The actual Local/Remote control state is evaluated by the priority scheme on the function block inputs. If more than one input is active, the input with the highest priority is selected.

The actual state is reflected on the CONTROL function outputs. Only one output is active at a time.

Table 178: Truth table for CONTROL

Input				Output
CTRL_OFF	**CTRL_LOC**	**CTRL_STA** [1]	**CTRL_REM**	
TRUE	any	any	any	OFF = TRUE
FALSE	TRUE	any	any	LOCAL = TRUE
FALSE	FALSE	TRUE	any	STATION = TRUE
FALSE	FALSE	FALSE	TRUE	REMOTE = TRUE
FALSE	FALSE	FALSE	FALSE	OFF = TRUE

The station authority check based on the IEC 61850 command originator category in control command can be enabled by setting the value of the *Station authority* setting to "Station, Remote" (The command originator validation is performed only if the *LR control* setting is set to "Binary input"). The station authority check is not in use by default.

[1] If station authority is not in use, the CTRL_STA input is interpreted as CTRL_REM.

3.17.10.3 L/R control access

Four different Local/Remote control access scenarios are possible depending on the selected station authority level: “L,R”, “L,R,L+R”, “L,S,R” and “L, S, S+R, L+S, L+S+R”. If control commands need to be allowed from multiple levels, multilevel access can be used. Multilevel access is possible only by using the station authority levels “L,R,L+R” and “L, S, S+R, L+S, L+S+R”. Multilevel access status is available from IEC 61850 data object CTRL.LLN0.MltLev.

Control access selection is made with R/L button or CONTROL function block and IEC 61850 data object CTRL.LLN0.LocSta. When writing CTRL.LLN0.LocSta IEC 61850 data object, IEC 61850 command originator category station must be used by the client, and remote IEC 61850 control access must be allowed by the relay station authority. CTRL.LLN0.LocSta data object value is retained in the nonvolatile memory. The present control status can be monitored in the HMI or PCM600 via **Monitoring** > **Control command** with the *LR state* parameter or from the IEC 61850 data object CTRL.LLN0. LocKeyHMI.

IEC 61850 command originator category is always set by the IEC 61850 client. The relay supports station and remote IEC 61850 command originator categories, depending on the selected station authority level.

3.17.10.4 Station authority level “L,R"

Relay's default station authority level is “L,R”. In this scenario only local or remote control access is allowed. Control access with IEC 61850 command originator category station is interpreted as remote access. There is no multilevel access.

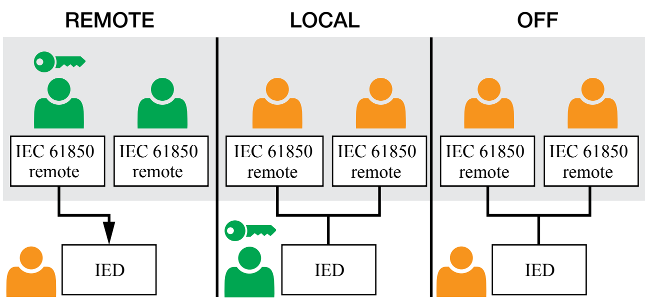


Figure 103: Station authority is “L,R”

When station authority level “L,R” is used, control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block inputs CTRL_STA and CTRL_ALL are not applicable for this station authority level.

Table 179: Station authority level “L,R” using R/L button

L/R control		L/R control status		Control access	
R/L button	CTRL.LLN0.LocSta	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKey HMI	Local user	IEC 61850 client [1]
Local	N/A	FALSE	1	x	
Remote	N/A	FALSE	2		x
Off	N/A	FALSE	0		

1 Client IEC 61850 command originator category check is not performed.

Table 180: Station authority "L,R" using CONTROL function block

L/R control		L/R control status		Control access	
Control FB input	CTRL.LLN0.LocSta	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKey HMI	Local user	IEC 61850 client [1]
CTRL_OFF	N/A	FALSE	0		
CTRL_LOC	N/A	FALSE	1	x	
CTRL_STA	N/A	FALSE	0		
CTRL_REM	N/A	FALSE	2		x
CTRL_ALL	N/A	FALSE	0		

3.17.10.5 Station authority level "L,R,L+R"

Station authority level "L,R, L+R" adds multilevel access support. Control access can also be simultaneously permitted from local or remote location. Simultaneous local or remote control operation is not allowed as one client and location at time can access controllable objects and they remain reserved until the previously started control operation is first completed by the client. Control access with IEC 61850 originator category station is interpreted as remote access.

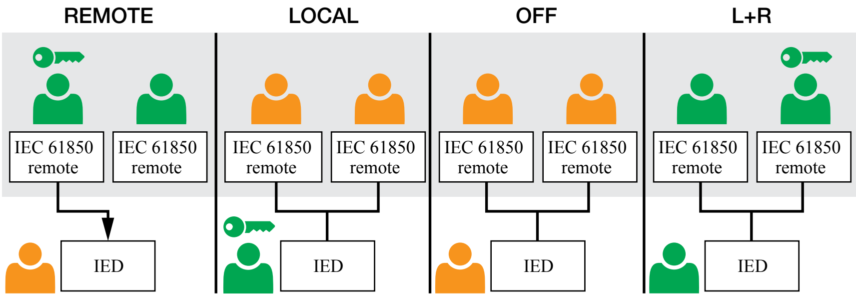


Figure 104: Station authority is "L,R,L+R"

When station authority level "L,R, L+R" is used, the control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block input `CTRL_STA` are not applicable for this station authority level.

Table 181: Station authority level "L,R,L+R" using R/L button

L/R Control		L/R Control status		Control access	
R/L button	CTRL.LLN0.LocSta	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKey HMI	Local user	IEC 61850 client[1]
Local	N/A	FALSE	1	x	
Remote	N/A	FALSE	2		x
Local + Remote	N/A	TRUE	4	x	x
Off	N/A	FALSE	0		

[1] Client IEC 61850 command originator category check is not performed.

Table 182: Station authority “L,R,L+R” using CONTROL function block

L/R Control		L/R Control status		Control access	
Control FB input	**CTRL.LLN0.LocSta**	**CTRL.LLN0.MltLev**	**L/R state CTRL.LLN0.LocKey HMI**	**Local user**	**IEC 61850 client[1]**
CTRL_OFF	N/A	FALSE	0		
CTRL_LOC	N/A	FALSE	1	x	
CTRL_STA	N/A	FALSE	0		
CTRL_REM	N/A	FALSE	2		x
CTRL_ALL	N/A	TRUE	4	x	x

3.17.10.6 Station authority level "L,S,R"

Station authority level "L,S,R" adds station control access. In this level IEC 61850 command originator category validation is performed to distinguish control commands with IEC 61850 command originator category set to “Remote” or “Station”. There is no multilevel access.

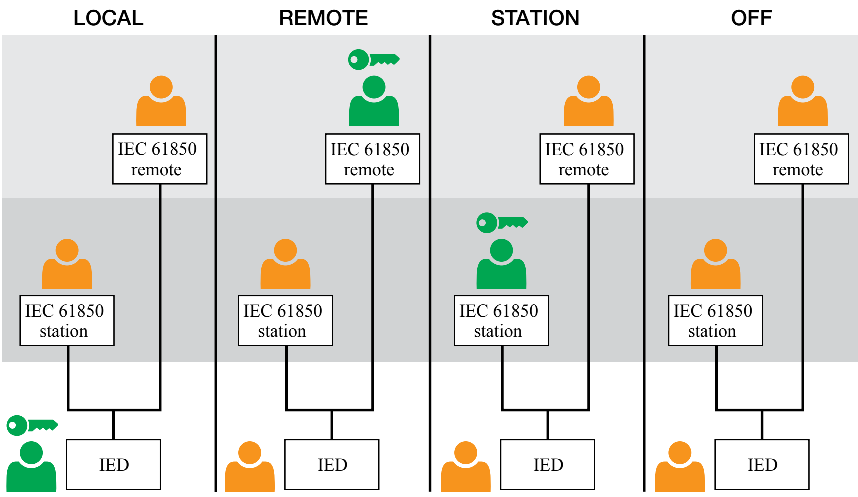


Figure 105: Station authority is "L,S,R"

When the station authority level “L,S,R” is used, the control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block input `CTRL_STA` are applicable for this station authority level.

Station control access can be reserved by using R/L button or CONTROL function block together with IEC 61850 data object CTRL.LLN0.LocSta.

Table 183: Station authority level "L,S,R" using R/L button

L/R Control		L/R Control status		Control access		
R/L button	CTRL.LLN0.LocSta[1]	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKeyHMI	Local user	IEC 61850 client[2]	IEC 61850 client[3]
Local	FALSE	FALSE	1	x		
Remote	FALSE	FALSE	2		x	
Remote	TRUE	FALSE	3			x
Off	FALSE	FALSE	0			

Table 184: Station authority level "L,S,R" using CONTROL function block

L/R Control		L/R Control status		Control access		
Control FB input	CTRL.LLN0.LocSta[1]	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKeyHMI	Local user	IEC 61850 client[2]	IEC 61850 client[3]
CTRL_OFF	FALSE	FALSE	0			
CTRL_LOC	FALSE	FALSE	1	x		
CTRL_STA	TRUE	FALSE	3			x
CTRL_REM [4]	TRUE	FALSE	3			x
CTRL_REM	FALSE	FALSE	2		x	
CTRL_ALL	FALSE	FALSE	0			

3.17.10.7 Station authority level "L,S,S+R,L+S,L+S+R"

Station authority level "L,S,S+R,L+S,L+S+R" adds station control access together with several different multilevel access scenarios. Control access can also be simultaneously permitted from local, station or remote location. Simultaneous local, station or remote control operation is not allowed as one client and location at time can access controllable objects and they remain reserved until the previously started control operation is first completed by the client.

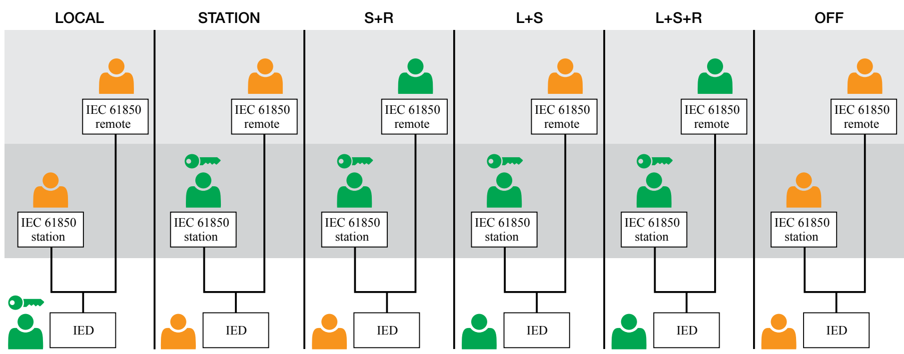


Figure 106: Station authority is "L,S,S+R,L+S,L+S+R"

When station authority level "L,S,S+R,L+S,L+S+R" is used, control access can be selected using R/L button or CONTROL function block. IEC 61850 data object

1 Station client reserves the control operating by writing controllable point LocSta.
2 Client IEC 61850 command originator category is remote.
3 Client IEC 61850 command originator category is station.
4 CTRL_STA unconnected in application configuration. Station client reserves the control operating by writing controllable point LocSta

CTRL.LLN0.LocSta and CONTROL function block input CTRL_STA are applicable for this station authority level.

“Station” and “Local + Station” control access can be reserved by using R/L button or CONTROL function block in combination with IEC 61850 data object CTRL.LLN0.LocSta.

Table 185: Station authority level “L,S,S+R,L+S,L+S+R” using R/L button

L/R Control		L/R Control status		Control access		
R/L button	CTRL.LLN0.LocSta[1]	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKeyHMI	Local user	IEC 61850 client[2]	IEC 61850 client[3]
Local	FALSE	FALSE	1	x		
Remote	FALSE	TRUE	7		x	x
Remote	TRUE	FALSE	3			x
Local + Remote	FALSE	TRUE	6	x	x	x
Local + Remote	TRUE	TRUE	5	x		x
Off	FALSE	FALSE	0			

Table 186: Station authority level “L,S,S+R,L+S,L+S+R” using CONTROL function block

L/R Control		L/R Control status		Control access		
Control FB input	CTRL.LLN0.LocSta[1]	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKeyHMI	Local user	IEC 61850 client[2]	IEC 61850 client[3]
CTRL_OFF	FALSE	FALSE	0			
CTRL_LOC	FALSE	FALSE	1	x		
CTRL_STA	FALSE	FALSE	3			x
CTRL_REM [4]	TRUE	TRUE	3			x
CTRL_REM	FALSE	TRUE	7		x	x
CTRL_ALL	FALSE	TRUE	6	x	x	x
CTRL_ALL [4]	TRUE	TRUE	5	x		x

3.17.10.8 Signals

Table 187: CONTROL Input signals

Name	Type	Default	Description
CTRL_OFF	BOOLEAN	0	Control input OFF
CTRL_LOC	BOOLEAN	0	Control input Local
CTRL_STA	BOOLEAN	0	Control input Station
CTRL_REM	BOOLEAN	0	Control input Remote
CTRL_ALL	BOOLEAN	0	Control input All

1 Station client reserves the control operating by writing controllable point LocSta.
2 Client IEC 61850 command originator category is remote.
3 Client IEC 61850 command originator category is station.
4 CTRL_STA unconnected in application configuration. Station client reserves the control operating by writing controllable point LocSta.

Table 188: CONTROL Output signals

Name	Type	Description
OFF	BOOLEAN	Control output OFF
LOCAL	BOOLEAN	Control output Local
STATION	BOOLEAN	Control output Station
REMOTE	BOOLEAN	Control output Remote
ALL	BOOLEAN	Control output All
BEH_BLK	BOOLEAN	Logical device CTRL block status
BEH_TST	BOOLEAN	Logical device CTRL test status

3.17.10.9 Settings

Table 189: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
LR control	1=LR key 2=Binary input			1=LR key	LR control through LR key or binary input
Station authority	1=L,R 2=L,S,R 3=L,R,L+R 4=L,S,S+R,L+S,L+S+R			1=L,R	Control command originator category usage
Control mode	1=On 2=Blocked 5=Off			1=On	Enabling and disabling control

3.17.10.10 Monitored data

Table 190: Monitored data

Name	Type	Values (Range)	Unit	Description
Command response	Enum	0=No commands 1=Select open 2=Select close 3=Operate open 4=Operate close 5=Direct open 6=Direct close 7=Cancel 8=Position reached 9=Position timeout 10=Object status only 11=Object direct		Latest command response

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		12=Object select 13=RL local allowed 14=RL remote allowed 15=RL off 16=Function off 17=Function blocked 18=Command progress 19=Select timeout 20=Missing authority 21=Close not enabled 22=Open not enabled 23=Internal fault 24=Already close 25=Wrong client 26=RL station allowed 27=RL change 28=Abortion by trip		
LR state	Enum	0=Off 1=Local 2=Remote 3=Station 4=L+R 5=L+S 6=L+S+R 7=S+R		LR state monitoring

3.17.11 Generic control point (16 pcs) SPCGAPC

3.17.11.1 Function block

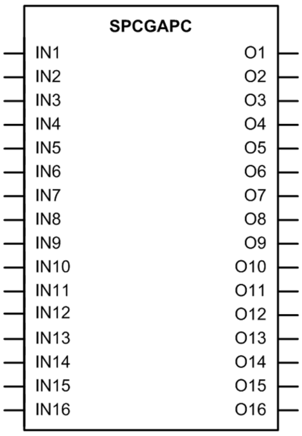


Figure 107: Function block

3.17.11.2 Functionality

The generic control point (16 pcs) function SPCGAPC can be used in combination with other function blocks such as FKEYGGIO. SPCGAPC offers the capability to activate its outputs through a local or remote control. The local control is provided through the buttons in the front panel and the remote control is provided through communications. SPCGAPC has two modes of operation. In the "Toggle" mode, the block toggles the output signal for every input pulse received. In the "Pulsed" mode, the block generates an output pulse of a preset duration.

For example, if the *Operation mode* is "Toggle", the output O# is initially “False”. The rising edge in IN# sets O# to “True”. The falling edge of IN# has no effect. Next rising edge of IN# sets O# to “False”.

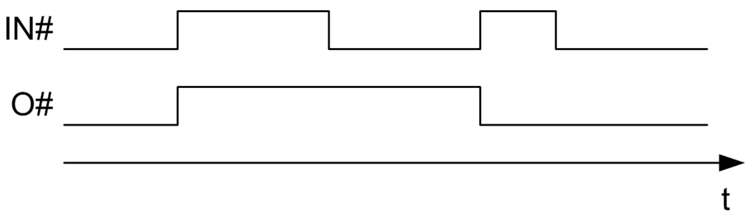


Figure 108: Operation in "Toggle" mode

From the remote communication point of view SPCGAPC toggled operation mode is always working as persistent mode. The output `O#` follows the value written to the input `IN#`.

3.17.11.3 Signals

Table 191: SPCGAPC Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
IN1	BOOLEAN	0=False	Input of control point 1
IN2	BOOLEAN	0=False	Input of control point 2
IN3	BOOLEAN	0=False	Input of control point 3
IN4	BOOLEAN	0=False	Input of control point 4
IN5	BOOLEAN	0=False	Input of control point 5
IN6	BOOLEAN	0=False	Input of control point 6
IN7	BOOLEAN	0=False	Input of control point 7
IN8	BOOLEAN	0=False	Input of control point 8
IN9	BOOLEAN	0=False	Input of control point 9
IN10	BOOLEAN	0=False	Input of control point 10
IN11	BOOLEAN	0=False	Input of control point 11
IN12	BOOLEAN	0=False	Input of control point 12
IN13	BOOLEAN	0=False	Input of control point 13
IN14	BOOLEAN	0=False	Input of control point 14
IN15	BOOLEAN	0=False	Input of control point 15
IN16	BOOLEAN	0=False	Input of control point 16

Table 192: SPCGAPC Output signals

Name	Type	Description
O1	BOOLEAN	Output 1 status
O2	BOOLEAN	Output 2 status
O3	BOOLEAN	Output 3 status
O4	BOOLEAN	Output 4 status
O5	BOOLEAN	Output 5 status

Table continues on the next page

Name	Type	Description
O6	BOOLEAN	Output 6 status
O7	BOOLEAN	Output 7 status
O8	BOOLEAN	Output 8 status
O9	BOOLEAN	Output 9 status
O10	BOOLEAN	Output 10 status
O11	BOOLEAN	Output 11 status
O12	BOOLEAN	Output 12 status
O13	BOOLEAN	Output 13 status
O14	BOOLEAN	Output 14 status
O15	BOOLEAN	Output 15 status
O16	BOOLEAN	Output 16 status

3.17.11.4 Settings

Table 193: SPCGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Loc Rem restriction	0=False 1=True			1=True	Local remote switch restriction
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 1	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 3	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 6	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 7	Generic control point description
Operation mode	0=Pulsed			-1=Off	Operation mode for generic control point

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=Toggle/Persistent -1=Off				
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 11	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 14	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 15	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 16	Generic control point description

3.17.12 Remote generic control points SPCRGAPC

3.17.12.1 Function block

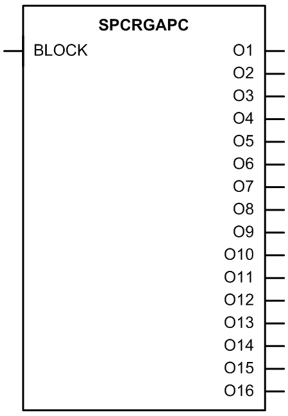


Figure 109: Function block

3.17.12.2 Functionality

The remote generic control points function SPCRGAPC is dedicated only for remote controlling, that is, SPCRGAPC cannot be controlled locally. The remote control is provided through communications.

3.17.12.3 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

SPCRGAPC has the *Operation mode*, *Pulse length* and *Description* settings available to control all 16 outputs. By default, the *Operation mode* setting is set to "Off". This disables the controllable signal output. SPCRGAPC also has a general setting *Loc Rem restriction*, which enables or disables the local or remote state functionality.

When the *Operation mode* is set to "Toggle", the corresponding output toggles between "True" and "False" for every input pulse received. The state of the output is stored in a nonvolatile memory and restored if the protection relay is restarted.

When the *Operation mode* is set to "Pulsed", the corresponding output can be used to produce the predefined length of pulses. Once activated, the output remains active for the duration of the set pulse length. When activated, the additional activation command does not extend the length of pulse. Thus, the pulse needs to be ended before the new activation can occur.

The *Description* setting can be used for storing signal names for each output.

Each control point or SPCRGAPC can only be accessed remotely through communication. SPCRGAPC follows the local or remote (L/R) state if the setting *Loc Rem restriction* is "true". If the *Loc Rem restriction* setting is "false", local or remote (L/R) state is ignored, that is, all controls are allowed regardless of the local or remote state.

The BLOCK input can be used for blocking the output functionality. The BLOCK input operation depends on the *Operation mode* setting. If the *Operation mode* setting is set to "Toggle", the output state cannot be changed when the input BLOCK is TRUE. If the *Operation mode* setting is set to "Pulsed", the activation of the BLOCK input resets the output to the FALSE state.

3.17.12.4 Signals

Table 194: SPCRGAPC Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 195: SPCRGAPC Output signals

Name	Type	Description
O1	BOOLEAN	Output 1 status
O2	BOOLEAN	Output 2 status
O3	BOOLEAN	Output 3 status
O4	BOOLEAN	Output 4 status
O5	BOOLEAN	Output 5 status
O6	BOOLEAN	Output 6 status
O7	BOOLEAN	Output 7 status
O8	BOOLEAN	Output 8 status
O9	BOOLEAN	Output 9 status
O10	BOOLEAN	Output 10 status
O11	BOOLEAN	Output 11 status
O12	BOOLEAN	Output 12 status
O13	BOOLEAN	Output 13 status
O14	BOOLEAN	Output 14 status
O15	BOOLEAN	Output 15 status
O16	BOOLEAN	Output 16 status

3.17.12.5 Settings

Table 196: SPCRGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Loc Rem restriction	0=False 1=True			1=True	Local remote switch restriction
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 1	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 3	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 6	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 7	Generic control point description
Operation mode	0=Pulsed			-1=Off	Operation mode for generic control point

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=Toggle/Persistent -1=Off				
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 11	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 14	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Description				SPCRGAPC1 Output 15	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGAPC1 Output 16	Generic control point description

3.17.13 Local generic control points SPCLGAPC

3.17.13.1 Function block

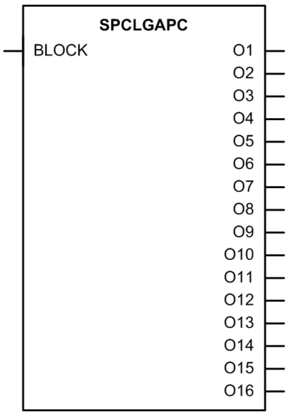


Figure 110: Function block

3.17.13.2 Functionality

The local generic control points function SPCLGAPC is dedicated only for local controlling, that is, SPCLGAPC cannot be controlled remotely. The local control is done through the buttons in the front panel.

3.17.13.3 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

SPCLGAPC has the *Operation mode*, *Pulse length* and *Description* settings available to control all 16 outputs. By default, the *Operation mode* setting is set to "Off". This disables the controllable signal output. SPCLGAPC also has a general setting *Loc Rem restriction*, which enables or disables the local or remote state functionality.

When the *Operation mode* is set to "Toggle", the corresponding output toggles between "True" and "False" for every input pulse received. The state of the output is stored in a nonvolatile memory and restored if the protection relay is restarted.

When the *Operation mode* is set to "Pulsed", the corresponding output can be used to produce the predefined length of pulses. Once activated, the output remains active for the duration of the set pulse length. When activated, the additional activation command does not extend the length of pulse. Thus, the pulse needs to be ended before the new activation can occur.

The *Description* setting can be used for storing signal names for each output.

Each control point or SPCLGAPC can only be accessed through the LHMI control. SPCLGAPC follows the local or remote (L/R) state if the *Loc Rem restriction* setting is "true". If the *Loc Rem restriction* setting is "false", local or remote (L/R) state is ignored, that is, all controls are allowed regardless of the local or remote state.

The BLOCK input can be used for blocking the output functionality. The BLOCK input operation depends on the *Operation mode* setting. If the *Operation mode* setting is set to "Toggle", the output state cannot be changed when the input BLOCK is TRUE. If the *Operation mode* setting is set to "Pulsed", the activation of the BLOCK input resets the output to the FALSE state.

3.17.13.4 Signals

Table 197: SPCLGAPC Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 198: SPCLGAPC Output signals

Name	Type	Description
O1	BOOLEAN	Output 1 status
O2	BOOLEAN	Output 2 status
O3	BOOLEAN	Output 3 status
O4	BOOLEAN	Output 4 status
O5	BOOLEAN	Output 5 status
O6	BOOLEAN	Output 6 status
O7	BOOLEAN	Output 7 status
O8	BOOLEAN	Output 8 status
O9	BOOLEAN	Output 9 status
O10	BOOLEAN	Output 10 status
O11	BOOLEAN	Output 11 status
O12	BOOLEAN	Output 12 status
O13	BOOLEAN	Output 13 status
O14	BOOLEAN	Output 14 status
O15	BOOLEAN	Output 15 status
O16	BOOLEAN	Output 16 status

3.17.13.5 Settings

Table 199: SPCLGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Loc Rem restriction	0=False 1=True			1=True	Local remote switch restriction
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 1	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 3	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 6	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 7	Generic control point description
Operation mode	0=Pulsed			-1=Off	Operation mode for generic control point

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=Toggle/Persistent -1=Off				
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 11	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 14	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Description				SPCLGAPC1 Output 15	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGAPC1 Output 16	Generic control point description

3.17.14 Programmable buttons FKEYGGIO

3.17.14.1 Function block

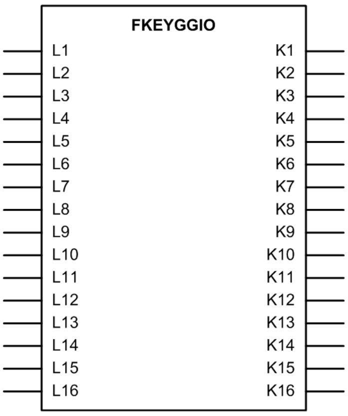


Figure 111: Function block

3.17.14.2 Functionality

The programmable buttons function FKEYGGIO is a simple interface between the panel and the application. The user input from the buttons available on the front panel is transferred to the assigned functionality and the corresponding LED is ON or OFF for indication. The behavior of each function key in the specific application is configured by connection with other application functions. This gives the maximum flexibility.

3.17.14.3 Operation principle

Inputs `L1..L16` represent the LEDs on the protection relay's LHMI. When an input is set to TRUE, the corresponding LED is lit. When a function key on LHMI is pressed, the corresponding output `K1..K16` is set to TRUE.

3.17.14.4 Signals

Table 200: FKEYGGIO Input signals

Name	Type	Default	Description
L1	BOOLEAN	0=False	LED 1
L2	BOOLEAN	0=False	LED 2
L3	BOOLEAN	0=False	LED 3
L4	BOOLEAN	0=False	LED 4
L5	BOOLEAN	0=False	LED 5
L6	BOOLEAN	0=False	LED 6
L7	BOOLEAN	0=False	LED 7
L8	BOOLEAN	0=False	LED 8
L9	BOOLEAN	0=False	LED 9
L10	BOOLEAN	0=False	LED 10
L11	BOOLEAN	0=False	LED 11
L12	BOOLEAN	0=False	LED 12
L13	BOOLEAN	0=False	LED 13
L14	BOOLEAN	0=False	LED 14
L15	BOOLEAN	0=False	LED 15
L16	BOOLEAN	0=False	LED 16

Table 201: FKEYGGIO Output signals

Name	Type	Description
K1	BOOLEAN	KEY 1
K2	BOOLEAN	KEY 2
K3	BOOLEAN	KEY 3
K4	BOOLEAN	KEY 4
K5	BOOLEAN	KEY 5
K6	BOOLEAN	KEY 6
K7	BOOLEAN	KEY 7
K8	BOOLEAN	KEY 8
K9	BOOLEAN	KEY 9
K10	BOOLEAN	KEY 10
K11	BOOLEAN	KEY 11
K12	BOOLEAN	KEY 12
K13	BOOLEAN	KEY 13
K14	BOOLEAN	KEY 14
K15	BOOLEAN	KEY 15
K16	BOOLEAN	KEY 16

3.17.15 Generic up-down counter UDFCNT

3.17.15.1 Function block

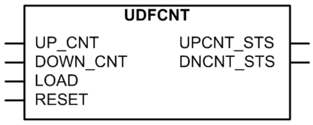


Figure 112: Function block

3.17.15.2 Functionality

The generic up-down counter function UDFCNT counts up or down for each positive edge of the corresponding inputs. The counter value output can be reset to zero or preset to some other value if required.

The function provides up-count and down-count status outputs, which specify the relation of the counter value to a loaded preset value and to zero respectively.

3.17.15.3 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of UDFCNT can be described with a module diagram. All the modules in the diagram are explained in the next sections.

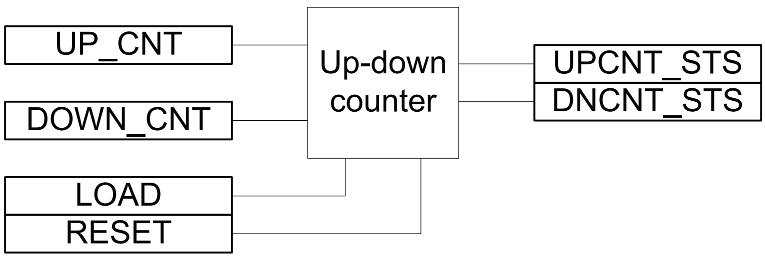


Figure 113: Functional module diagram

Up-down counter

Each rising edge of the `UP_CNT` input increments the counter value `CNT_VAL` by one and each rising edge of the `DOWN_CNT` input decrements the `CNT_VAL` by one. If there is a rising edge at both the inputs `UP_CNT` and `DOWN_CNT`, the counter value `CNT_VAL` is unchanged. The `CNT_VAL` is available in the monitored data view.

The counter value `CNT_VAL` is stored in a nonvolatile memory. The range of the counter is 0...+2147483647. The count of `CNT_VAL` saturates at the final value of 2147483647, that is, no further increment is possible.

The value of the setting *Counter load value* is loaded into counter value `CNT_VAL` either when the `LOAD` input is set to "True" or when the *Load Counter* is set to "Load" in the LHMI. Until the `LOAD` input is "True", it prevents all further counting.

The function also provides status outputs UPCNT_STS and DNCNT_STS. The UPCNT_STS is set to "True" when the CNT_VAL is greater than or equal to the setting *Counter load value*. DNCNT_STS is set to "True" when the CNT_VAL is zero.

The RESET input is used for resetting the function. When this input is set to "True" or when *Reset counter* is set to "reset", the CNT_VAL is forced to zero.

3.17.15.4 Application

When UDFCNT is connected to a relay binary input, two settings of binary input need to be checked to ensure the counter is working correctly.

- *Input # filter time*. All pulses that are shorter than the filter time are not detected.
- *Binary input oscillation suppression threshold*. The binary input is blocked if the number of valid state changes during one second is equal to or greater than the set oscillation level value.

With the correct settings, UDFCNT can record correctly up to 20 pulses per second.

For example, to constantly record 20 pulses per second from slot X110 binary input 1, when the pulse length is 25 ms pulse high and 25 ms pulse low time, the following settings are recommended.

- *Input 1 filter time* is set to “5...15 ms” via **Configuration** > **I/O modules** > **X110(BIO)** > **Input filtering**
- *Input osc. level* is set to “45...50 events/s” via **Configuration** > **I/O modules** > **Common settings**
- *Input osc. hyst* is set to “2 events/s” via **Configuration** > **I/O modules** > **Common settings**

3.17.15.5 Signals

Table 202: UDFCNT Input signals

Name	Type	Default	Description
UP_CNT	BOOLEAN	0=False	Input for up counting
DOWN_CNT	BOOLEAN	0=False	Input for down counting
RESET	BOOLEAN	0=False	Reset input for counter
LOAD	BOOLEAN	0=False	Load input for counter

Table 203: UDFCNT Output signals

Name	Type	Description
UPCNT_STS	BOOLEAN	Status of the up counting
DNCNT_STS	BOOLEAN	Status of the down counting

3.17.15.6 Settings

Table 204: UDFCNT Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Counter load value	0...2147483647		1	10000	Preset counter value
Reset counter	0=Cancel 1=Reset			0=Cancel	Resets counter value
Load counter	0=Cancel 1=Load			0=Cancel	Loads the counter to preset value

3.17.15.7 Monitored data

Table 205: UDFCNT Monitored data

Name	Type	Values (Range)	Unit	Description
CNT_VAL	INT64	0...2147483647		Output counter value

3.18 Factory settings restoration

In case of configuration data loss or any other file system error that prevents the protection relay from working properly, the whole file system can be restored to the original factory state. All default settings and configuration files stored in the factory are restored. For further information on restoring factory settings, see the operation manual.

3.19 Load profile record LDPRLRC

3.19.1 Function block

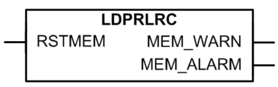


Figure 114: Function block

3.19.2 Functionality

The protection relay is provided with a load profile recorder. The load profile feature stores the historical load data captured at a periodical time interval (demand interval). Up to 12 load quantities can be selected for recording and storing in a nonvolatile memory. The value range for the recorded load quantities is about eight times the nominal value, and values larger than that saturate. The recording time depends on a settable demand interval parameter and the amount of quantities selected. The record output is in the COMTRADE format.

3.19.2.1 Quantities

Selectable quantities are product-dependent.

Table 206: Quantity Description

Quantity Sel x	Description
Disabled	Quantity not selected
IL1	Phase 1 current
IL2	Phase 2 current
IL3	Phase 3 current
Io	Neutral/earth/residual current
IL1B	Phase 1 current, B side
IL2B	Phase 2 current, B side
IL3B	Phase 3 current, B side
IoB	Neutral/earth/residual current, B side
U12	Phase-to-phase 12 voltage
U23	Phase-to-phase 23 voltage
U31	Phase-to-phase 31 voltage
UL1	Phase-to-earth 1 voltage
UL2	Phase-to-earth 2 voltage
UL3	Phase-to-earth 3 voltage
UL1B	Phase-to-earth 1 voltage, B side
UL2B	Phase-to-earth 2 voltage, B side
UL3B	Phase-to-earth 3 voltage, B side
S	Apparent power
P	Real power
Q	Reactive power
PF	Power factor

If the data source for the selected quantity is removed, for example, with Application Configuration in PCM600, the load profile recorder stops recording it and the previously collected data are cleared.

3.19.2.2 Length of record

The recording capability is about 7.4 years when one quantity is recorded and the demand interval is set to 180 minutes. The recording time scales down proportionally when a shorter demand time is selected or more quantities are recorded. The recording lengths in days with different settings used are presented in *Table 207*. When the recording buffer is fully occupied, the oldest data are overwritten by the newest data.

Table 207: Recording capability in days with different settings

	Demand interval						
	1 minute	5 minutes	10 minutes	15 minutes	30 minutes	60 minutes	180 minutes
Amount of quantities	**Recording capability in days**						
1	15.2	75.8	151.6	227.4	454.9	909.7	2729.2
2	11.4	56.9	113.7	170.6	341.1	682.3	2046.9
3	9.1	45.5	91.0	136.5	272.9	545.8	1637.5
4	7.6	37.9	75.8	113.7	227.4	454.9	1364.6
5	6.5	32.5	65.0	97.5	194.9	389.9	1169.6
6	5.7	28.4	56.9	85.3	170.6	341.1	1023.4
7	5.1	25.3	50.5	75.8	151.6	303.2	909.7
8	4.5	22.7	45.5	68.2	136.5	272.9	818.8
9	4.1	20.7	41.4	62.0	124.1	248.1	744.3
10	3.8	19.0	37.9	56.9	113.7	227.4	682.3
11	3.5	17.5	35.0	52.5	105.0	209.9	629.8
12	3.2	16.2	32.5	48.7	97.5	194.9	584.8

3.19.2.3 Uploading of record

The protection relay stores the load profile COMTRADE files to the C:\LDP\COMTRADE folder. The files can be uploaded with the PCM600 tool or any appropriate computer software that can access the C:\LDP\COMTRADE folder.

The load profile record consists of two COMTRADE file types: the configuration file (.CFG) and the data file (.DAT). The file name is same for both file types.

To ensure that both the uploaded file types are generated from the same data content, the files need to be uploaded successively. Once either of the files is uploaded, the recording buffer is halted to give time to upload the other file.

Data content of the load profile record is sequentially updated. Therefore, the size attribute for both COMTRADE files is "0".

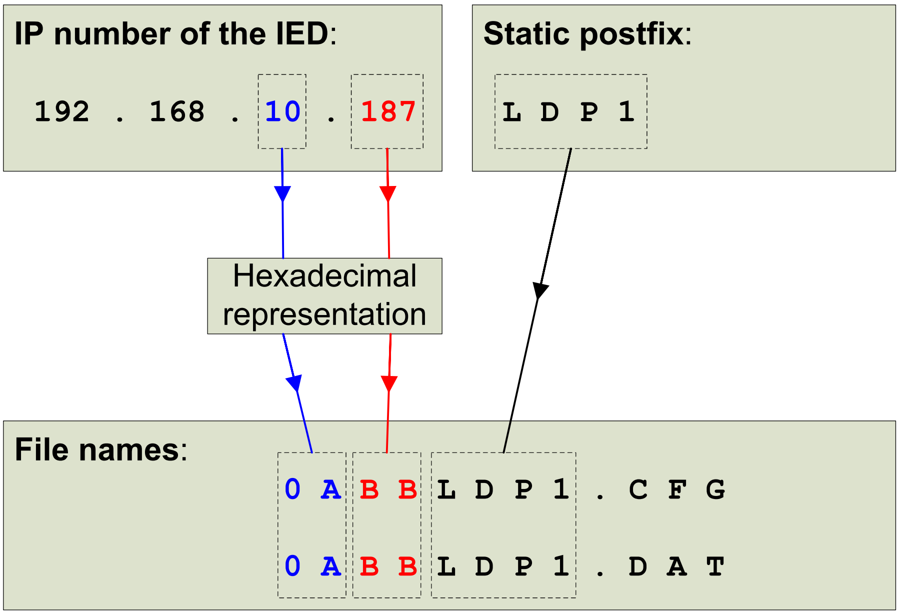


Figure 115: Load profile record file naming

3.19.2.4 Clearing of record

The load profile record can be cleared with *Reset load profile rec* via HMI, communication or the ACT input in PCM600. Clearing of the record is allowed only on the engineer and administrator authorization levels.

The load profile record is automatically cleared if the quantity selection parameters are changed or any other parameter which affects the content of the COMTRADE configuration file is changed. Also, if data source for selected quantity is removed, for example, with ACT, the load profile recorder stops recording and previously collected data are cleared.

3.19.3 Configuration

The load profile record can be configured with the PCM600 tool or any tool supporting the IEC 61850 standard.

The load profile record can be enabled or disabled with the *Operation* setting under the **Configuration/Load Profile Record** menu.

Each protection relay can be mapped to each of the quantity channels of the load profile record. The mapping is done with the *Quantity selection* setting of the corresponding quantity channel.

The IP number of the protection relay and the content of the *Bay name* setting are both included in the COMTRADE configuration file for identification purposes.

The memory consumption of load profile record is supervised, and indicated with two signals MEM_WARN and MEM_ALARM, which could be used to notify the customer that recording should be backlogged by reading the recorded data from the protection relay. The levels for MEM_WARN and MEM_ALARM are set by two parameters *Mem.warn level* and *Mem. Alarm level*.

3.19.4 Signals

Table 208: LDPRLRC Output signals

Name	Type	Description
MEM_WARN	BOOLEAN	Recording memory warning status
MEM_ALARM	BOOLEAN	Recording memory alarm status

3.19.5 Settings

Table 209: LDPRLRC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Quantity Sel 1	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 2	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 3	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 4	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Quantity Sel 5	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 6	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 7	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 8	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 9	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 10	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 11	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B 51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Quantity Sel 12	0=Disabled			0=Disabled	Select quantity to be recorded

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=IL1 2=IL2 3=IL3 4=Io 5=IL1B 6=IL2B 7=IL3B 8=IoB 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF 25=SB 26=PB 27=QB 28=PFB 29=SL1 30=SL2 31=SL3 32=PL1 33=PL2 34=PL3 35=QL1 36=QL2 37=QL3 38=PFL1 39=PFL2 40=PFL3 41=SL1B 42=SL2B 43=SL3B 44=PL1B 45=PL2B 46=PL3B 47=QL1B 48=QL2B 49=QL3B 50=PFL1B				

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	51=PFL2B 52=PFL3B 53=IL1C 54=IL2C 55=IL3C				
Mem. warning level	0...100	%	1	0	Set memory warning level
Mem. alarm level	0...100	%	1	0	Set memory alarm level

3.19.6 Monitored data

Table 210: LDPRLRC Monitored data

Name	Type	Values (Range)	Unit	Description
Rec. memory used	INT32	0...100	%	How much recording memory is currently used

3.20 ETHERNET channel supervision function blocks

3.20.1 Redundant Ethernet channel supervision RCHLCCH

3.20.1.1 Function block

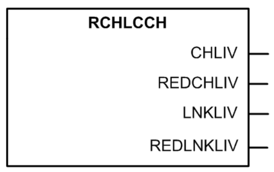


Figure 116: Function block

3.20.1.2 Functionality

Redundant Ethernet channel supervision RCHLCCH represents LAN A and LAN B redundant Ethernet channels.

3.20.1.3 Signals

Table 211: RCHLCCH output signals

Parameter	Values (Range)	Unit	Step	Default	Description
CHLIV	True False				Status of redundant Ethernet channel LAN A. When *Redundant mode* is set to "HSR" or "PRP", value is "True" if the protection relay is receiving redundancy supervision frames. Otherwise value is "False".
REDCHLIV	True False				Status of redundant Ethernet channel LAN B. When *Redundant mode* is set to "HSR" or "PRP", value is "True" if the protection relay is receiving redundancy supervision frames. Otherwise value is "False".
LNKLIV	Up Down				Link status of redundant port LAN A. Valid only when *Redundant mode* is set to "HSR" or "PRP".
REDLNKLIV	Up Down				Link status of redundant port LAN B. Valid only when *Redundant mode* is set to "HSR" or "PRP".

3.20.1.4 Settings

Table 212: Redundancy settings

Parameter	Values (Range)	Unit	Step	Default	Description
Redundant mode	None PRP HSR			None	Mode selection for Ethernet switch on redundant communication modules. The "None" mode is used with normal and Self-healing Ethernet topologies.

3.20.1.5 Monitored data

Monitored data is available in four locations.

- **Monitoring** > **Communication** > **Ethernet** > **Activity** > **CHLIV_A**
- **Monitoring** > **Communication/** > **Ethernet** > **Activity** > **REDCHLIV_B**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **LNKLIV_A**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **REDLNKLIV_B**

3.20.2 Ethernet channel supervision SCHLCCH

3.20.2.1 Function block

Figure 117: Function block

3.20.2.2 Functionality

Ethernet channel supervision SCHLCCH represents X1/LAN, X2/LAN and X3/LAN Ethernet channels.

An unused Ethernet port can be set "Off" with the setting **Configuration** > **Communication** > **Ethernet** > **Rear port(s)** > **Port x Mode**. This setting closes the port from software, disabling the Ethernet communication in that port. Closing an unused Ethernet port enhances the cyber security of the relay.

3.20.2.3 Signals

Table 213: SCHLCCH1 output signals

Parameter	Values (Range)	Unit	Step	Default	Description
CH1LIV	True False				Status of Ethernet channel X1/LAN. Value is "True" if the port is receiving Ethernet frames. Valid only when *Redundant mode* is set to "None" or port is not one of the redundant ports (LAN A or LAN B).
LNK1LIV	Up Down				Link status of Ethernet port X1/LAN.

Table 214: SCHLCCH2 output signals

Parameter	Values (Range)	Unit	Step	Default	Description
CH2LIV	True False				Status of Ethernet channel X2/LAN. Value is "True" if the port is receiving Ethernet frames. Valid only when *Redundant mode* is set to "None" or port is not one of the redundant ports (LAN A or LAN B).
LNK2LIV	Up Down				Link status of Ethernet port X2/LAN.

Table 215: SCHLCCH3 output signals

Parameter	Values (Range)	Unit	Step	Default	Description
CH3LIV	True False				Status of Ethernet channel X3/LAN. Value is "True" if the port is receiving Ethernet frames. Valid only when *Redundant mode* is set to "None" or port is not one of the redundant ports (LAN A or LAN B).
LNK3LIV	Up Down				Link status of Ethernet port X3/LAN.

3.20.2.4 Settings

Table 216: Port mode settings

Parameter	Values (Range)	Unit	Step	Default	Description
Port 1 Mode	Off On			On	Mode selection for rear port(s). If port is not used, it can be set to “Off”. Port cannot be set to “Off” when *Redundant mode* is “HSR” or “PRP” and port is one of the redundant ports (LAN A or LAN B) or when port is used for line differential communication.
Port 2 Mode	Off On			On	Mode selection for rear port(s). If port is not used, it can be set to “Off”. Port cannot be set to “Off” when *Redundant mode* is “HSR” or “PRP” and port is one of the redundant ports (LAN A or LAN B).
Port 3 Mode	Off On			On	Mode selection for rear port(s). If port is not used, it can be set to “Off”. Port cannot be set to “Off” when *Redundant mode* is “HSR” or “PRP” and port is one of the redundant ports (LAN A or LAN B).

3.20.2.5 Monitored data

Monitored data is available in six locations.

- **Monitoring** > **Communication** > **Ethernet** > **Activity** > **CH1LIV**
- **Monitoring** > **Communication** > **Ethernet** > **Activity** > **CH2LIV**
- **Monitoring/** > **Communication** > **Ethernet** > **Activity** > **CH3LIV**
- **Monitoring/** > **Communication** > **Ethernet** > **Link statuses** > **LNK1LIV**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **LNK2LIV**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **LNK3LIV**

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

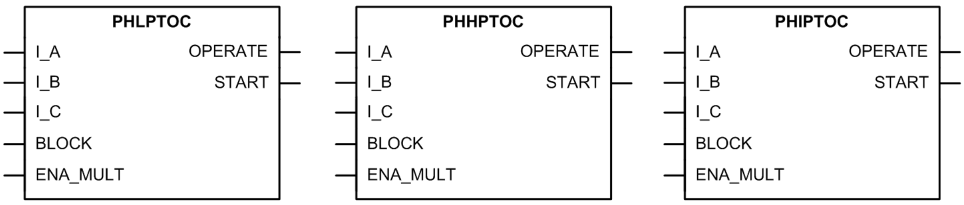


Figure 118: Function block

4.1.1.3 Functionality

The three-phase non-directional overcurrent protection function PHxPTOC is used as one-phase, two-phase or three-phase non-directional overcurrent and short-circuit protection.

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 PHxPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

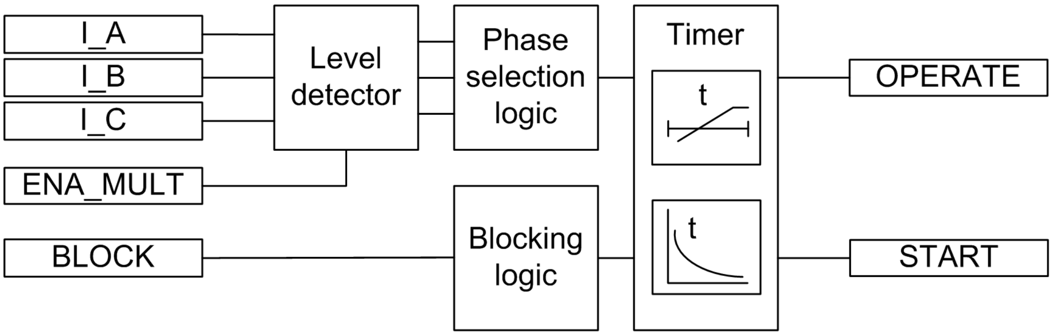


Figure 119: Functional module diagram

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.

The protection relay does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the `ENA_MULT` input.

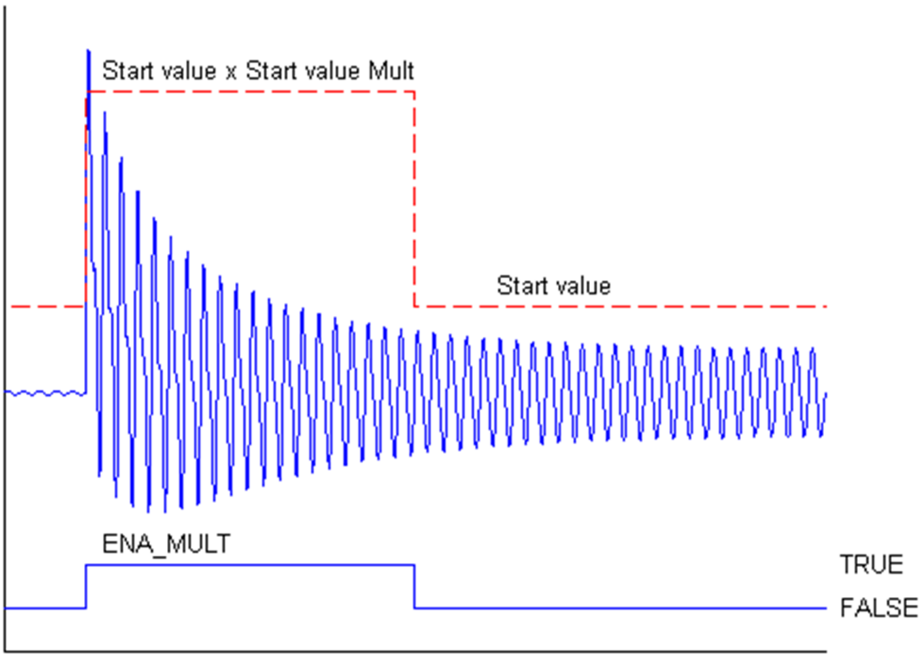


Figure 120: Start value behavior with ENA_MULT input activated

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. 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 *Chapter 11.2.1 IDMT curves for overcurrent protection* 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.1.1.5 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 217: Measurement modes supported by PHxPTOC stages

Measurement mode	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 *Chapter 11.5 Measurement modes* in this manual.

4.1.1.6 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 protection relay 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 DT characteristics can be chosen by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The timer characteristics supported by different stages comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages:

Table 218: Timer characteristics supported by different stages

Operating curve type	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
(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 *Chapter 11 General function block features* in this manual.

Table 219: Reset time characteristics supported by different stages

Reset curve type	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.

4.1.1.7 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 overcurrent protection

The purpose of transformer overcurrent protection is to operate as main protection, when differential protection is not used. It can also be used as coarse back-up protection for differential protection in faults inside the zone of protection, that is, faults occurring in incoming or outgoing feeders, in the region of transformer terminals and tank cover. This means that the magnitude range of the fault current can be very wide. The range varies from $6xI_n$ to several hundred times I_n, depending on the impedance of the transformer and the source impedance of the feeding network. From this point of view, it is clear that the operation must be both very fast and selective, which is usually achieved by using coarse current settings.

The purpose is also to protect the transformer from short circuits occurring outside the protection zone, that is through-faults. Transformer overcurrent protection also provides protection for the LV-side busbars. In this case the magnitude of the fault current is typically lower than 12xI_n depending on the fault location and transformer impedance. Consequently, the protection must operate as fast as possible taking into account the selectivity requirements, switching-in currents, and the thermal and mechanical withstand of the transformer and outgoing feeders.

Traditionally, overcurrent protection of the transformer has been arranged as shown in *Figure 121*. The low-set stage PHLPTOC operates time-selectively both in transformer and LV-side busbar faults. The high-set stage PHHPTOC operates instantaneously making use of current selectivity only in transformer HV-side faults. If there is a possibility, that the fault current can also be fed from the LV-side up to the HV-side, the transformer must also be equipped with LV-side overcurrent protection. Inrush current detectors are used in start-up situations to multiply the current start value setting in each particular protection relay where the inrush current can occur. The overcurrent and contact based circuit breaker failure protection CCBRBRF is used to confirm the protection scheme in case of circuit breaker malfunction.

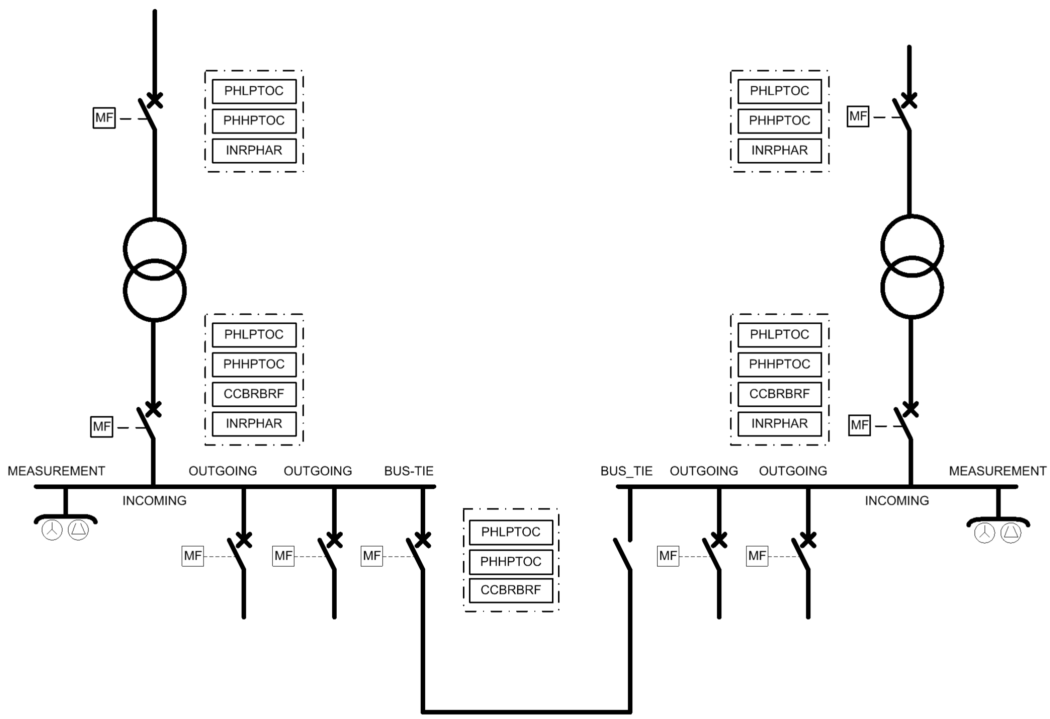


Figure 121: Example of traditional time selective transformer overcurrent protection

The operating times of the main and backup overcurrent protection of the above scheme become quite long, this applies especially in the busbar faults and also in the transformer LV-terminal faults. In order to improve the performance of the above scheme, a multiple-stage overcurrent protection with reverse blocking is proposed. *Figure 122* shows this arrangement.

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 122* 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 220: 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.

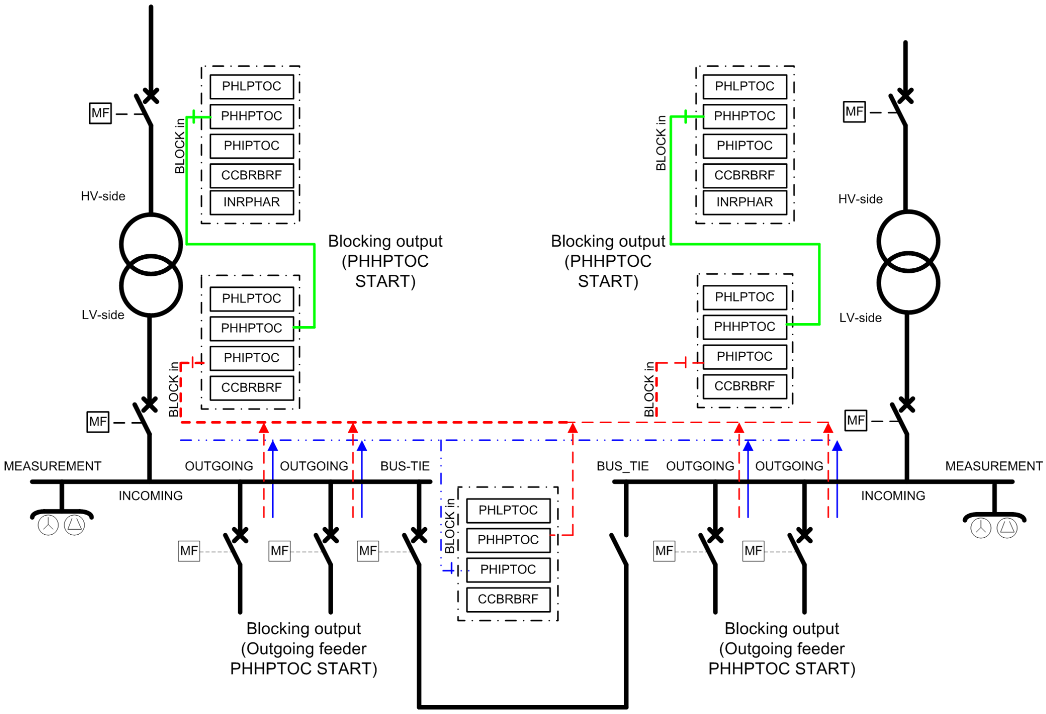


Figure 122: Numerical overcurrent protection functionality for a typical sub-transmission/distribution substation (feeder protection not shown). Blocking output = digital output signal from the start of a protection stage, Blocking in = digital input signal to block the operation of a protection stage

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 very low. Also, the effects of switching inrush currents on the setting values can be reduced by using the protection relay's 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 *Chapter 11.5 Measurement modes* 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 123* 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. In this way the start value is multiplied with a predefined setting during the inrush situation and nuisance tripping can be avoided.

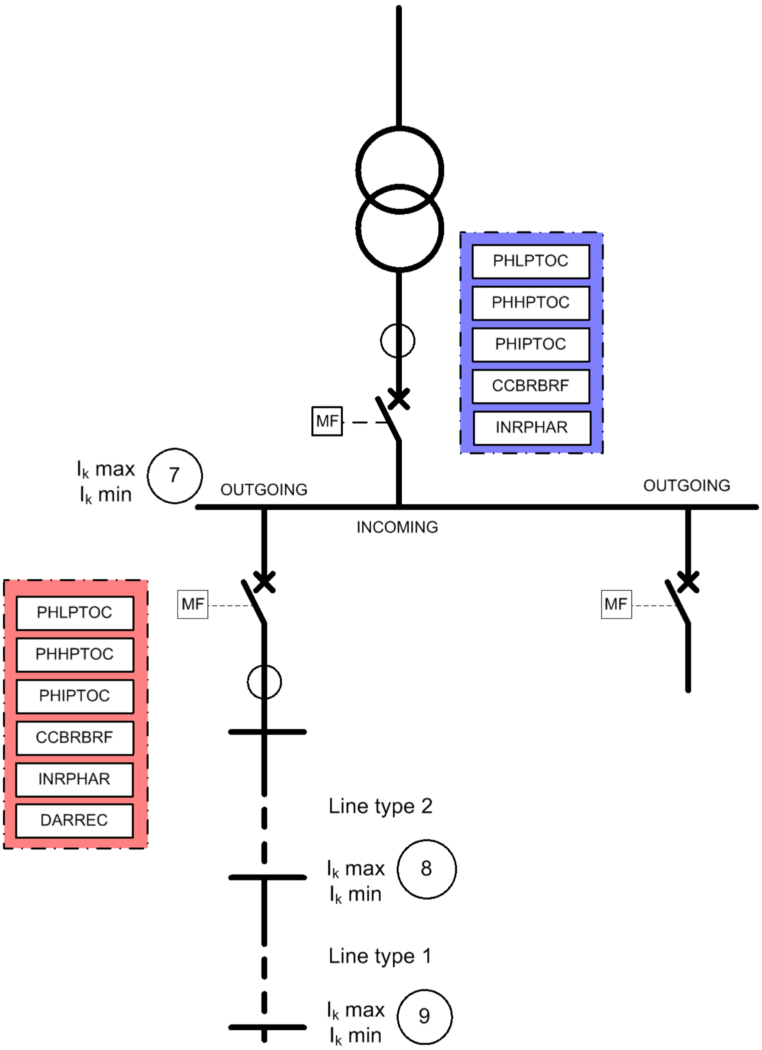


Figure 123: Functionality of numerical multiple-stage overcurrent protection

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 124*, the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

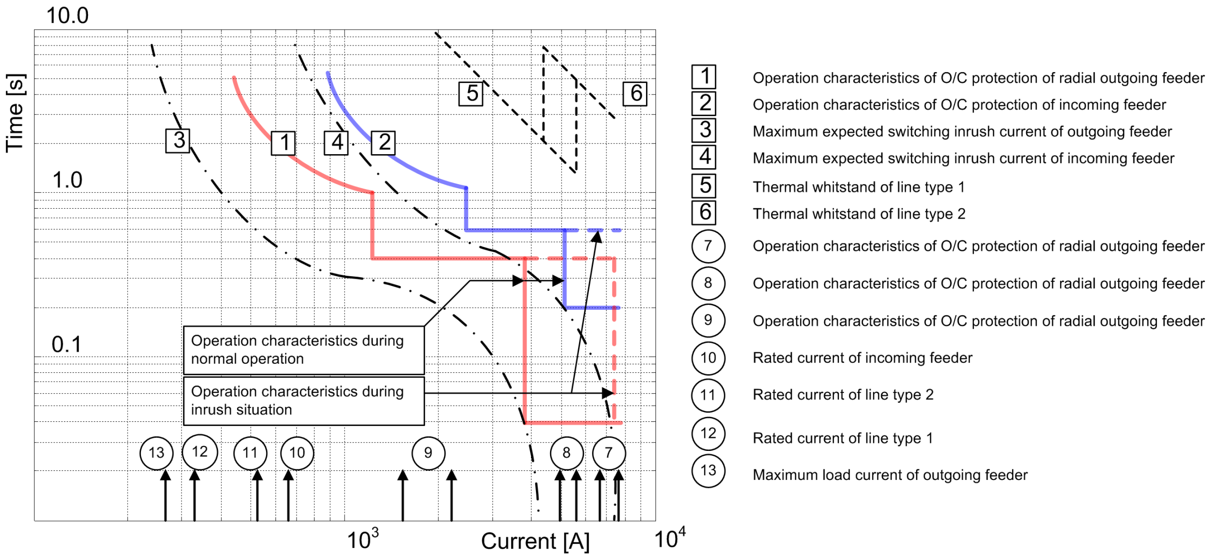


Figure 124: Example coordination of numerical multiple-stage overcurrent protection

4.1.1.8 Signals

Table 221: PHLPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 222: PHHPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 223: PHIPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 224: PHLPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 225: PHHPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 226: PHIPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.1.1.9 Settings

Table 227: PHLPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	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 IDMT curves
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv.			15=IEC Def. Time	Selection of time delay curve type

Parameter	Values (Range)	Unit	Step	Default	Description
	7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type				

Table 228: PHLPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 229: PHLPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 230: PHLPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Peak-to-Peak 5=Wide P-to-P				

Table 231: PHHPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	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
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv. 5=ANSI Def. Time 9=IEC Norm. inv. 10=IEC Very inv. 12=IEC Ext. inv. 15=IEC Def. Time 17=Programmable			15=IEC Def. Time	Selection of time delay curve type

Table 232: PHHPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 233: PHHPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 234: PHHPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

Table 235: PHIPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.2...40.00 [1]	xIn	0.01	1.00	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Operate delay time	20...200000 [2] 40...200000 [3]	ms	10	20 [2] 40 [3]	Operate delay time

Table 236: PHIPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation

Table 237: PHIPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

1 In relay patch software 2.1.2, the *Start value* setting range has been extended to start from 0.2 xIn. There is a limitation to the new extended setting range 0.2…1.0 xIn. Firstly, the extended setting range is settable only from the LHMI. New range values cannot be set from the relay tools. Secondly, when *Start value* is set below 1.0 xIn, the Operate delay time setting must be ≥40 ms to avoid degrading the relay surge immunity, and to avoid relay faulty operations due to high surge spikes.

2 REF620 and REM620

3 RET620

4.1.1.10 Monitored data

Table 238: PHLPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHLPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 239: PHHPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHHPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 240: PHIPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHIPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.1.11 Technical data

Table 241: PHxPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
	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 ,		Minimum	Typical	Maximum
	PHIPTOC: I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	16 ms 11 ms	19 ms 12 ms	23 ms 14 ms
	PHHPTOC and PHLPTOC: I_{Fault} = 2 × set *Start value*	23 ms	26 ms	29 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<40 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		
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		

4.1.1.12 Technical revision history

Table 242: PHIPTOC Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting
C	Minimum and default values changed to 20 ms for the *Operate delay time* setting Minimum value changed to 1.00 x In for the *Start value* setting
D	Internal improvement
E	Internal improvement

[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

Table 243: PHHPTOC Technical revision history

Technical revision	Change
C	*Measurement mode* "P-to-P + backup" replaced with "Peak-to-Peak"
D	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting
E	Internal improvement
F	Internal improvement

Table 244: PHLPTOC Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting
C	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting
D	Internal improvement
E	Internal improvement

4.1.2 Three-independent-phase non-directional overcurrent protection PH3xPTOC

4.1.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-independent-phase non-directional overcurrent protection, low stage	PH3LPTOC	3I_3>	51P-1_3
Three-independent-phase non-directional overcurrent protection, high stage	PH3HPTOC	3I_3>>	51P-2_3
Three-independent-phase non-directional overcurrent protection, instantaneous stage	PH3IPTOC	3I_3>>>	50P/51P_3

4.1.2.2 Function block

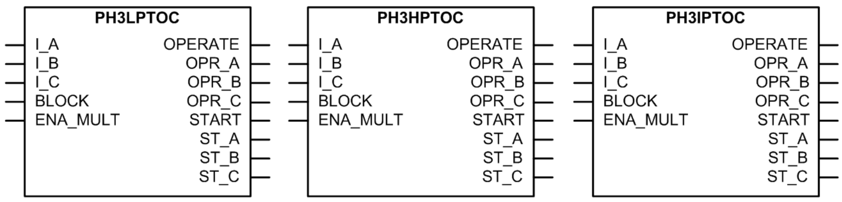


Figure 125: Function block

4.1.2.3 Functionality

The three-independent-phase non-directional overcurrent protection function PH3xPTOC 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. Each phase has its own timer. The operating time characteristics for low-stage PH3LPTOC and high-stage PH3HPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage PH3IPTOC 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.

4.1.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

PH3xPTOC is used as single-phase and three-phase non-directional overcurrent and short circuit protection. The phase operation mode is selected with the *Operation curve type* setting. The operation is further specified with the *Num of start phases* setting, which sets the number of phases in which the current must exceed the set current start value before the corresponding start and operating signals can be activated.

The operation of PH3xPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

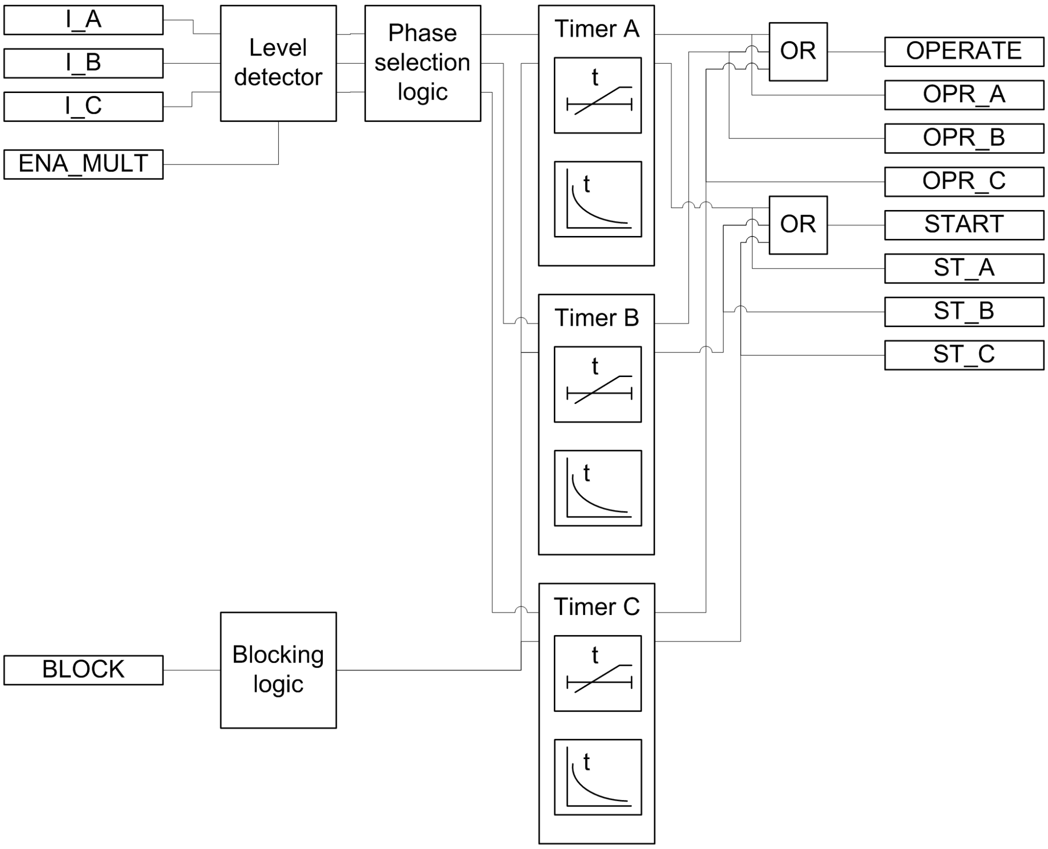


Figure 126: Functional module diagram

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.

The IED does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA_MULT input.

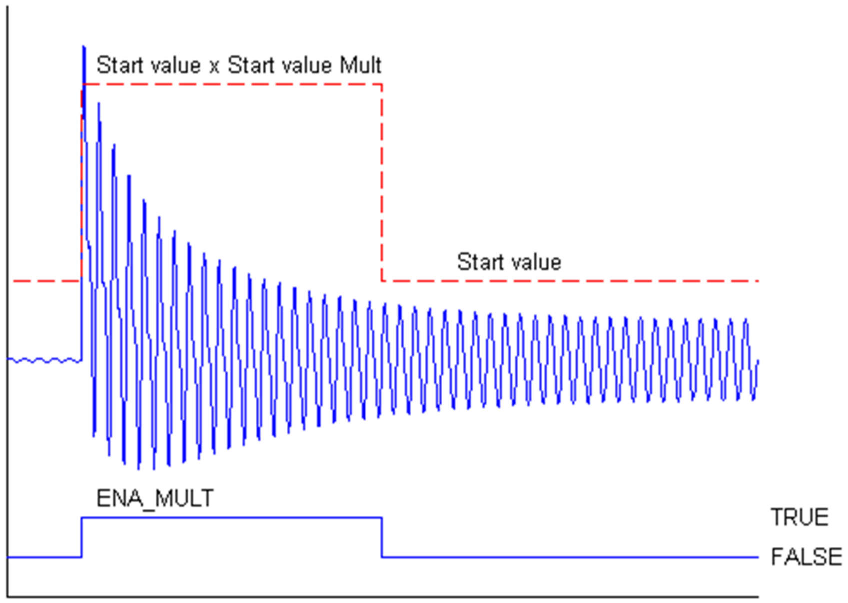


Figure 127: Start value behavior with ENA_MULT input activated

Phase selection logic

The phase selection logic detects the faulty phase or phases and controls the timers according to the set value of the *Num of start phases* setting.

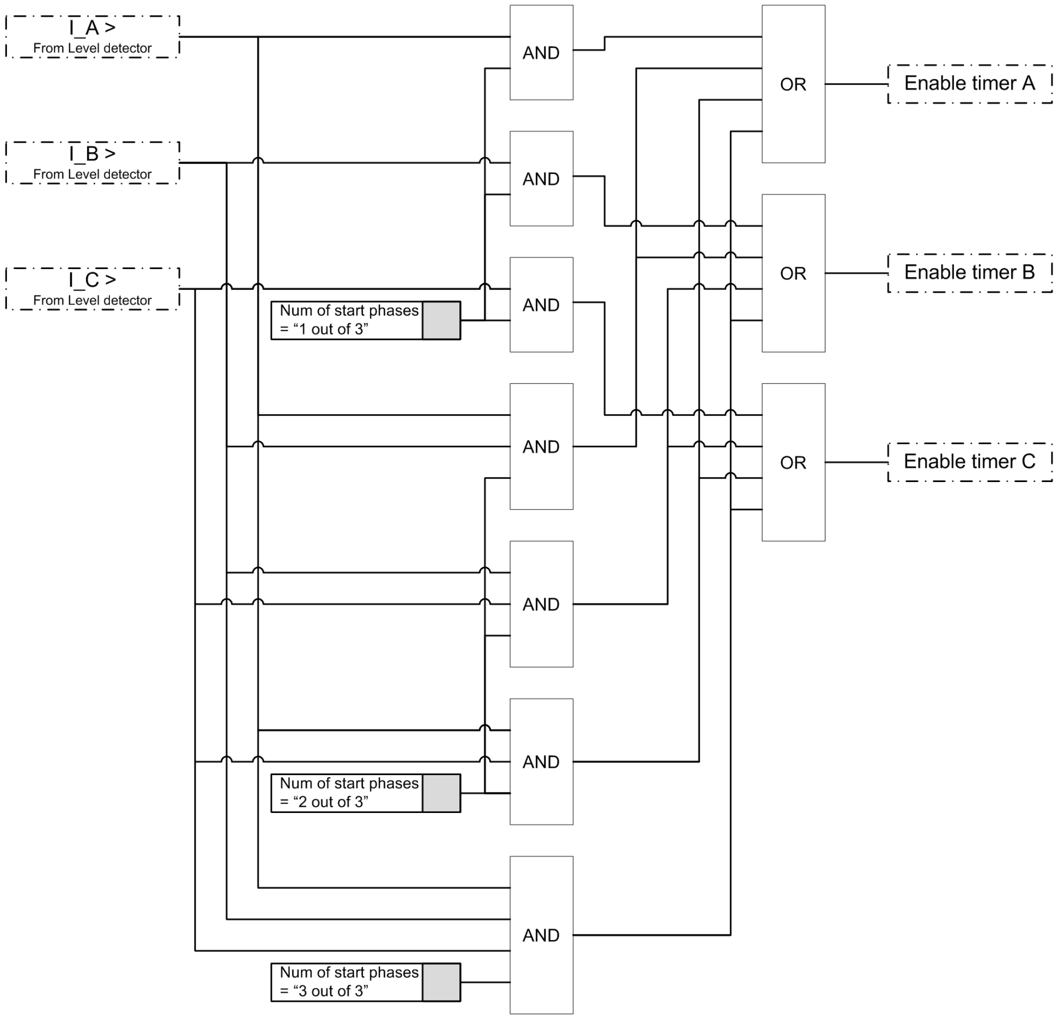


Figure 128: Logic diagram for phase selection module

When the *Number of start phases* setting is set to "1 out of 3" and the fault is in one or several phases, the phase selection logic sends an enabling signal to the faulty phase timers. In case the fault disappears, the related timer-enabling signal is removed.

When the setting is "2 out of 3" or "3 out of 3", the single-phase faults are not detected. The setting "3 out of 3" requires the fault to be present in all three phases.

Timer A, Timer B, Timer C

The function design contains three independent phase-segregated timers that are controlled by common settings. This design allows true three-phase overcurrent protection which is useful in some applications.

Common `START` and `OPERATE` outputs are created by ORing the phase-specific start and operating outputs.

Each phase has its own phase-specific start and operating outputs: `ST_A`, `ST_B`, `ST_C`, `OPR_A`, `OPR_B` and `OPR_C`.

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 programmable IDMT curve is selected, the operating time characteristics are defined with the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

The shortest IDMT operation time is adjustable. It can be set up with the global parameter in the HMI menu: **Configuration** > **System** > **IDMT Sat point**. More information can be found in *Chapter 11 General function block features*.

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 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.

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 *Chapter 11 General function block features* 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode**, which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE, OPR_A, OPR_B and OPR_C outputs are not activated.

4.1.2.5 Timer characteristics

PH3xPTOC supports both DT and IDMT characteristics. The timer characteristics can be selected 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, a programmable curve can be used if none of the standard curves are applicable. The DT characteristic can be chosen 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 245: IDMT curves supported by different stages

Operating curve type	Supported by	
	PH3LPTOC	PH3HPTOC
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	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	
(17) Programmable	x	x

PH3IPTOC supports only definite time characteristic.

For a detailed description of timers, see *Chapter 11 General function block features* in this manual.

Table 246: Reset time characteristics supported by different stages

Reset curve type	PH3LPTOC	PH3HPTOC	Note
(1) Immediate	x	x	Available for all operating time curves
(2) Def time reset	x	x	Available for all operating 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 PH3IPTOC or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

4.1.2.6 Application

PH3xPTOC is used in several applications in the power system. The applications include different protections, for example.

- 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

PH3xPTOC 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-phase and three-phase short circuits. Therefore, it can be chosen how many phases, at minimum, must have currents above the start level for the function to operate.

Many applications require several steps using different current start levels and time delays. PH3xPTOC consists of three protection stages:

- Low PH3LPTOC
- High PH3HPTOC
- Instantaneous PH3IPTOC

PH3LPTOC is used for overcurrent protection. The function contains several types of time delay characteristics. PH3HPTOC and PH3IPTOC are used for the fast clearing of very high overcurrent situations.

Transformer overcurrent protection

The purpose of the transformer overcurrent protection is to operate as the main protection when differential protection is not used. It can also be used as a coarse backup protection for differential protection in the faults inside the zone of protection, that is, faults occurring in incoming or outgoing feeders, in the region of transformer terminals and in the tank cover. This means that the magnitude range of the fault current can be very wide. The range varies from 6xIn to several hundred times In, depending on the impedance of the transformer and the source impedance of the feeding network. From this point of view, it is clear that the operation must be both very fast and selective, which is usually achieved by using coarse current settings.

The purpose is also to protect the transformer from short circuits occurring outside the protection zone, that is, from through-faults. Transformer overcurrent protection also provides protection for the LV-side busbars. In this case, the magnitude of the fault current is typically lower than 12xIn, depending on the fault location and transformer impedance. Consequently, the protection must operate as fast as possible, taking into account the selectivity requirements, switching-in currents and the thermal and mechanical withstand of the transformer and outgoing feeders.

Traditionally, overcurrent protection of the transformer has been arranged as shown in *Figure 129*. The low-set stage PH3LPTOC operates time-selectively both in transformer and LV-side busbar faults. The high-set stage PH3HPTOC operates instantaneously, making use of current selectivity only in the transformer HV-side faults. If there is a possibility that the fault current can also be fed from the LV-side up to the HV-side, the transformer must also be equipped with an LV-side overcurrent protection. Inrush current detectors are used in startup situations to multiply the current start value setting in each particular IED where the inrush current can occur. The overcurrent- and contact-based circuit breaker failure protection CCBRBRF is used to confirm the protection scheme in case of circuit breaker malfunction.

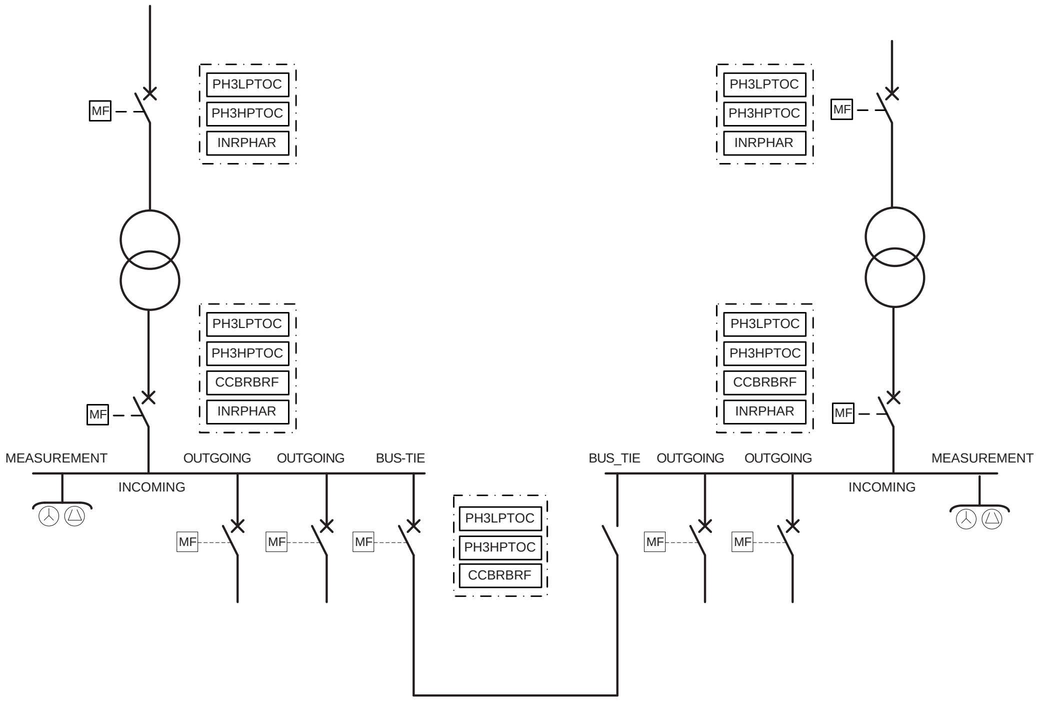


Figure 129: Example of traditional time selective transformer overcurrent protection

The operating times of the main and backup overcurrent protection of the above scheme become quite long. This applies especially in the busbar faults and also in the transformer LV-terminal faults. To improve the performance of the above scheme, a multiple-stage overcurrent protection with a reverse blocking is proposed. *Figure 130* shows this arrangement.

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 accelerate the operation of the overcurrent protection in the busbar and transformer LV-side faults without impairing the selectivity. Also, the security degree of the 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 130* 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.

Table 247: 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

If 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.

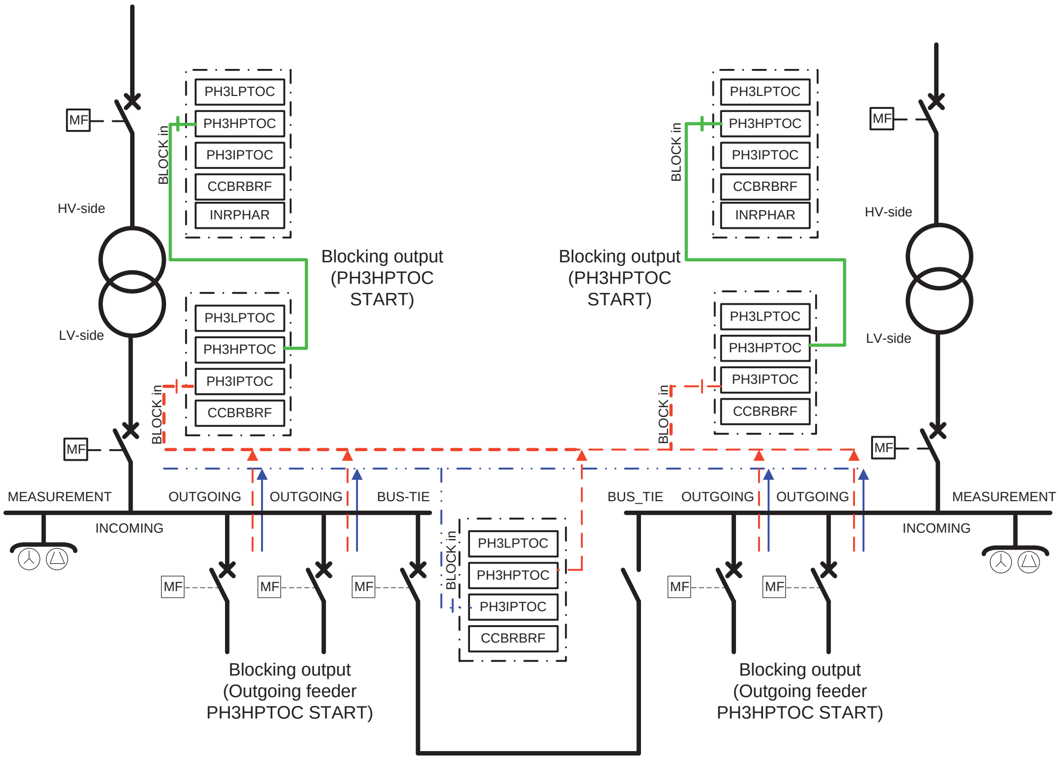


Figure 130: Numerical overcurrent protection functionality for a typical sub-transmission/distribution substation (feeder protection not shown). Blocking output = digital output signal from the start of a protection stage, Blocking in = digital input signal to block the operation of a protection stage

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 very low. Also, the effects of switching inrush currents on the setting values can be reduced 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 maintaining selectivity and also for the protection to operate without additional time delays. For additional information about available measuring modes and current transformer requirements, see *Chapter 11.5 Measurement modes* 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.

Often the above requirements can be best fulfilled using multiple-stage overcurrent units. *Figure 131* 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 PH3LPTOC operates in the IDMT-mode and the two higher stages, PH3HPTOC and PH3IPTOC, in the DT-mode. Also the thermal withstand of the line types along the feeder and the 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 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. This way, the start value is multiplied with a predefined setting during the inrush situation, and nuisance tripping can be avoided.

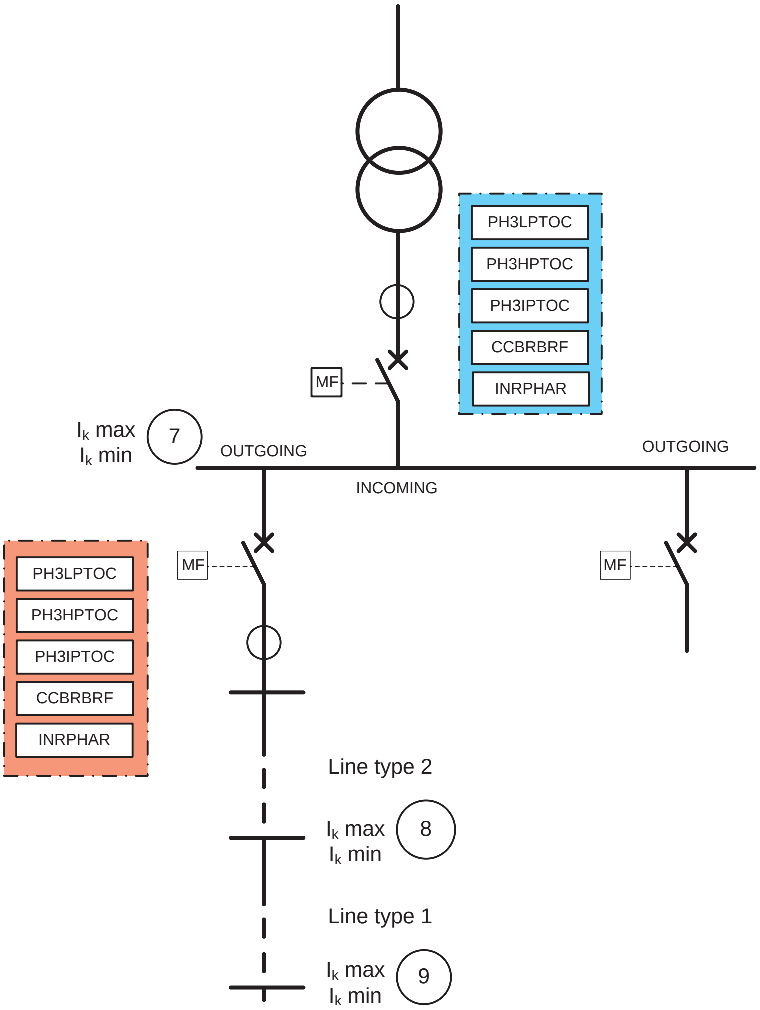


Figure 131: Functionality of numerical multiple-stage overcurrent protection

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 132*, the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

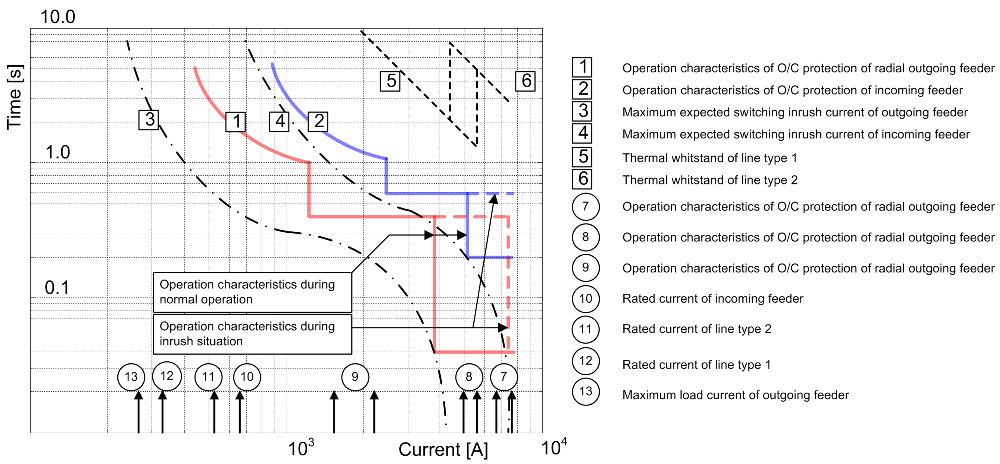


Figure 132: Example coordination of numerical multiple-stage overcurrent protection

4.1.2.7 Signals

Table 248: PH3LPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 249: PH3HPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 250: PH3IPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for acti-vating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for cur-rent multiplier

Table 251: PH3LPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_A	BOOLEAN	Operate phase A
OPR_B	BOOLEAN	Operate phase B
OPR_C	BOOLEAN	Operate phase C
START	BOOLEAN	Start
ST_A	BOOLEAN	Start phase A
ST_B	BOOLEAN	Start phase B
ST_C	BOOLEAN	Start phase C

Table 252: PH3HPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_A	BOOLEAN	Operate phase A
OPR_B	BOOLEAN	Operate phase B
OPR_C	BOOLEAN	Operate phase C
START	BOOLEAN	Start
ST_A	BOOLEAN	Start phase A
ST_B	BOOLEAN	Start phase B
ST_C	BOOLEAN	Start phase C

Table 253: PH3IPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_A	BOOLEAN	Operate phase A
OPR_B	BOOLEAN	Operate phase B

Table continues on the next page

Name	Type	Description
OPR_C	BOOLEAN	Operate phase C
START	BOOLEAN	Start
ST_A	BOOLEAN	Start phase A
ST_B	BOOLEAN	Start phase B
ST_C	BOOLEAN	Start phase C

4.1.2.8 Settings

Table 254: PH3LPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	0.01	0.05	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scal-ing the start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type

Table 255: PH3LPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 256: PH3LPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 257: PH3LPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	10	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	10	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

Table 258: PH3HPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	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
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv. 5=ANSI Def. Time 9=IEC Norm. inv. 10=IEC Very inv. 12=IEC Ext. inv. 15=IEC Def. Time 17=Programmable			15=IEC Def. Time	Selection of time delay curve type

Table 259: PH3HPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset			1=Immediate	Selection of reset curve type

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Inverse reset				

Table 260: PH3HPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start pha-ses	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for oper-ate activation
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer program-mable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer program-mable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer program-mable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer program-mable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer program-mable curve

Table 261: PH3HPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	10	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	10	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used meas-urement mode

Table 262: PH3IPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	1.00...40.00	xIn	0.01	1.00	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scal-ing the start value
Operate delay time	20...200000	ms	10	20	Operate delay time

Table 263: PH3IPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start pha-ses	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for oper-ate activation

Table 264: PH3IPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

4.1.2.9 Monitored data

Table 265: PH3LPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PH3LPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 266: PH3HPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PH3HPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 267: PH3IPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PH3IPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.2.10 Technical data

Table 268: PH3xPTOC Technical data

Characteristic		Value
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz
	PH3LPTOC	±1.5% of the set value or ±0.002 × I_n
	PH3HPTOC and PH3IPTOC	±1.5% of set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n)

Table continues on the next page

Characteristic		Value		
		±5.0% of the set value (at currents in the range of 10…40 × I_n)		
Start time ,		Minimum	Typical	Maximum
	PH3IPTOC: I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	15 ms 11 ms	16 ms 14 ms	17 ms 17 ms
	PH3HPTOC and PH3LPTOC: I_{Fault} = 2 × set *Start value*	23 ms	25 ms	28 ms
Reset time		<40 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		
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 Peak-to-Peak + backup: No suppression		

4.1.3 Three-phase directional overcurrent protection DPHxPDOC

4.1.3.1 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

[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

4.1.3.2 Function block

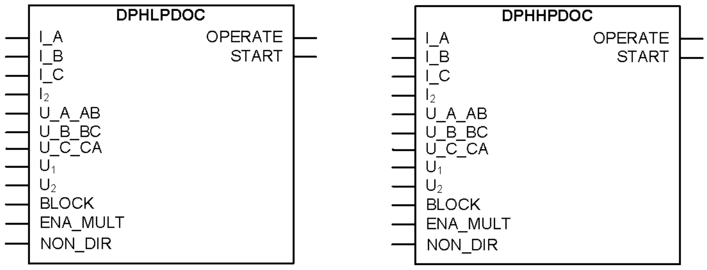


Figure 133: Function block

4.1.3.3 Functionality

The three-phase directional overcurrent protection function 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.

4.1.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DPHxPDOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

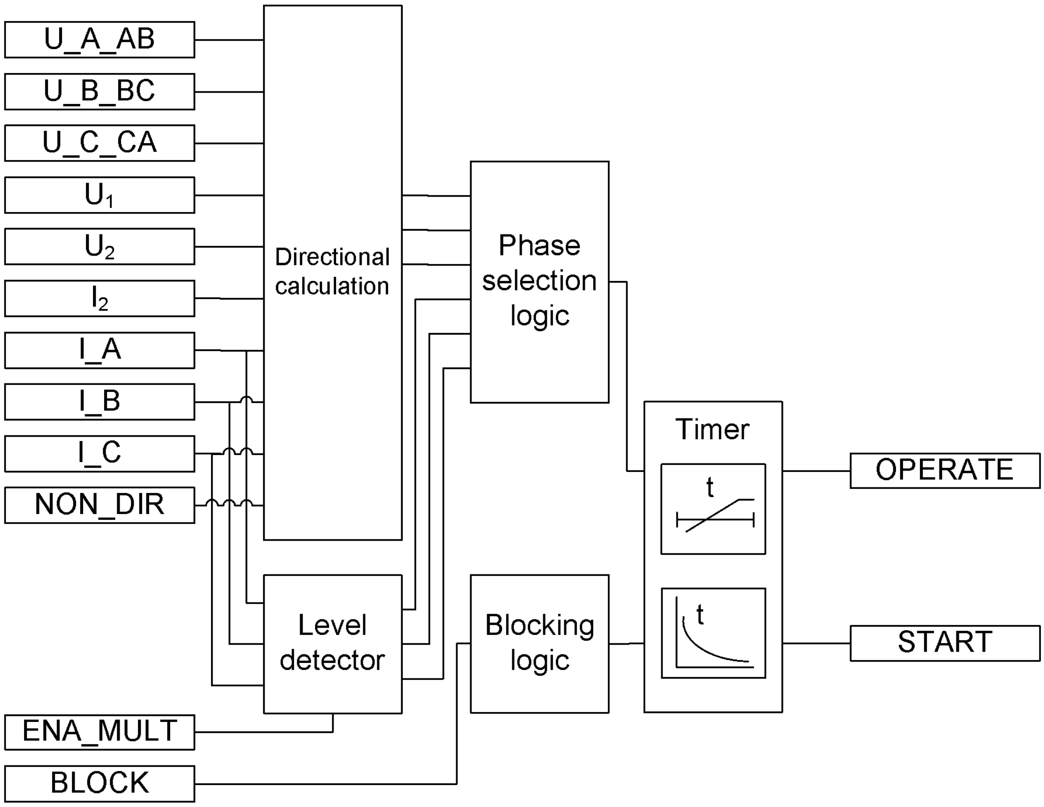


Figure 134: Functional module diagram

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 269: 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 "True", 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 protection relay 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 positive phase sequence voltage measured before the fault occurred, assuming that the voltage is not affected by the fault. 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 voltage memory cannot be used for the "Negative sequence voltage" polarization because it is not possible to substitute the positive sequence voltage for negative sequence voltage without knowing the network unsymmetry level. This is the reason why the fictive voltage angle and corresponding direction information are frozen immediately for this polarization mode when the need for a voltage memory arises and these are kept frozen until the time set with *Voltage Mem time* elapses.

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 falls below *Min operate voltage* at a close fault, the 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* and hysteresis. The fictive voltage is also discarded if the measured voltage stays below *Min operate voltage* and hysteresis 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 two reasons:

- The fictive voltage is discarded after *Voltage Mem time*
- The phase angle cannot be reliably measured before the fault situation.

DPHxPDOC can be forced to the non-directional operation with the `NON_DIR` input. When the `NON_DIR` input is active, DPHxPDOC operates as a non-directional overcurrent protection, regardless of the *Directional mode* setting.

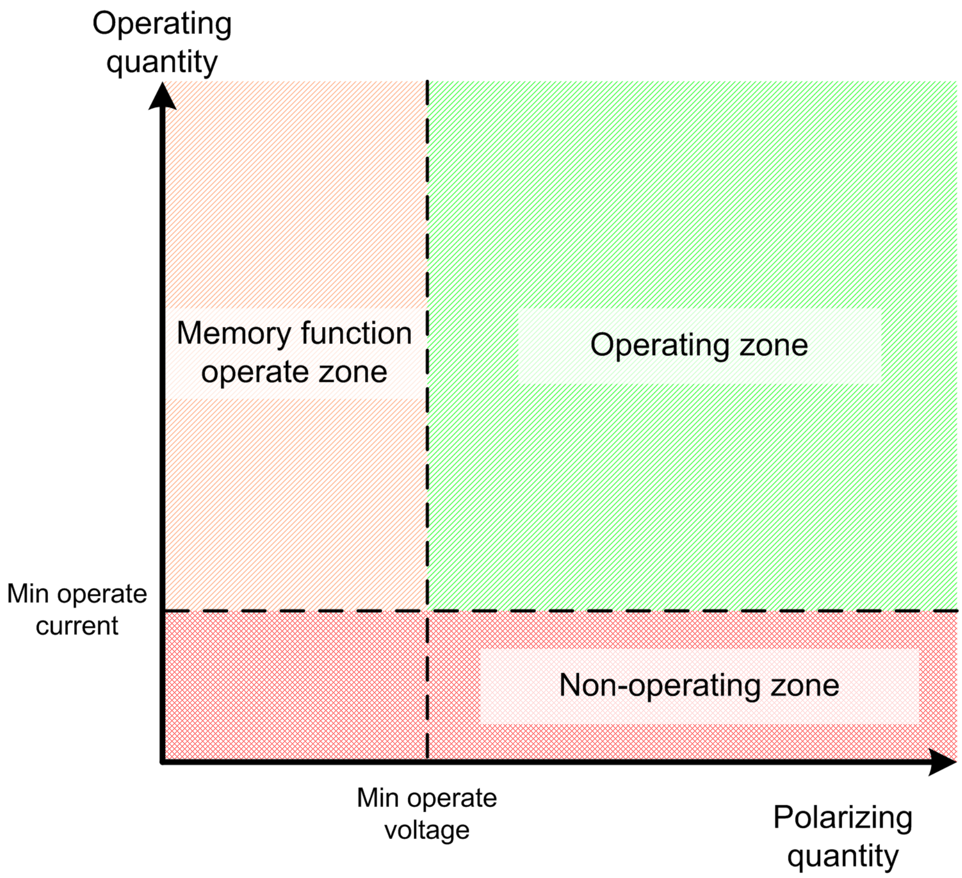


Figure 135: Operating zones at minimum magnitude levels

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.

The protection relay does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA_MULT input.

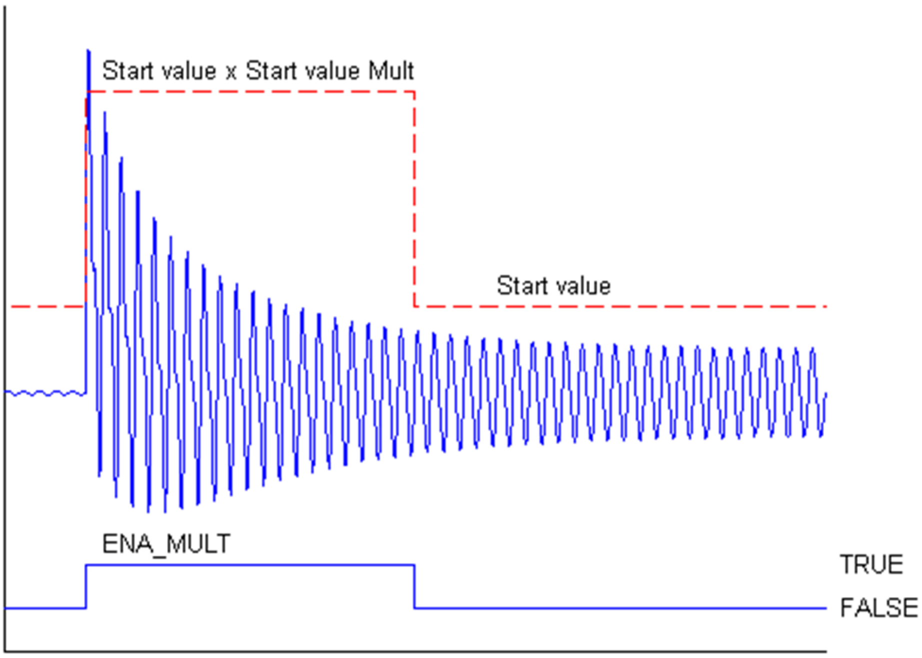


Figure 136: Start value behavior with ENA_MULT input activated

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.

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 *Chapter 11.2.1 IDMT curves for overcurrent protection* 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.1.3.5 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 270: Measurement modes supported by DPHxPDOC stages

Measurement mode	DPHLPDOC	DPHHPDOC
RMS	x	x
DFT	x	x
Peak-to-Peak	x	x

4.1.3.6 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.

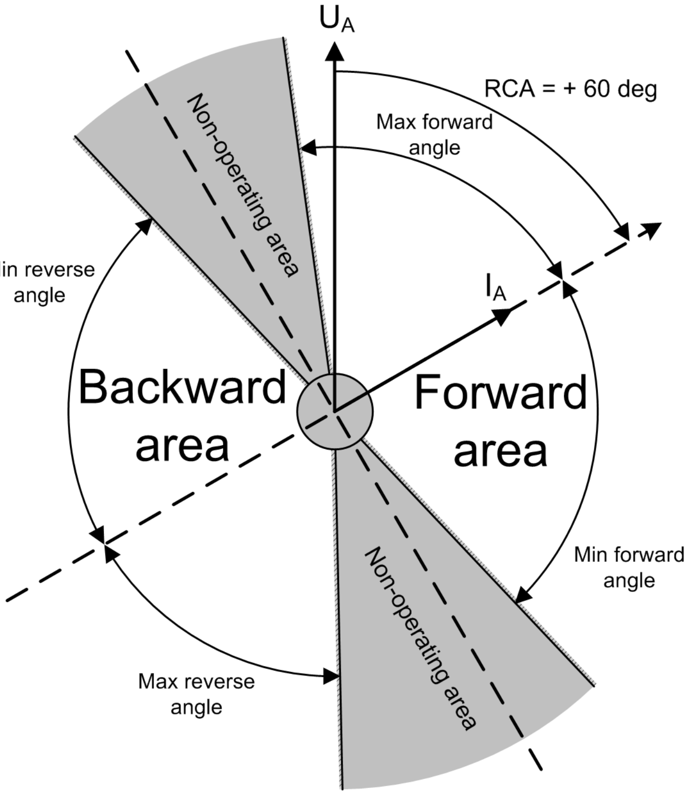


Figure 137: Configurable operating sectors

Table 271: 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 272: 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 273: 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.

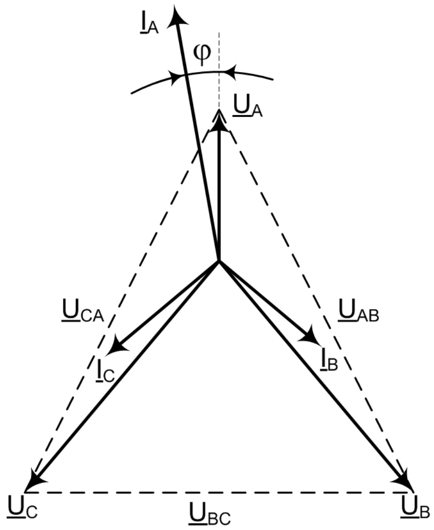


Figure 138: Single-phase earth fault, phase A

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.

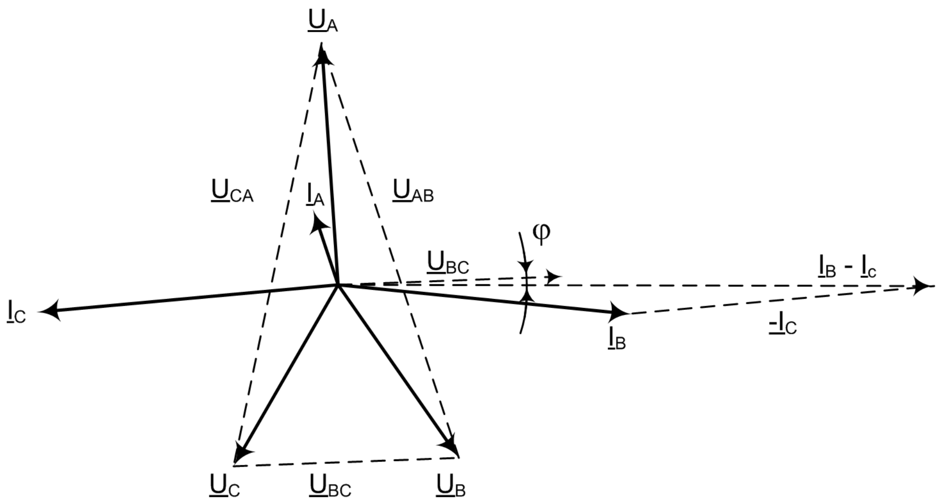


Figure 139: Two-phase short circuit, short circuit is between phases B and C

Cross-polarizing as polarizing quantity

Table 274: 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.

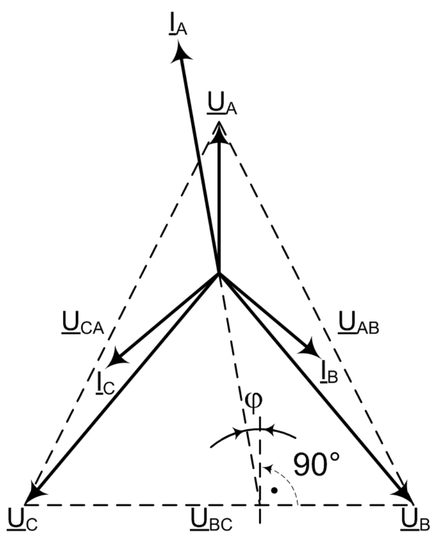


Figure 140: Single-phase earth fault, phase A

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.

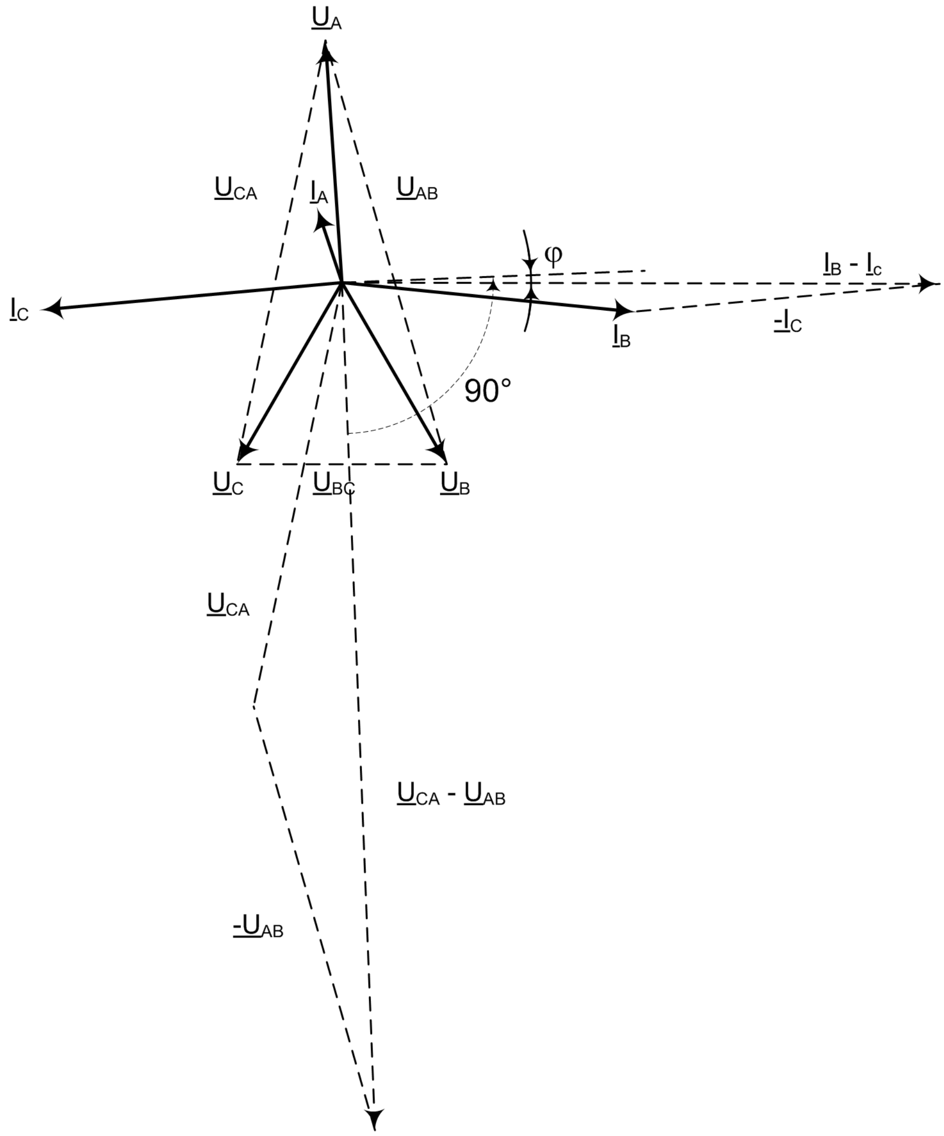


Figure 141: Two-phase short circuit, short circuit is between phases B and C

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 6)

This means that the actuating polarizing quantity is - $\underline{U}_2$.

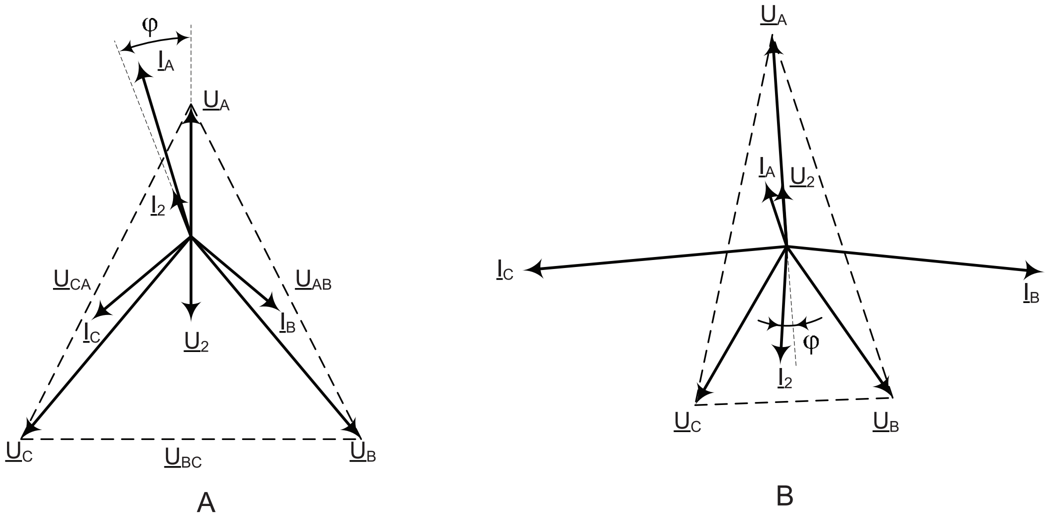


Figure 142: Phasors in a single-phase earth fault, phases A-N, and two-phase short circuit, phases B and C, when the actuating polarizing quantity is the negative-sequence voltage -U2

Positive sequence voltage as polarizing quantity

Table 275: 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	$\underline{I}_C - \underline{I}_A$	$\underline{U}_1$	$ANGLE\_C = \varphi(\underline{U}_1) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 150^\circ$

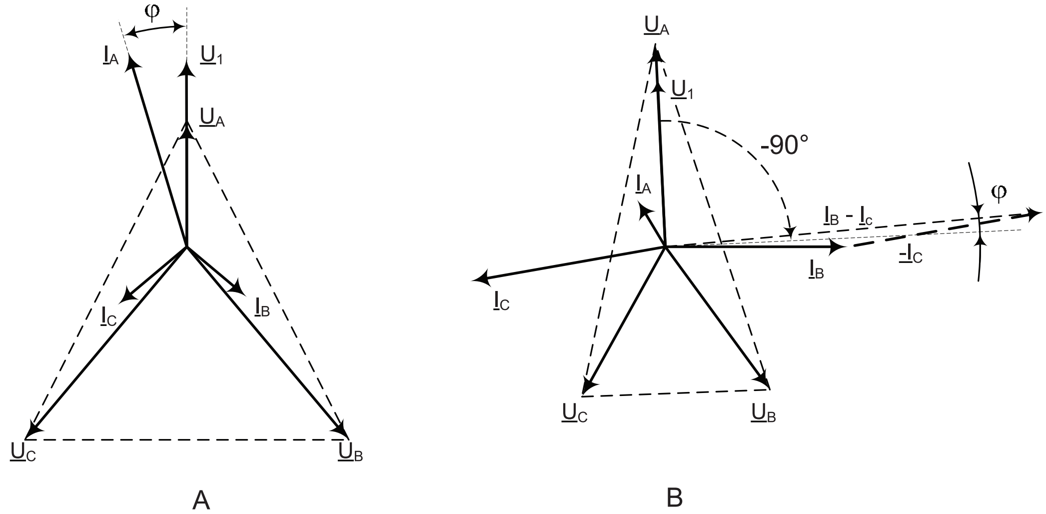


Figure 143: Phasors in a single-phase earth fault, phase A to ground, and a two-phase short circuit, phases B-C, are short-circuited when the polarizing quantity is the positive-sequence voltage U 1

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 protection relay using the parameter in the HMI menu **Configuration** > **System** > **Phase rotation**. The default parameter value is "ABC".

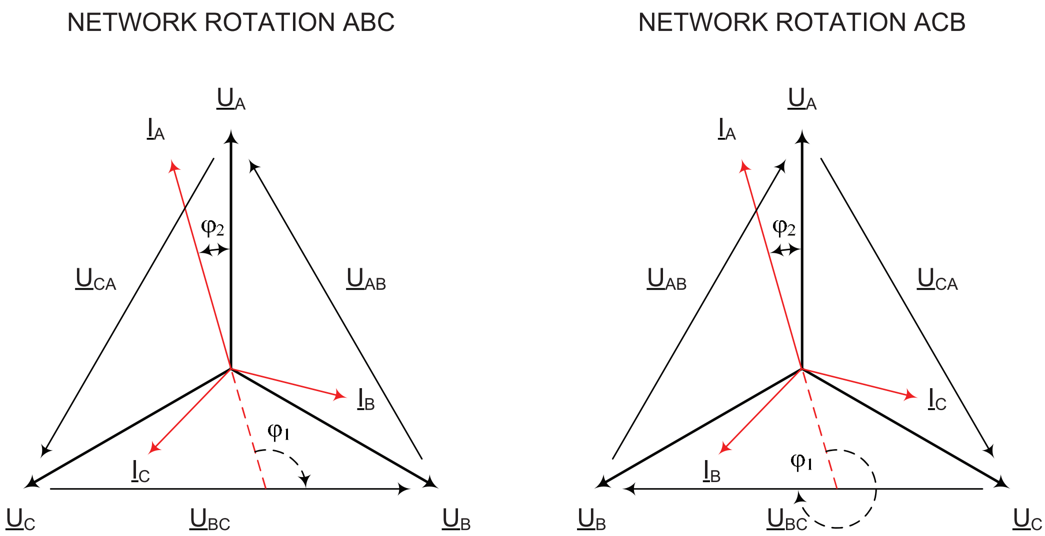


Figure 144: Examples of network rotating direction

4.1.3.7 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 protection relays 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 protection relays 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 protection relays 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 protection relays 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.

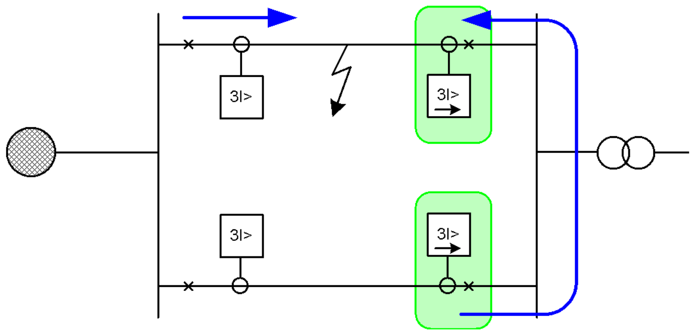


Figure 145: Overcurrent protection of parallel lines using directional protection relays

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.

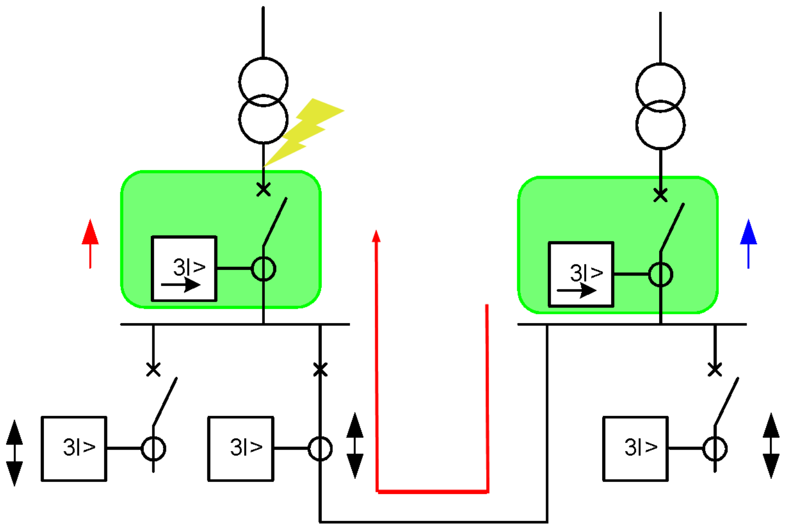


Figure 146: Overcurrent protection of parallel operating transformers

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 protection relays 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.

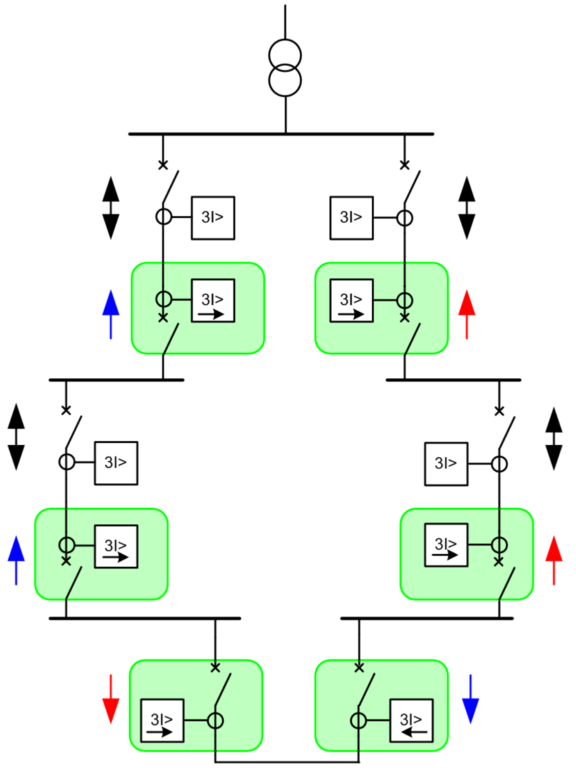


Figure 147: Closed ring network topology where feeding lines are protected with directional overcurrent protection relays

4.1.3.8 Signals

Table 276: DPHLPDOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative phase sequence current
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
U_1	SIGNAL	0	Positive phase sequence voltage

Table continues on the next page

Name	Type	Default	Description
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enabling signal for current multiplier
NON_DIR	BOOLEAN	0=False	Forces protection to non-directional

Table 277: DPHHPDOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative phase sequence current
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
U_1	SIGNAL	0	Positive phase sequence voltage
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enabling signal for current multiplier
NON_DIR	BOOLEAN	0=False	Forces protection to non-directional

Table 278: DPHLPDOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 279: DPHHPDOC Output signals

Name	Type	Description
START	BOOLEAN	Start
OPERATE	BOOLEAN	Operate

4.1.3.9 Settings

Table 280: DPHLPDOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	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 IDMT curves
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	80	Minimum phase angle in reverse direction

Table 281: DPHLPDOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Voltage Mem time	0...3000	ms	1	40	Voltage memory time
Pol quantity	1=Self pol 4=Neg. seq. volt. 5=Cross pol 7=Pos. seq. volt.			5=Cross pol	Reference quantity used to determine fault direction

Table 282: DPHLPDOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 283: DPHLPDOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage

Table 284: DPHHPDOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	0.01	0.10	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv. 5=ANSI Def. Time 9=IEC Norm. inv. 10=IEC Very inv. 12=IEC Ext. inv. 15=IEC Def. Time 17=Programmable			15=IEC Def. Time	Selection of time delay curve type
Operate delay time	40...200000	ms	10	40	Operate delay time
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	80	Minimum phase angle in reverse direction

Table 285: DPHHPDOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Voltage Mem time	0...3000	ms	1	40	Voltage memory time
Pol quantity	1=Self pol 4=Neg. seq. volt. 5=Cross pol 7=Pos. seq. volt.			5=Cross pol	Reference quantity used to determine fault direction

Table 286: DPHHPDOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation

Table 287: DPHHPDOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage

4.1.3.10 Monitored data

Table 288: DPHLPDOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information
DIR_A	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase C
ANGLE_A	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase A
ANGLE_B	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase B
ANGLE_C	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase C
VMEM_USED	BOOLEAN	0=False 1=True		Voltage memory in use status
DPHLPDOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 289: DPHHPDOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information
DIR_A	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase C
ANGLE_A	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase A
ANGLE_B	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase B
ANGLE_C	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase C

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
VMEM_USED	BOOLEAN	0=False 1=True		Voltage memory in use status
DPHHPDOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.3.11 Technical data

Table 290: DPHxPDOC Technical data

Characteristic		Value		
Operation accuracy	DPHLPDOC	Depending on the frequency of the current/voltage measured: f_n ±2 Hz		
		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 time [1, 2]	I_{Fault}= 2.0 x set *Start value*	Minimum	Typical	Maximum
		39 ms	43 ms	47 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		

Table continues on the next page

1 *Measurement mode* and *Pol quantity* = default, current before fault = 0.0 × I_n, voltage before fault = 1.0 × U_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

Characteristic		Value
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,…

4.1.3.12 Technical revision history

Table 291: DPHHPDOC Technical revision history

Technical revision	Change
B	Added a new input NON_DIR
C	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.
D	Monitored data VMEM_USED indicating voltage memory use.
E	Internal improvement.

Table 292: DPHLPDOC Technical revision history

Technical revision	Change
B	Added a new input NON_DIR
C	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.
D	Monitored data VMEM_USED indicating voltage memory use.
E	Internal improvement.

4.1.4 Directional three-independent-phase directional overcurrent protection DPH3xPDOC

[3] Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20

4.1.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional three-independent-phase directional overcurrent protection, low stage	DPH3LPDOC	3_3I> ->	67-1_3
Directional three-independent-phase directional overcurrent protection, high stage	DPH3HPDOC	3I_3>> ->	67-2_3

4.1.4.2 Function block

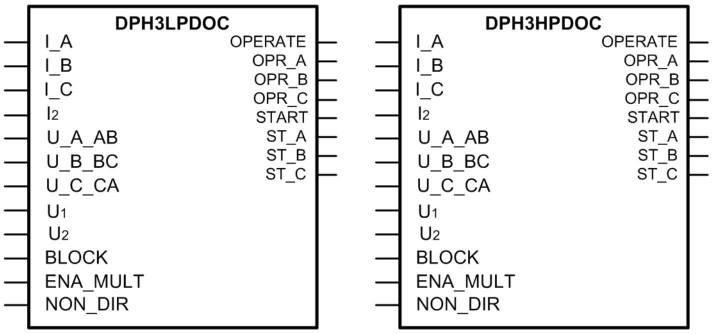


Figure 148: Function block

4.1.4.3 Functionality

Directional three-independent-phase directional overcurrent protection function DPH3xPDOC is used as one-phase, two-phase or three-phase directional overcurrent and short circuit protection for feeders.

DPH3xPDOC starts when the value of the current exceeds the set limit and directional criterion is fulfilled. Each phase has its own timer. The operation time characteristics for the low stage, DPH3LPDOC, and the high stage, DPH3HPDOC, 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 operation 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.

4.1.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DPH3xPDOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

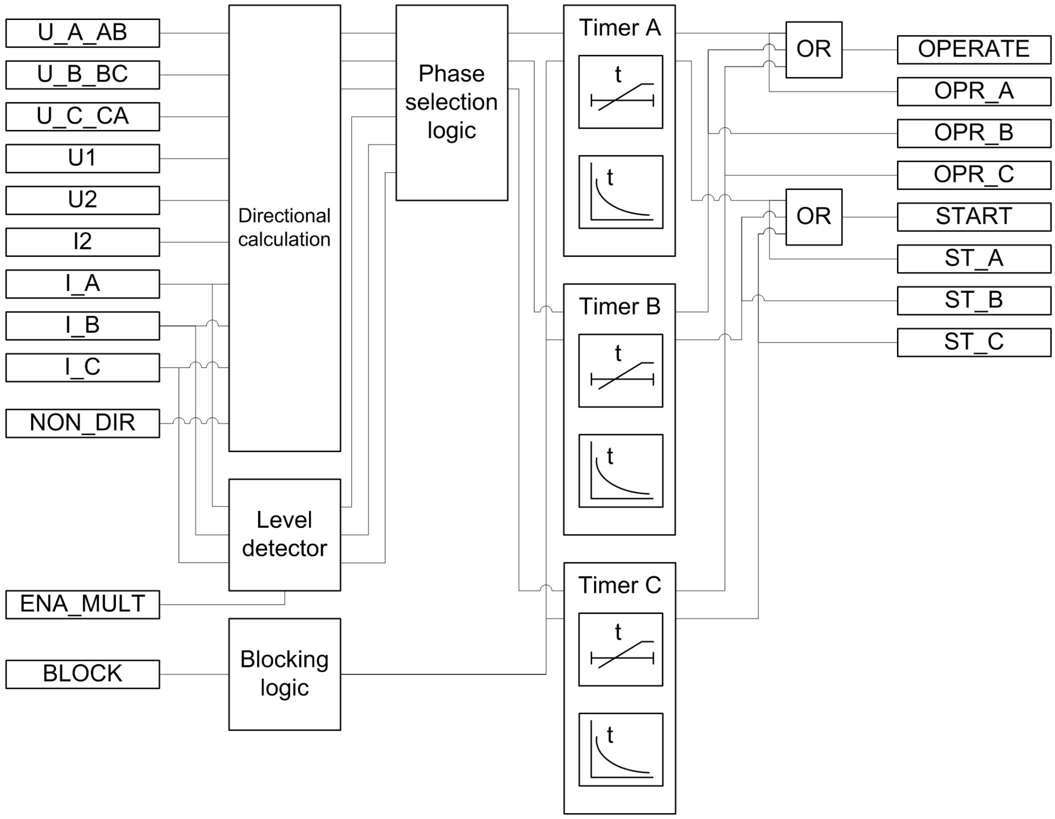


Figure 149: Functional module diagram

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 293: 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 "True", 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.

DPH3xPDOC 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 the 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 positive-phase sequence voltage measured before the fault occurred, assuming that the voltage is not affected by the fault. 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 voltage memory cannot be used for the negative-sequence voltage polarization because it is not possible to substitute the positive-sequence voltage for negative-sequence voltage without knowing the network asymmetry level. This is the reason why the fictive voltage angle and corresponding direction information are frozen immediately for this polarization mode when the need for a voltage memory arises, and these are kept frozen until the time set with *Voltage Mem time* elapses.

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 falls below *Min operate voltage* at a close fault, the 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* and hysteresis. The fictive voltage is discarded 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 two reasons:

- The fictive voltage is discarded if the fault current disappears while the fictive voltage is in use
- The phase angle cannot be reliably measured before the fault situation.

DPH3xPDOC can be forced to non-directional operation with the `NON_DIR` input. When the `NON_DIR` input is active, DPH3xPDOC operates as a non-directional overcurrent protection regardless of the *Directional mode* setting.

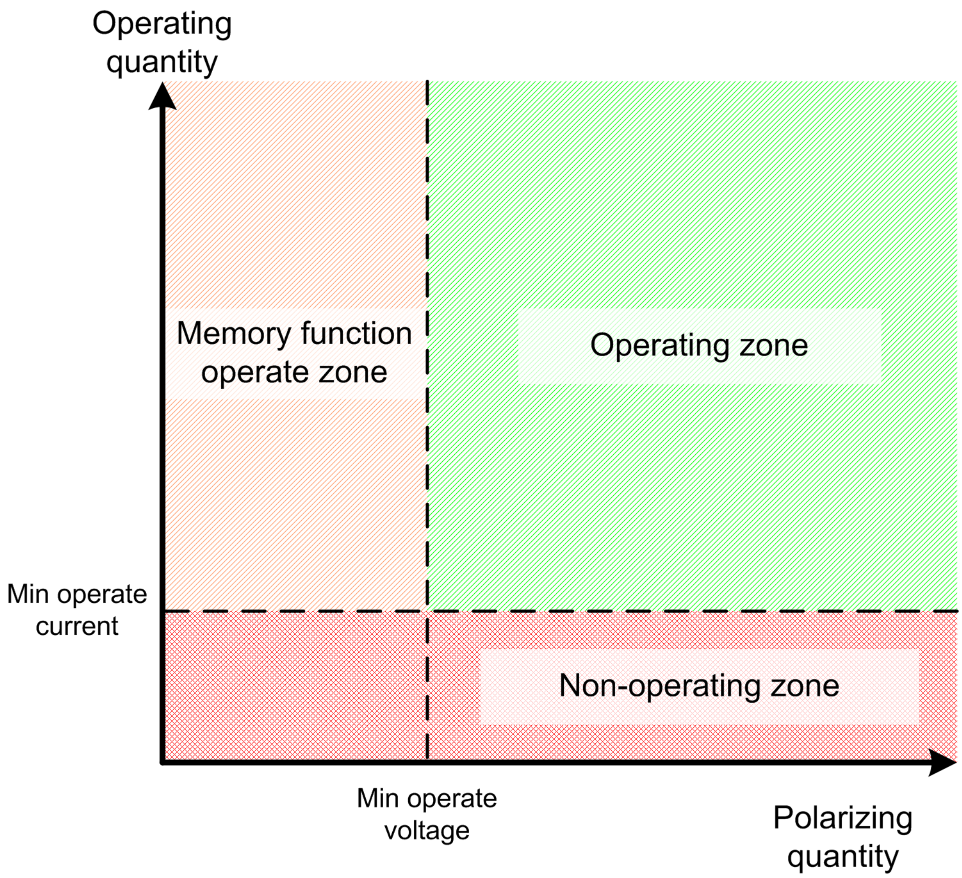


Figure 150: Operating zones at minimum magnitude levels

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, together with the directional results of that phase, to the phase selection logic. If the ENA_MULT input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

The IED does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA_MULT input.

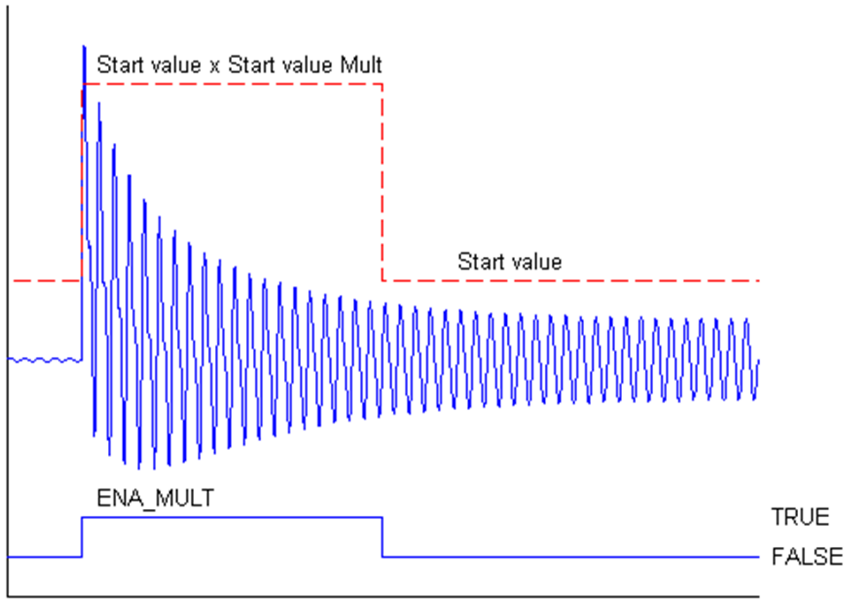


Figure 151: Start value behavior with ENA_MULT input activated

Phase selection logic

The phase selection logic detects the faulty phase or phases and controls the timers according to the set value of the *Num of start phases* setting.

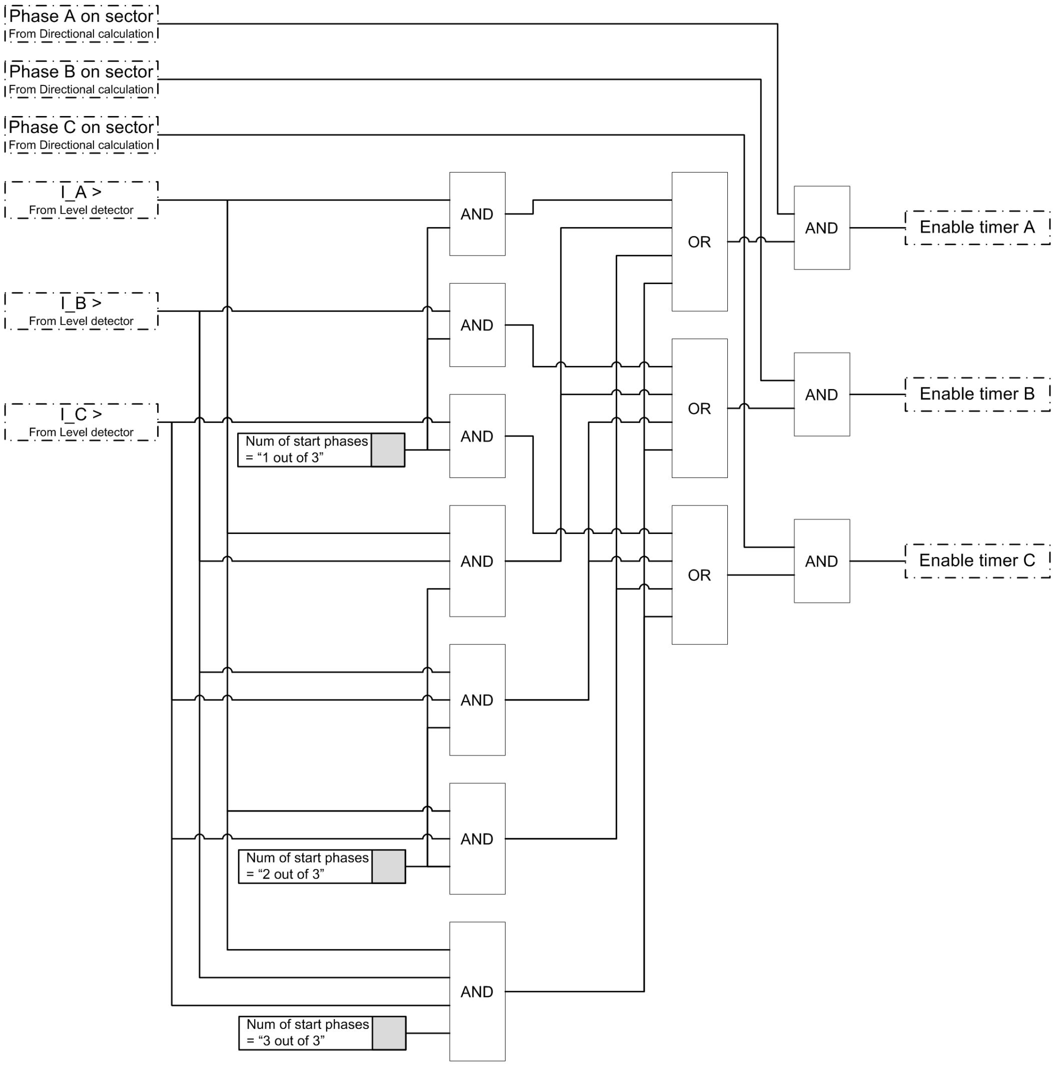


Figure 152: Logic diagram for phase selection module

When the *Number of start phase* setting is set to "1 out of 3" and the fault is in one or several phases, the phase selection logic sends an enabling signal to the faulty phase timers. If the fault disappears, the related timer-enabling signal is removed.

When the *Number of start phase* setting is "2 out of 3" or "3 out of 3", single-phase faults are not detected. The value "3 out of 3" requires the fault to be present in all three phases.

Timer A, Timer B, Timer C

The function design contains three independent phase-segregated timers which are controlled by common settings. This design allows a true three-phase overcurrent protection which is useful in some applications.

The common `START` and `OPERATE` outputs are created by "ORing" the phasespecific starting and operating outputs.

Each phase has its own phase-specific starting and operating outputs: `ST_A`, `ST_B`, `ST_C`, `OPR_A`, `OPR_B` and `OPR_C`.

Once activated, each timer activates its 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 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*.

The shortest IDMT operation time is adjustable. The setup can be done with a global parameter in the HMI menu: **Configuration** > **System** > **IDMT Sat point**. More information can be found in *Chapter 11 General function block features* in this manual.

If a drop-off situation happens, that is, a fault suddenly disappears before the operation 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. If the drop-off situation continues, the reset timer is reset and the START output is deactivated.

The "Inverse reset" selection is only supported with ANSI or programmable IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The *Time multiplier* setting is used for scaling the IDMT operating and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operating 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 *Chapter 11 General function block features* 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE, OPR_A, OPR_B and OPR_C outputs are not activated.

4.1.4.5 Timer characteristics

DPH3xPDOC supports both DT and IDMT characteristics. The timer characteristics can be selected 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 the ABB praxis and are referred to as RI and RD. In addition to this, a programmable curve can be used if none of the standard curves are applicable. The DT characteristic can be chosen by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The list of characteristics, which matches the list in the IEC 61850-7-4 specification, indicates the characteristics supported by different stages.

Table 294: IDMT curves supported by different stages

Operating curve type	Supported by	
	DPH3LPDOC	DPH3HPDOC
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	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	
(17) Programmable	x	x

For a detailed description of the timers, see *Chapter 11 General function block features* in this manual.

Reset curve type	Supported by		Note
	DPH3LPDOC	DPH3HPDOC	
(1) Immediate	x	x	Available for all operating time curves
(2) Def time reset	x	x	Available for all operating time curves
(3) Inverse reset	x	x	Available only for ANSI and user programmable curves

4.1.4.6 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.

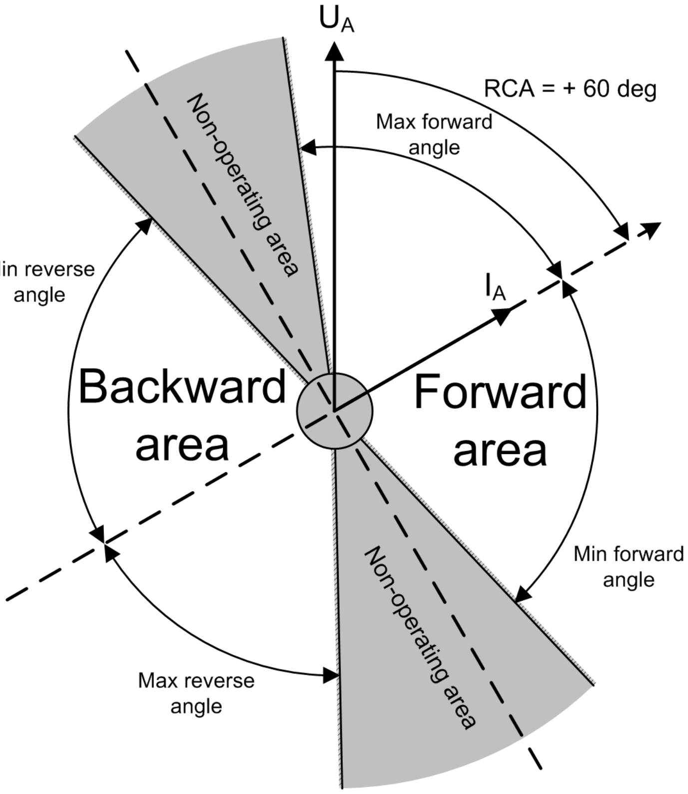


Figure 153: Configurable operating sectors

Table 295: 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 296: 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 297: 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.

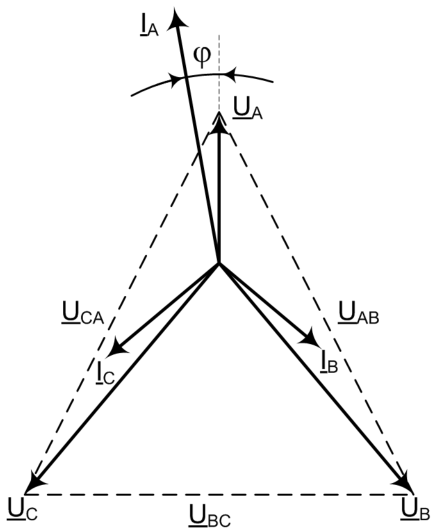


Figure 154: Single-phase earth fault, phase A

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.

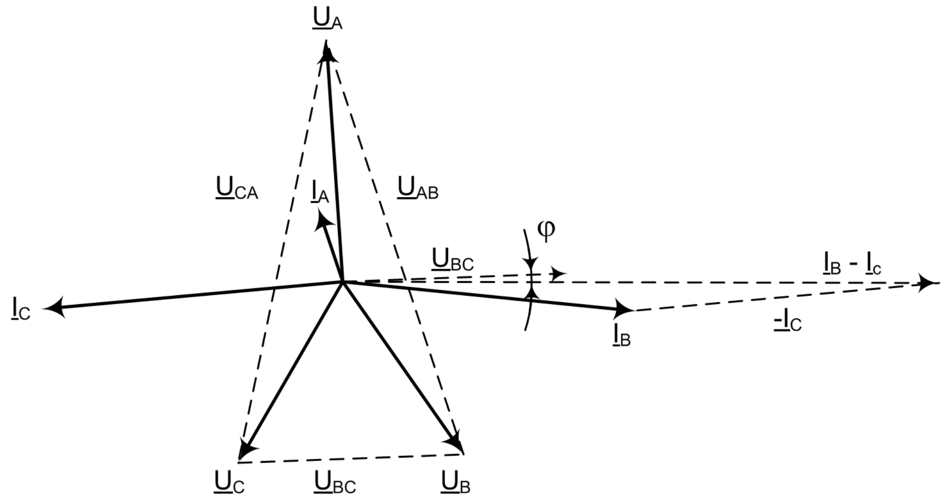


Figure 155: Two-phase short circuit, short circuit is between phases B and C

Cross-polarizing as polarizing quantity

Table 298: 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.

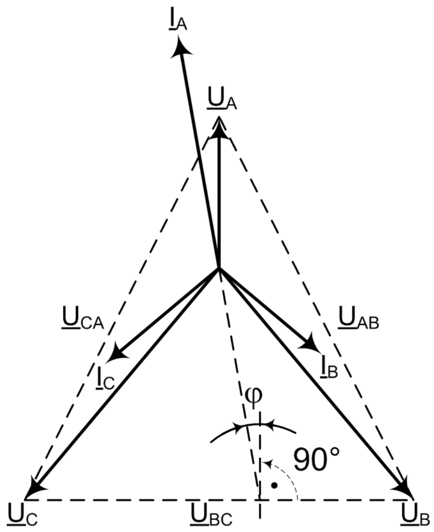


Figure 156: Single-phase earth fault, phase A

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.

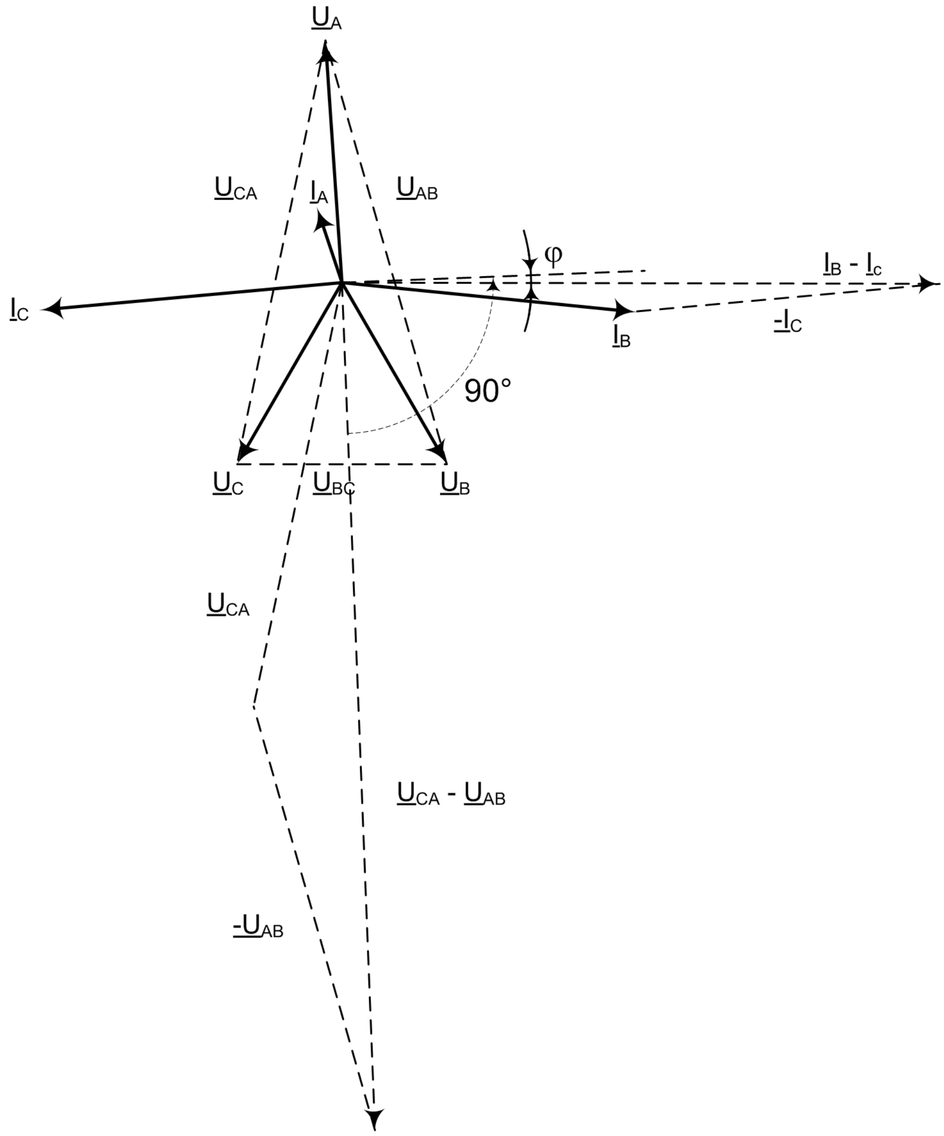


Figure 157: Two-phase short circuit, short circuit is between phases B and C

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 7)

This means that the actuating polarizing quantity is $-\underline{U}_2$.

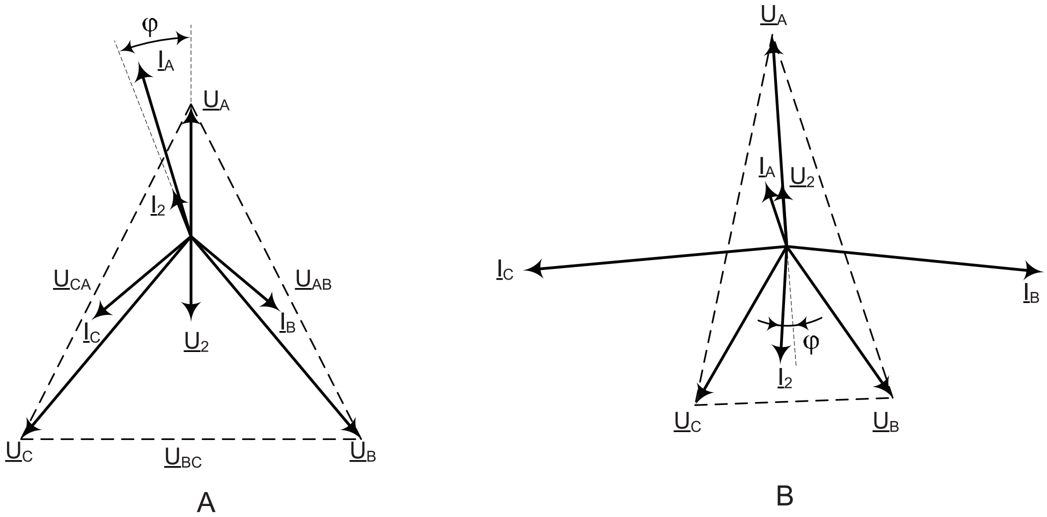


Figure 158: Phasors in a single-phase earth fault, phases A-N, and two-phase short circuit, phases B and C, when the actuating polarizing quantity is the negative-sequence voltage -U2

Positive sequence voltage as polarizing quantity

Table 299: 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	$\underline{I}_C - \underline{I}_A$	$\underline{U}_1$	$ANGLE\_C = \varphi(\underline{U}_1) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 150^\circ$

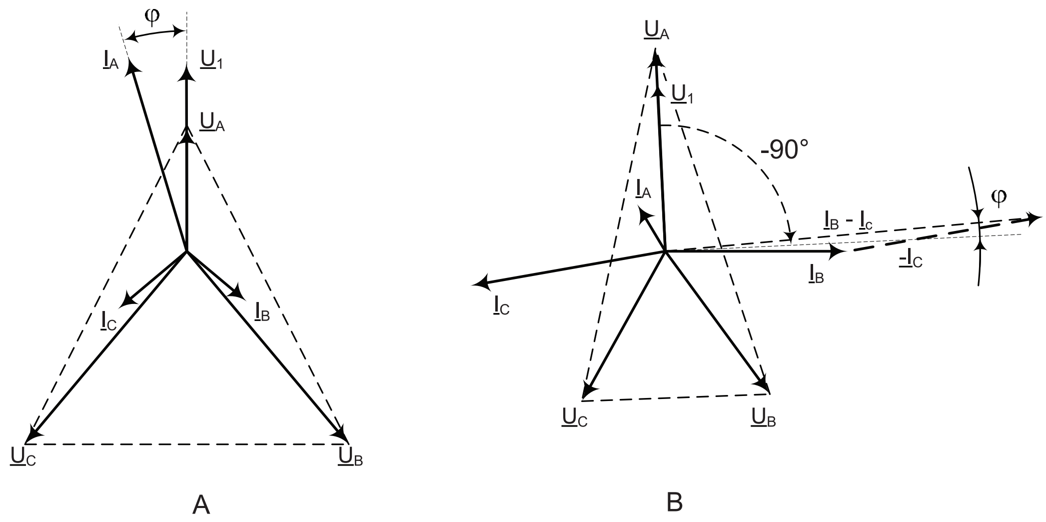


Figure 159: Phasors in a single-phase earth fault, phase A to ground, and a two-phase short circuit, phases B-C, are short-circuited when the polarizing quantity is the positive-sequence voltage U 1

Network rotation direction

Typically, the network rotatiion direction is counterclockwise and defined as "ABC". If the network rotation direction is reversed, meaning clockwise, that is, "ACB", the equations for calculating the angle difference need to be changed. The network rotation direction is defined with a system parameter *Phase rotation*. The change in the network rotation direction affects the polarization method of the phase-to-phase voltages where the calculated angle difference needs to be rotated 180 degrees. Also, when the sequence components are used, the calculation of the components is affected but the angle difference calculation remains the same. The sequence components are the positive-sequence voltage or negative-sequence voltage components. When the phase-to-ground voltages are used as the polarizing method, the network rotation direction change has no effect on the direction calculation.

The network rotation direction is set in the IED using the parameter in the HMI menu **Configuration** > **System** > **Phase rotation**. The default parameter value is "ABC".

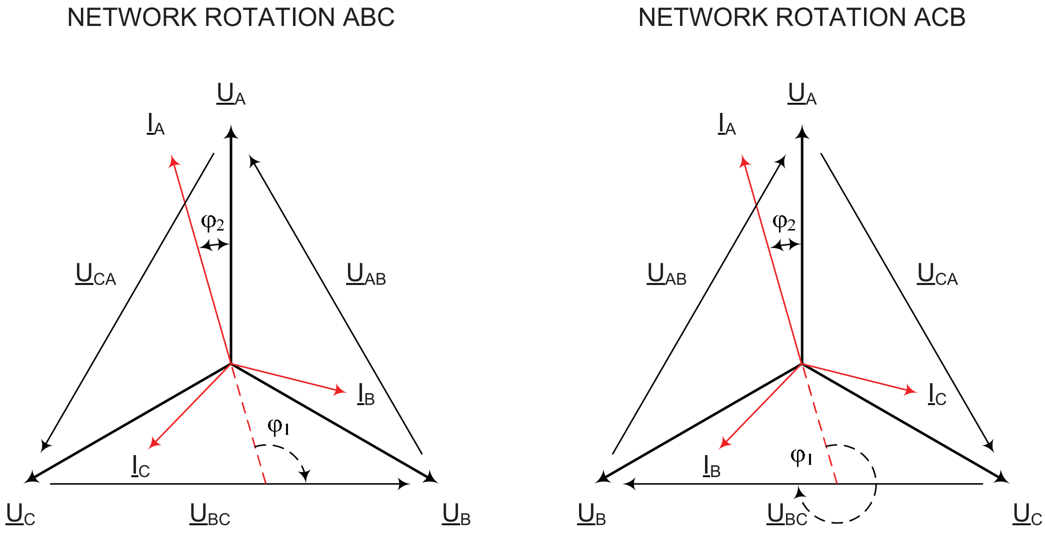


Figure 160: Examples of network rotating direction

4.1.4.7 Application

DPH3xPDOC is used as short circuit protection in three-phase distribution or sub transmission networks operating at 50 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 DPH3xPDOC 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 the 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. DPH3xPDOC is also used in the ring-connected supply feeders between substations or feeders with two feeding sources.

Parallel lines or transformers

When the lines are connected in parallel and a fault occurs in one of the lines, it is practical to have DPH3xPDOC 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.

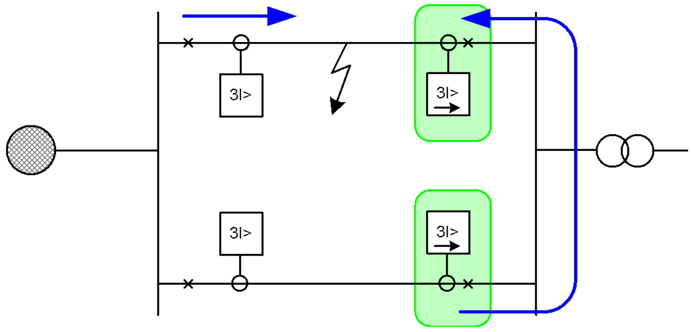


Figure 161: Overcurrent protection of parallel lines using directional protection relays

DPH3xPDOC 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 LVside up to the HV-side. Therefore, the transformer is also equipped with directional overcurrent protection.

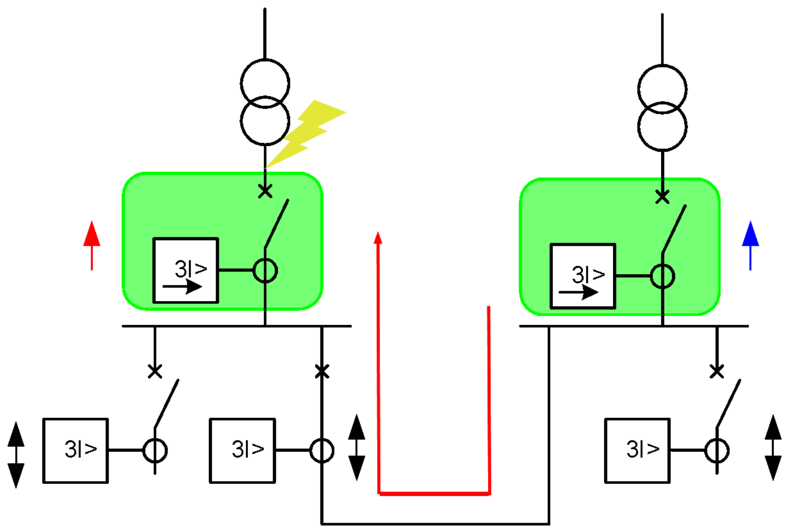


Figure 162: Overcurrent protection of parallel operating transformers

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 from at least 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 nondirectional functionality where faults can be detected in both directions.

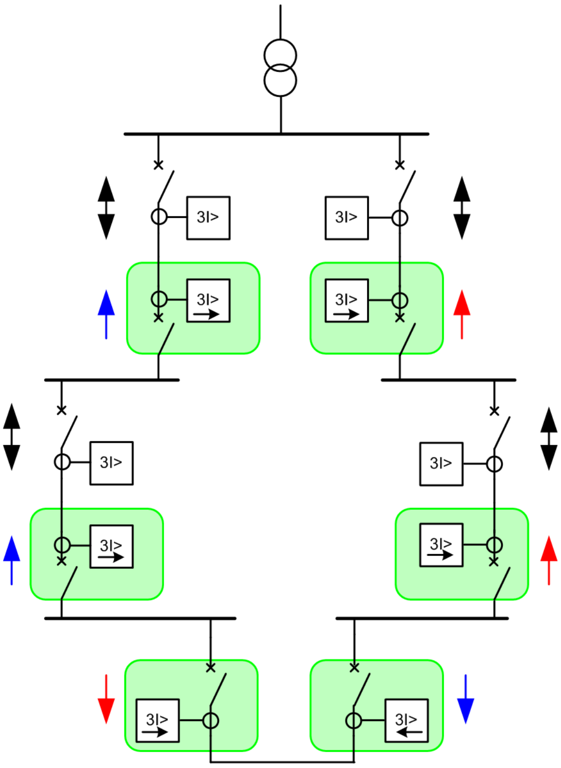


Figure 163: Closed-ring network topology where feeding lines are protected with directional overcurrent IEDs

4.1.4.8 Signals

Table 300: DPH3LPDOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative phase sequence current
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
U_1	SIGNAL	0	Positive phase sequence voltage

Table continues on the next page

Name	Type	Default	Description
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enabling signal for current multiplier
NON_DIR	BOOLEAN	0=False	Forces protection to non-directional

Table 301: DPH3HPDOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative phase sequence current
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
U_1	SIGNAL	0	Positive phase sequence voltage
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enabling signal for current multiplier
NON_DIR	BOOLEAN	0=False	Forces protection to non-directional

Table 302: DPH3LPDOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table continues on the next page

Name	Type	Description
OPR_A	BOOLEAN	Operate phase A
OPR_B	BOOLEAN	Operate phase B
OPR_C	BOOLEAN	Operate phase C
ST_A	BOOLEAN	Start phase A
ST_B	BOOLEAN	Start phase B
ST_C	BOOLEAN	Start phase C

Table 303: DPH3HPDOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
OPR_A	BOOLEAN	Operate phase A
OPR_B	BOOLEAN	Operate phase B
OPR_C	BOOLEAN	Operate phase C
ST_A	BOOLEAN	Start phase A
ST_B	BOOLEAN	Start phase B
ST_C	BOOLEAN	Start phase C

4.1.4.9 Settings

Table 304: DPH3LPDOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	0.01	0.05	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scal-ing the start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time			15=IEC Def. Time	Selection of time delay curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	17=Programmable 18=RI type 19=RD type				
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	80	Minimum phase angle in reverse direction

Table 305: DPH3LPDOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Pol quantity	1=Self pol 4=Neg. seq. volt. 5=Cross pol 7=Pos. seq. volt.			5=Cross pol	Reference quantity used to determine fault direction

Table 306: DPH3LPDOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 307: DPH3LPDOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage

Table 308: DPH3HPDOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	0.01	0.10	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv. 5=ANSI Def. Time 9=IEC Norm. inv. 10=IEC Very inv. 12=IEC Ext. inv. 15=IEC Def. Time 17=Programmable			15=IEC Def. Time	Selection of time delay curve type
Operate delay time	40...200000	ms	10	40	Operate delay time
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	80	Minimum phase angle in reverse direction

Table 309: DPH3HPDOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Pol quantity	1=Self pol 4=Neg. seq. volt. 5=Cross pol 7=Pos. seq. volt.			5=Cross pol	Reference quantity used to determine fault direction

Table 310: DPH3HPDOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation

Table 311: DPH3HPDOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage

4.1.4.10 Monitored data

Table 312: DPH3LPDOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction infor-mation
DIR_A	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase C
ANGLE_A	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase A
ANGLE_B	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase B
ANGLE_C	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase C
DPH3LPDOC	Enum	1=on 2=blocked 3=test		Status

Name	Type	Values (Range)	Unit	Description
		4=test/blocked 5=off		

Table 313: DPH3HPDOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction infor-mation
DIR_A	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase C
ANGLE_A	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase A
ANGLE_B	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase B
ANGLE_C	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase C
DPH3HPDOC	Enum	1=on		Status

Name	Type	Values (Range)	Unit	Description
		2=blocked 3=test 4=test/blocked 5=off		

4.1.4.11 Technical data

Table 314: DPH3xPDOC Technical data

Characteristic		Value		
Operation accuracy	DPH3LPDOC	Depending on the frequency of the current/voltage measured: f_n ±2 Hz		
		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°		
	DPH3HPDOC	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 ,	I_{Fault}= 2.0 x set *Start value*	Minimum	Typical	Maximum
		38 ms	40 ms	43 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 ms		
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 Peak-to-Peak + backup: No suppression		

1 *Measurement mode* and *Pol quantity* = default, current before fault = 0.0 × I_n, voltage before fault = 1.0 × U_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

4.1.5 Three-phase voltage-dependent overcurrent protection PHPVOC

4.1.5.1 Identification

Function description	**IEC 61850 identification**	**IEC 60617 identification**	**ANSI/IEEE C37.2 device number**
Three-phase voltage-dependent overcurrent protection	PHPVOC	3I(U)>	51V

4.1.5.2 Function block

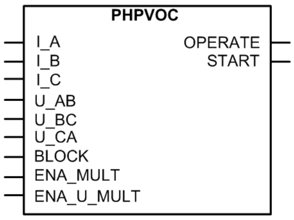


Figure 164: Function block

4.1.5.3 Functionality

The three-phase 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.

4.1.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHPVOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

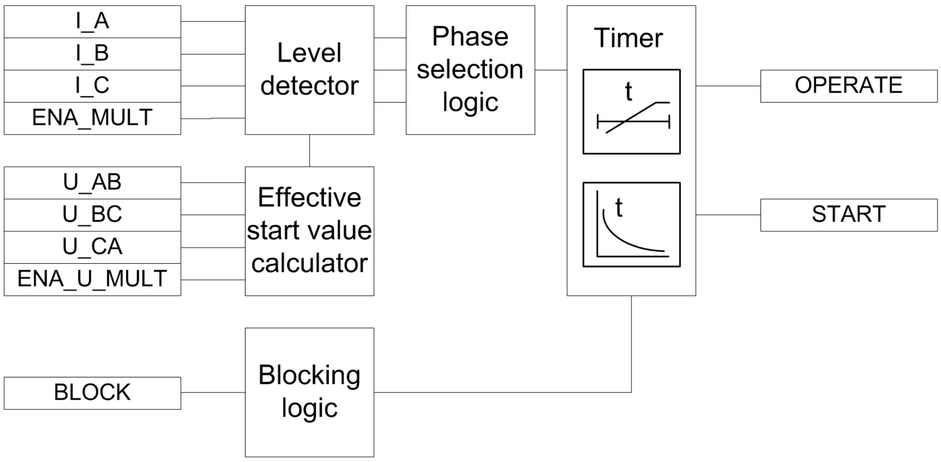


Figure 165: Functional module diagram

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".

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.

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 when the *Voltage high limit* setting is equal to the *Voltage low limit* setting. The effective start value is calculated based on the equations.

Voltage level	Effective start value (I> effective)
U < *Voltage high limit*	*Start value low*
U ≥ *Voltage high limit*	*Start value*

In this example, U represents the measured input voltage. This voltage step characteristic is graphically represented in *Figure 166*.

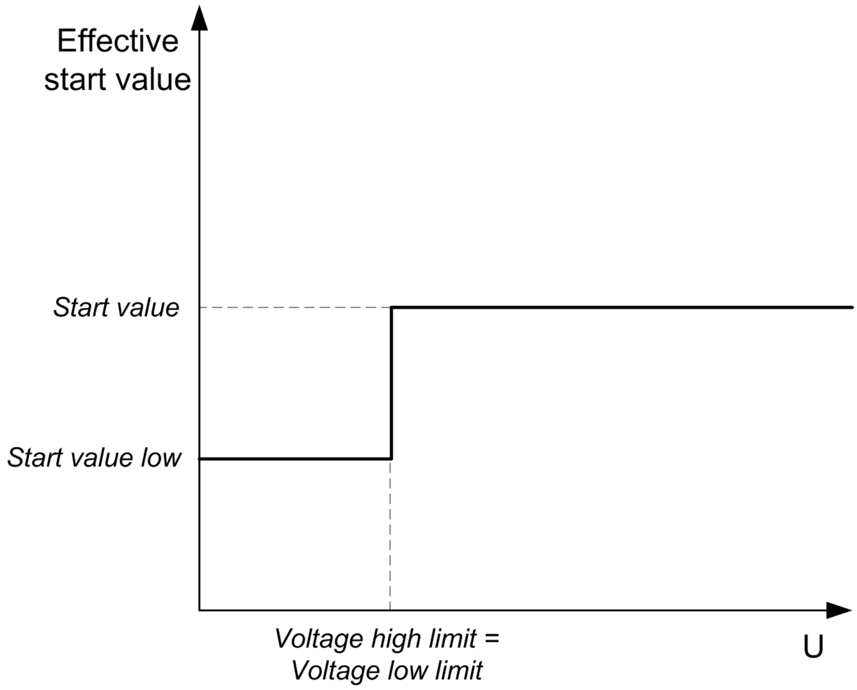


Figure 166: Effective start value for voltage step characteristic

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.

Voltage level	Effective start value (I> effective)
U < *Voltage low limit*	*Start value low*
U ≥ *Voltage high limit*	*Start value*

If *Voltage low limit* ≤ U < *Voltage high limit,*

$$I > (effective) = A - \left[\left(\frac{A - I>}{C - D} \right) \cdot (C - U) \right]$$

(Equation 8)

A	set *Start value low*
I>	set *Start value*
C	set *Voltage high limit*
D	set *Voltage low limit*

Here U represents the measured input voltage. The voltage slope characteristic is graphically represented.

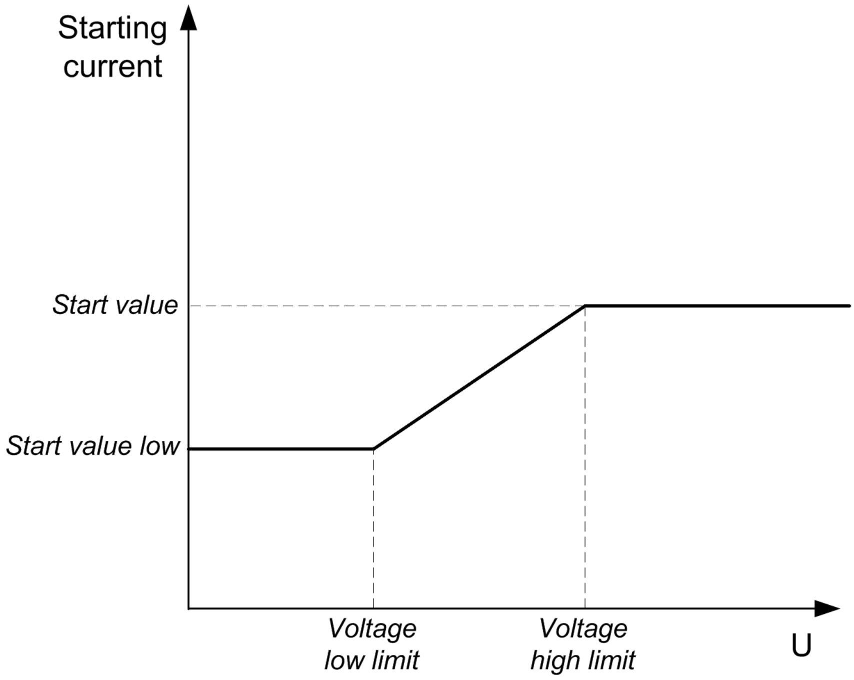


Figure 167: Effective start value or voltage slope characteristic

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 lower 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_U_MULT.

$$\begin{aligned}&\text{If } ENA\_U\_MULT \text{ is } TRUE:\\&\text{Effective start value} = \text{Start value low}\end{aligned}$$

(Equation 9)

$$\begin{aligned}&\text{If } ENA\_U\_MULT \text{ is } FALSE:\\&\text{Effective start value} = \text{Start value}\end{aligned}$$

(Equation 10)

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_U_MULT 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.

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 settings *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

In a drop-off situation, that is, when 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 trip 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.1.5.5 Application

The three-phase 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 below the full-load current. If the generator excitation power is fed from the generator terminals, a voltage drop caused by a short circuit also leads to low fault current. 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 to maintain high fault currents by controlling the generator excitation system. 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.

Voltage step characteristic is applied to generators used in industrial systems. Under close-up 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 ensure 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, the 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, ensuring the operation of PHPVOC despite 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.

4.1.5.6 Signals

Table 315: PHPVOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
U_AB	SIGNAL	0	Phase-to-phase voltage AB
U_BC	SIGNAL	0	Phase-to-phase voltage BC
U_CA	SIGNAL	0	Phase-to-phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
ENA_LOW_LIM	BOOLEAN	0=False	Enable signal for voltage dependent lower start value

Table 316: PHPVOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.1.5.7 Settings

Table 317: PHPVOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	0.01	0.05	Start value
Start value low	0.05...1.00	xIn	0.01	0.05	Lower start value based on voltage control
Voltage high limit	0.01...1.00	xUn	0.01	1.00	Voltage high limit for voltage control
Voltage low limit	0.01...1.00	xUn	0.01	1.00	Voltage low limit for voltage control
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	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type
Operate delay time	40...200000	ms	10	40	Operate delay time

Table 318: PHPVOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 319: PHPVOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 320: PHPVOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Control mode	1=Voltage control 2=Input control 3=Voltage and input Ctl 4=No Volt dependency			1=Voltage control	Type of control
Minimum operate time	40...60000	ms	1	40	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.5.8 Monitored data

Table 321: PHPVOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
EFF_ST_VAL_A	FLOAT32	0.00...50.00	xIn	Effective start value for phase A
EFF_ST_VAL_B	FLOAT32	0.00...50.00	xIn	Effective start value for phase B
EFF_ST_VAL_C	FLOAT32	0.00...50.00	xIn	Effective start value for phase C
PHPVOC	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Name	Type	Values (Range)	Unit	Description
		5=off		

4.1.5.9 Technical data

Table 322: PHPVOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current and voltage: f_n ±2 Hz
	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 , [2]	Typically 26 ms
Reset time	Typically 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 inverse time mode	±5.0% of the set value or ±20 ms
Suppression of harmonics	-50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

4.1.6 Three-phase thermal protection for feeders, cables and distribution transformers T1PTTR

4.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR	3Ith>F	49F

[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

4.1.6.2 Function block

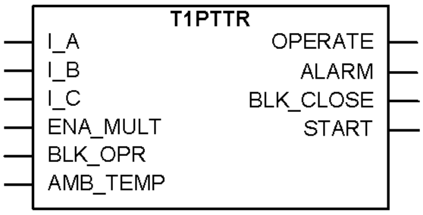


Figure 168: Function block

4.1.6.3 Functionality

The increased utilization of power systems closer to the thermal limits has generated a need for a thermal overload function for power lines as well.

A thermal overload is in some cases not detected by other protection functions, and the introduction of the three-phase thermal protection for feeders, cables and distribution transformers 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 operates 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.

4.1.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of T1PTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured locally or remotely. Local measurement is done by the protection relay. Remote measurement uses analog GOOSE to connect `AMB_TEMP` input.

If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

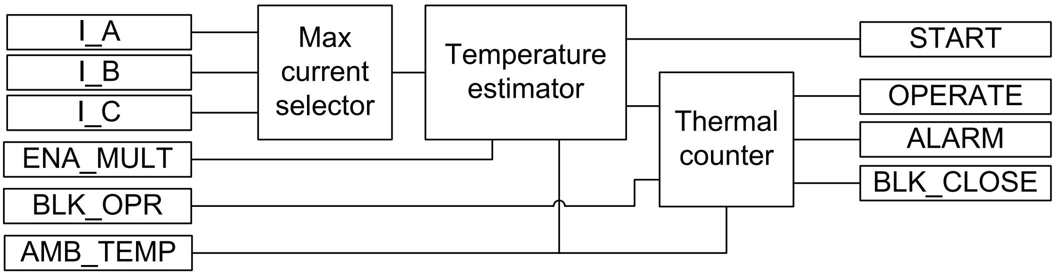


Figure 169: Functional module diagram

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 11)

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 12)

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
t	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 or it can be measured. 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 calculation is only performed if the final temperature is calculated to be above the operation temperature:

$$t_{operate} = -\tau \cdot \ln\left(\frac{\Theta_{final} - \Theta_{operate}}{\Theta_{final} - \Theta_n}\right)$$

(Equation 13)

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 *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 14)

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 ambient temperature can be measured with the RTD measurement. The measured temperature value is then connected, for example, from the AI_VAL3 output of the X130 (RTD) function to the AMB_TEMP input of T1PTTR.

The *Env temperature Set* setting is used to define the ambient temperature if the ambient temperature measurement value is not connected to the AMB_TEMP input. The *Env temperature Set* setting is also used when the ambient temperature measurement connected to T1PTTR is set to “Not in use” in the X130 (RTD) function.

The temperature calculation is initiated from the value defined with the *Initial temperature* setting parameter. This is done in case the protection relay 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 protection relay is restarted.

The thermal time constant of the protected circuit is given in seconds with the *Time constant* setting. Please see cable manufacturers manuals for further details.

T1PTTR thermal model complies with the IEC 60255-149 standard.

4.1.6.5 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.
- Overheating can damage the insulation on cables which in turn increases the risk of phase-to-phase or phase-to-earth faults.

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.

4.1.6.6 Signals

Table 323: T1PTTR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current

Table continues on the next page

Name	Type	Default	Description
I_C	SIGNAL	0	Phase C current
BLK_OPR	BOOLEAN	0=False	Block signal for operate outputs
ENA_MULT	BOOLEAN	0=False	Enable Current multiplier
AMB_TEMP	FLOAT32	0	The ambient temperature used in the calculation

Table 324: T1PTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Thermal Alarm
BLK_CLOSE	BOOLEAN	Thermal overload indicator. To inhibit reclose.

4.1.6.7 Settings

Table 325: T1PTTR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Env temperature Set	-50...100	°C	1	40	Ambient temperature used when no external temperature measurement available
Current reference	0.05...4.00	xIn	0.01	1.00	The load current leading to Temperature raise temperature
Temperature rise	0.0...200.0	°C	0.1	75.0	End temperature rise above ambient
Time constant	60...60000	s	1	2700	Time constant of the line in seconds.
Maximum temperature	20.0...200.0	°C	0.1	90.0	Temperature level for operate
Alarm value	20.0...150.0	°C	0.1	80.0	Temperature level for start (alarm)
Reclose temperature	20.0...150.0	°C	0.1	70.0	Temperature for reset of block reclose after operate

Table 326: T1PTTR Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Current multiplier	1...5		1	1	Current multiplier when function is used for parallel lines

Table 327: T1PTTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 328: T1PTTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Initial temperature	-50.0...100.0	°C	0.1	0.0	Temperature raise above ambient temperature at startup

4.1.6.8 Monitored data

Table 329: T1PTTR Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP	FLOAT32	-100.0...9999.9	°C	The calculated temperature of the protected object
TEMP_RL	FLOAT32	0.00...99.99		The calculated temperature of the protected object relative to the operate level
T_OPERATE	INT32	0...60000	s	Estimated time to operate
T_ENA_CLOSE	INT32	0...60000	s	Estimated time to deactivate BLK_CLOSE
TEMP_AMB	FLOAT32	-99...999	°C	The ambient temperature used in the calcu-lation
T1PTTR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.6.9 Technical data

Table 330: T1PTTR Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	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 accuracy [1]	±2.0% of the theoretical value or ±0.50 s

4.1.6.10 Technical revision history

Table 331: T1PTTR Technical revision history

Technical revision	Change
C	Removed the Sensor available setting parameter
D	Added the AMB_TEMP input
E	Internal improvement.
F	Internal improvement.

4.1.7 Three-phase thermal overload protection, two time constants T2PTTR

4.1.7.1 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/C	49T/G/C

4.1.7.2 Function block

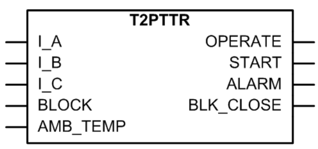


Figure 170: Function block

[1] Overload current > 1.2 × Operate level temperature

4.1.7.3 Functionality

The three-phase thermal overload, two time constants, 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.

4.1.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of T2PTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured locally or remotely. Local measurement is done by the protection relay. Remote measurement uses analog GOOSE to connect AMB_TEMP input.

If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

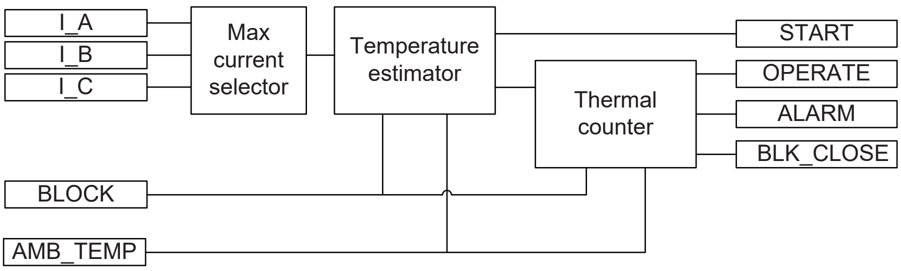


Figure 171: Functional module diagram

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 15)

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 value is added to the calculated final temperature rise estimation. If the total value of temperature is higher than the set operate 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 16)

ΔΘ	calculated temperature rise (°C) in transformer
I	measured phase current with the highest TRMS value
I_{ref}	the set value of the *Current reference* setting (rated current of the protected object)
T_{ref}	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 *Weighting factor p* setting (weighting factor for the short time constant)
Δt	time step between the calculation of the actual temperature
t_1	the set value of the *Short time constant* setting (the short heating / cooling time constant)
t_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 protection relay is able to follow both fast and slow changes in the temperature of the protected object.

The *Weighting factor p* setting is the weighting factor between *Short time constant* τ_1 and *Long time constant* τ_2. The higher the value of the *Weighting factor p* setting, the larger is the share of the steep part of the heating curve. When *Weighting factor p* =1, only *Short-time constant* is used. When *Weighting factor p* = 0, only *Long time constant* is used.

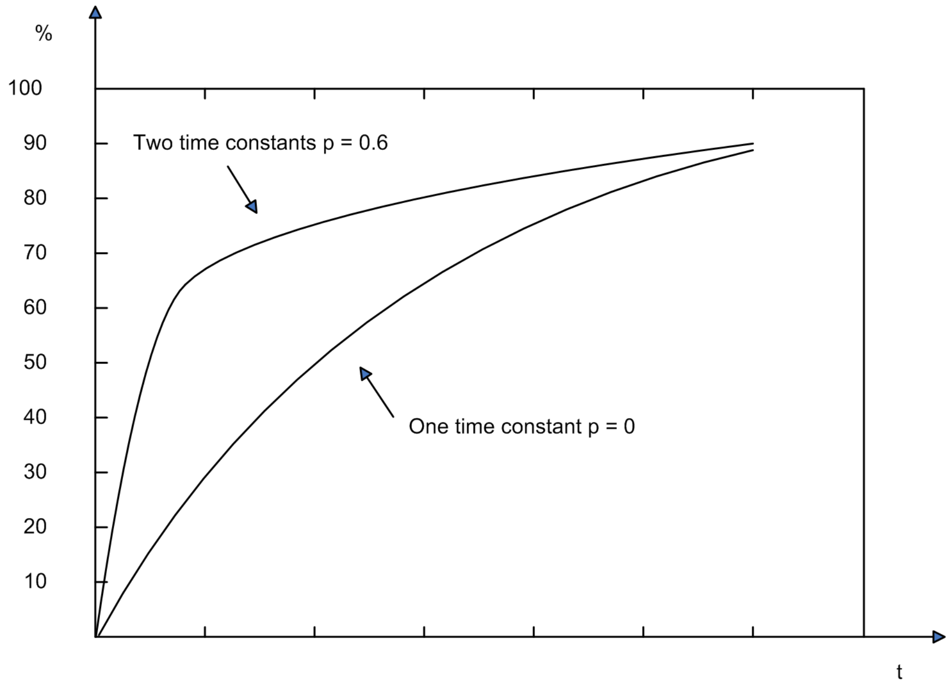


Figure 172: Effect of the Weighting factor p factor and the difference between the two time constants and one time constant models

The actual temperature of the transformer is calculated by adding the ambient temperature to the calculated temperature.

$$\Theta = \Delta\Theta + \Theta_{amb}$$

(Equation 17)

Θ	temperature in transformer (°C)
$\Delta\Theta$	calculated temperature rise (°C) in transformer
Θ_{amb}	set value of the *Env temperature Set* setting or measured ambient temperature

The ambient temperature can be measured with RTD measurement. The measured temperature value is connected, for example, from the `AI_VAL3` output of the X130 (RTD) function to the `AMB_TEMP` input of T2PTTR.

The *Env temperature Set* setting is used to define the ambient temperature if the ambient temperature measurement value is not connected to the `AMB_TEMP` input. The *Env temperature Set* setting is also used when the ambient temperature measurement connected to T2PTTR is set to “Not in use” in the X130 (RTD) function.

The temperature calculation is initiated from the value defined with the *Initial temperature* and *Max temperature* setting parameters. The initial value is a percentage of *Max temperature* defined by *Initial temperature*. This is done when the protection relay is powered up or the function is turned off and back on or reset through the Clear menu. The temperature is stored in a nonvolatile memory and restored if the protection relay 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.

4.1.7.5 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, a single time constant, it can be converted to two time constants. The single time constant is also used by itself if the p-factor *Weighting factor p* 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 332: Conversion table between one and two time constants

Single time constant (min)	*Short time constant* (min)	*Long time constant* (min)	*Weighting factor p*
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.

4.1.7.6 Signals

Table 333: T2PTTR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
AMB_TEMP	FLOAT32	0	The ambient temperature used in the calculation

Table 334: T2PTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Thermal Alarm
BLK_CLOSE	BOOLEAN	Thermal overload indicator. To inhibite reclose.

4.1.7.7 Settings

Table 335: T2PTTR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Env temperature Set	-50...100	°C	1	40	Ambient temperature used when no external temperature measurement available
Temperature rise	0.0...200.0	°C	0.1	78.0	End temperature rise above ambient
Max temperature	0.0...200.0	°C	0.1	105.0	Maximum temperature allowed for the transformer
Operate temperature	80.0...120.0	%	0.1	100.0	Operate temperature, percent value
Alarm temperature	40.0...100.0	%	0.1	90.0	Alarm temperature, percent value

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Reclose temperature	40.0...100.0	%	0.1	60.0	Temperature for reset of block reclose after operate
Short time constant	6...60000	s	1	450	Short time constant in seconds
Long time constant	60...60000	s	1	7200	Long time constant in seconds
Weighting factor p	0.00...1.00		0.01	0.40	Weighting factor of the short time constant

Table 336: T2PTTR Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Current reference	0.05...4.00	xIn	0.01	1.00	The load current leading to Temperature raise temperature

Table 337: T2PTTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 338: T2PTTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Initial temperature	0.0...100.0	%	0.1	80.0	Initial temperature, percent value

4.1.7.8 Monitored data

Table 339: T2PTTR Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP	FLOAT32	-100.0...9999.9	°C	The calculated temperature of the protected object
TEMP_RL	FLOAT32	0.00...99.99		The calculated temperature of the protected object relative to the operate level
T_OPERATE	INT32	0...60000	s	Estimated time to operate
T_ENA_CLOSE	INT32	0...60000	s	Estimated time to deactivate BLK_CLOSE in seconds

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
TEMP_AMB	FLOAT32	-99...999	°C	The ambient temperature used in the calcu-lation
T2PTTR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.7.9 Technical data

Table 340: T2PTTR Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Current measurement: ±1.5% of the set value or ±0.002 x I_n (at currents in the range of 0.01...4.00 x I_n)
Operate time accuracy[1]	±2.0% of the theoretical value or ±0.50 s

4.1.7.10 Technical revision history

Table 341: T2PTTR Technical revision history

Technical revision	Change
B	Added the `AMB_TEMP` input
C	Internal improvement.
D	Internal improvement.

4.1.8 Motor load jam protection JAMPTOC

4.1.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor load jam protection	JAMPTOC	Ist>	51LR

1 Overload current > 1.2 x Operate level temperature

4.1.8.2 Function block

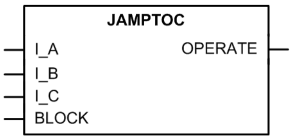


Figure 173: Function block

4.1.8.3 Functionality

The motor load jam protection function 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 the function outputs.

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 JAMPTOC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

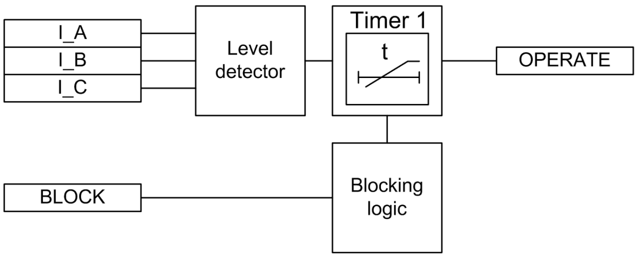


Figure 174: Functional module diagram

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 internal `START` signal is activated. The value is available only through the Monitored data view. The time characteristic is according to DT. When the operation timer has reached the *Operate delay time* value, 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.1.8.5 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.

4.1.8.6 Signals

Table 342: JAMPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 343: JAMPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate

4.1.8.7 Settings

Table 344: JAMPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Start value	0.10...10.00	xIn	0.01	2.50	Start value
Operate delay time	100...120000	ms	10	2000	Operate delay time

Table 345: JAMPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	100	Reset delay time

4.1.8.8 Monitored data

Table 346: JAMPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START	BOOLEAN	0=False 1=True		Start
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
JAMPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Name	Type	Values (Range)	Unit	Description
		5=off		

4.1.8.9 Technical data

Table 347: JAMPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × I_n
Reset time	Typically 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

4.1.8.10 Technical revision history

Table 348: JAMPTOC Technical revision history

Technical revision	Change
B	Internal improvement
C	Internal improvement

4.1.9 Loss of load supervision LOFLPTUC

4.1.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Loss of load supervision	LOFLPTUC	3I<	37

4.1.9.2 Function block

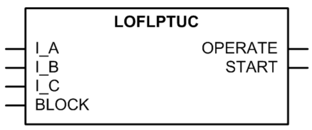


Figure 175: Function block

4.1.9.3 Functionality

The loss of load supervision function 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.

4.1.9.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LOFLPTUC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

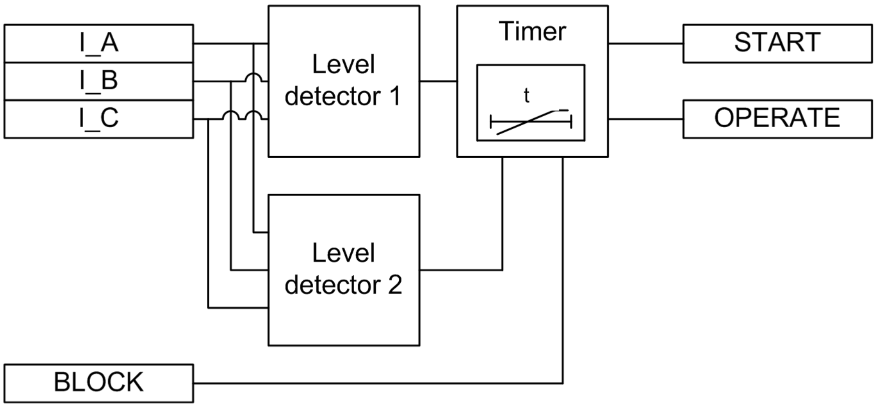


Figure 176: Functional module diagram

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.

4.1.9.5 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.

4.1.9.6 Signals

Table 349: LOFLPTUC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block all binary outputs by resetting timers

Table 350: LOFLPTUC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.1.9.7 Settings

Table 351: LOFLPTUC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value low	0.01...0.50	xIn	0.01	0.10	Current setting/Start value low
Start value high	0.01...1.00	xIn	0.01	0.50	Current setting/Start value high
Operate delay time	400...600000	ms	10	2000	Operate delay time

Table 352: LOFLPTUC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 353: LOFLPTUC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.9.8 Monitored data

Table 354: LOFLPTUC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
LOFLPTUC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.9.9 Technical data

Table 355: LOFLPTUC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × I_n
Start time	Typically 300 ms
Reset time	Typically 40 ms

Table continues on the next page

Characteristic	Value
Reset ratio	Typically 1.04
Retardation time	<35 ms
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms

4.1.9.10 Technical revision history

Table 356: LOFLPTUC Technical revision history

Technical revision	Change
B	Internal improvement
C	Internal improvement

4.1.10 Loss of phase, undercurrent PHPTUC

4.1.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Loss of phase, undercurrent	PHPTUC1	3I<	37

4.1.10.2 Function block

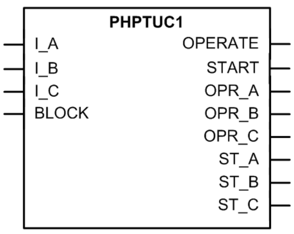


Figure 177: Function block

4.1.10.3 Functionality

The loss of phase, undercurrent, protection function PHPTUC is used to detect an undercurrent that is considered as a fault condition.

PHPTUC starts when the current is less than the set limit. Operation time characteristics are according to definite time (DT).

The function contains a blocking functionality. It is possible to block function outputs and reset the definite timer, if desired..

4.1.10.4 Operation principle

The function can be enabled and disabled with the *Operation setting*. The corresponding parameter values are "On" and "Off".

The operation of PHPTUC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

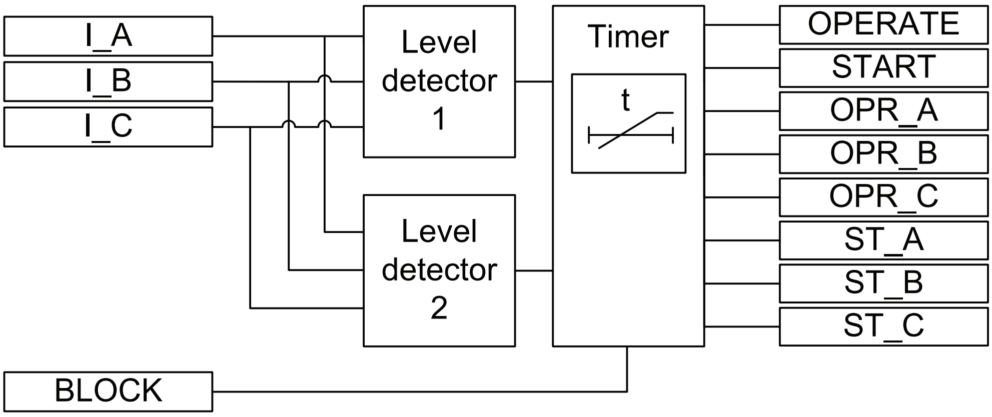


Figure 178: Functional module diagram

Level detector 1

This module compares the phase currents (RMS value) to the *Start value* setting. The *Operation mode*setting can be used to select the "Three Phase" or "Single Phase" mode.

If in the "Three Phase" mode all the phase current values are less than the value of the *Start value* setting, the 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* value of the element.

If in the "Single Phase" mode any of the phase current values are less than the value of the *Start value* setting, the condition is detected and an enable signal is sent to the timer. This signal is disabled after all the phase currents have exceeded the set *Start value* value of the element.

The protection relay does not accept the *Start value* to be smaller than *Current block value*.

Level detector 2

This is a low-current detection module that monitors the de-energized condition of the protected object. The module compares the phase currents (RMS value) to the *Start value low* setting. If all the phase current values are less than the *Start value low* setting, a signal is sent to block the operation of the timer.

Timer

Once activated, the timer activates the `START` output and the phase-specific `ST_X output`. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output and the phase-specific `OPR_X` output are 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 through the monitored data view.

The BLOCK signal blocks the operation of the function and resets the timer.

4.1.10.5 Application

In some cases, smaller distribution power transformers are used where the high-side protection involves only power fuses. When one of the high-side fuses blows in a single-phase condition, knowledge of it on the secondary side is lacking. The resulting negative-sequence current leads to a premature failure due to excessive heating and breakdown of the transformer insulation. Knowledge of this condition when it occurs allows for a quick fuse replacement and saves the asset.

The *Current block value* setting can be set to zero to not block PHPTUC with a low three-phase current. However, this results in an unnecessary event sending when the transformer or protected object is disconnected.

Phase-specific start and operate can give a better picture about the evolving faults when one phase has started first and another follows.

PHPTUC is meant to be a general protection function, so that it could be used in other cases too

In case of undercurrent-based motor protection, see the Loss of load protection.

4.1.10.6 Signals

Table 357: PHPTUC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block all binary outputs by resetting timers

Table 358: PHPTUC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_A	BOOLEAN	Operate phase A
OPR_B	BOOLEAN	Operate phase B
OPR_C	BOOLEAN	Operate phase C
START	BOOLEAN	Start
ST_A	BOOLEAN	Start phase A
ST_B	BOOLEAN	Start phase B
ST_C	BOOLEAN	Start phase C

4.1.10.7 Settings

Table 359: PHPTUC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Current block value	0.00...0.50	xIn	0.01	0.10	Low current setting to block internally
Start value	0.01...1.00	xIn	0.01	0.50	Current setting to start
Operate delay time	50...200000	ms	10	2000	Operate delay time

Table 360: PHPTUC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Three Phase 2=Single Phase			1=Three Phase	Number of phases needed to start

Table 361: PHPTUC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.10.8 Monitored data

Table 362: PHPTUC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHPTUC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.10.9 Technical data

Table 363: PHPTUC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current and voltages: f_n ±2 Hz
	±1.5% of the set value or ± 0.002 × I_n
Start time	Typically <55 ms
Reset time	<40 ms

Table continues on the next page

Characteristic	Value
Reset ratio	Typically 1.04
Retardation time	<35 ms
Operate time accuracy in definite time mode	mode ±1.0% of the set value or ±20 ms

4.1.11 Thermal overload protection for motors MPTTR

4.1.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Thermal overload protection for motors	MPTTR	3Ith>M	49M

4.1.11.2 Function block

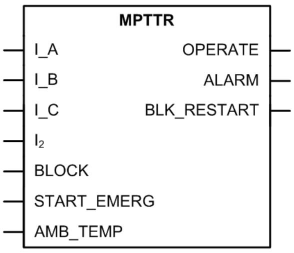


Figure 179: Function block

4.1.11.3 Functionality

The thermal overload protection for motors 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.

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.

4.1.11.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MPTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured locally or remotely. Local measurement is done by the protection relay. Remote measurement uses analog GOOSE to connect AMB_TEMP input.

If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

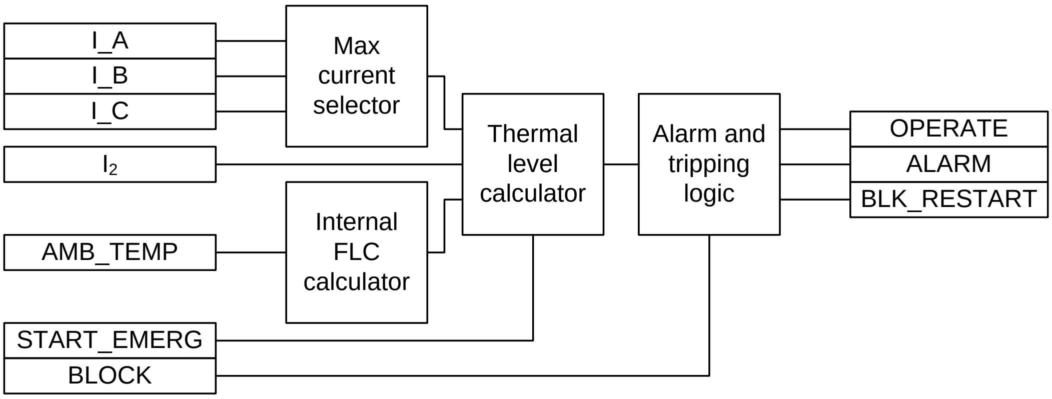


Figure 180: Functional module diagram

Max current selector

Max current selector selects the highest measured TRMS phase current and reports it to Thermal level calculator.

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 "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 "Use input" mode, the internal FLC is calculated from temperature data available through resistance temperature detectors (RTDs) using the AMB_TEMP input.

Table 364: 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 ambient temperature is used for calculating thermal level and it is available in the monitored data view from the `TEMP_AMB` output. The activation of the `BLOCK` input does not affect the `TEMP_AMB` output.

The *Env temperature Set* setting is used:

- If the ambient temperature measurement value is not connected to the AMB_TEMP input in ACT.
- When the ambient temperature measurement connected to 49M is set to "Not in use" in the RTD function.
- In case of any errors or malfunctioning in the RTD output.

Thermal level calculator

The module calculates the thermal load considering the TRMS and negative-sequence currents. The heating up 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. By deploying a protection based on both current components, abnormal heating of the motor is avoided.

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 18)

$$\theta_A = \left[\left(\frac{I}{k \times I_r} \right)^2 + K_2 \times \left(\frac{I_2}{k \times I_r} \right)^2 \right] \times \left(1 - e^{-t/\tau} \right) \times 100\%$$

(Equation 19)

I	TRMS value of the measured max of phase currents
I_r	set *Current reference*, 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*
t	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 20)

θ_{02}	initial thermal level when cooling begins

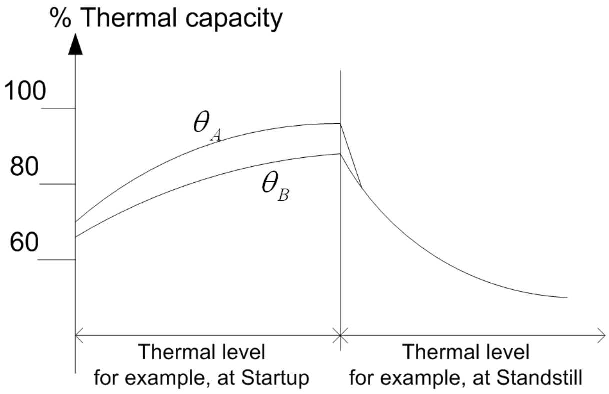


Figure 181: Thermal behavior

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 365: 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 protection relay is defined by the *Initial thermal Val* setting.

The temperature calculation is initiated from the value defined in the *Initial thermal Val* setting. This is done if the protection relay is powered up or the function is turned off and back on or reset through the Clear menu.

The calculated temperature of the protected object relative to the operate level, the TEMP_RL output, is available through the monitored data view. The activation of the BLOCK input does not affect the calculated temperature.

The thermal level at the beginning of the start-up condition of a motor and at the end of the start-up condition is available in the monitored 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 start-up is available through 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 emergency start signal START_EMERG is set high, the thermal level is set to a value below the thermal restart inhibit level. This allows at least one motor start-up, even though the thermal level has exceeded the restart inhibit level.

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 *Current reference* or the thermal content drops below 100 percent.

The activation of the BLOCK input blocks the ALARM, BLK_RESTART and OPERATE outputs.

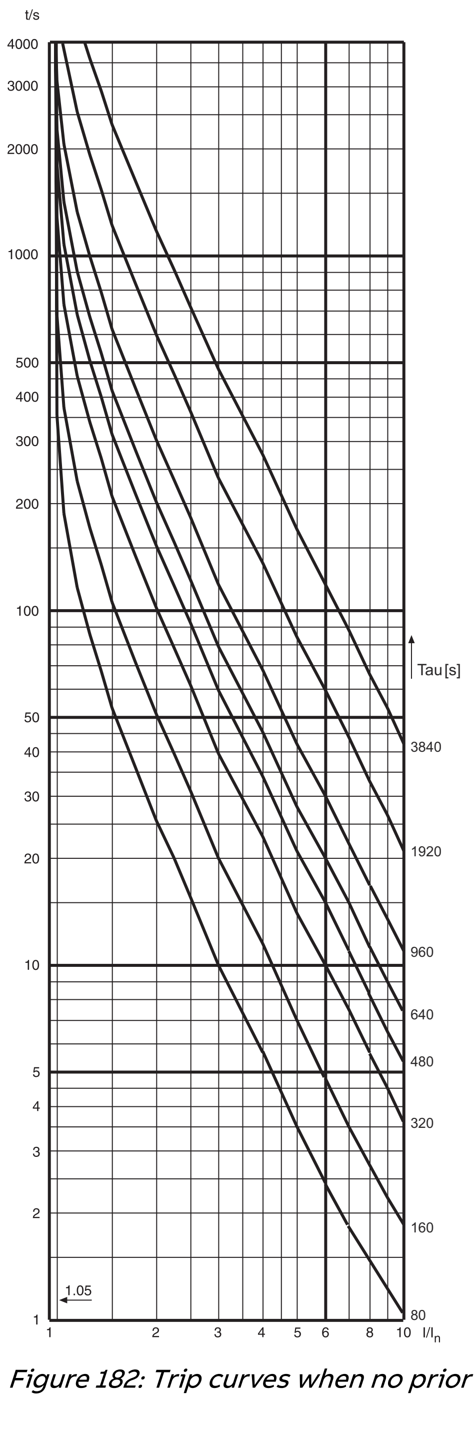


Figure 182: Trip curves when no prior load and p=20...100 %. Overload factor = 1.05.

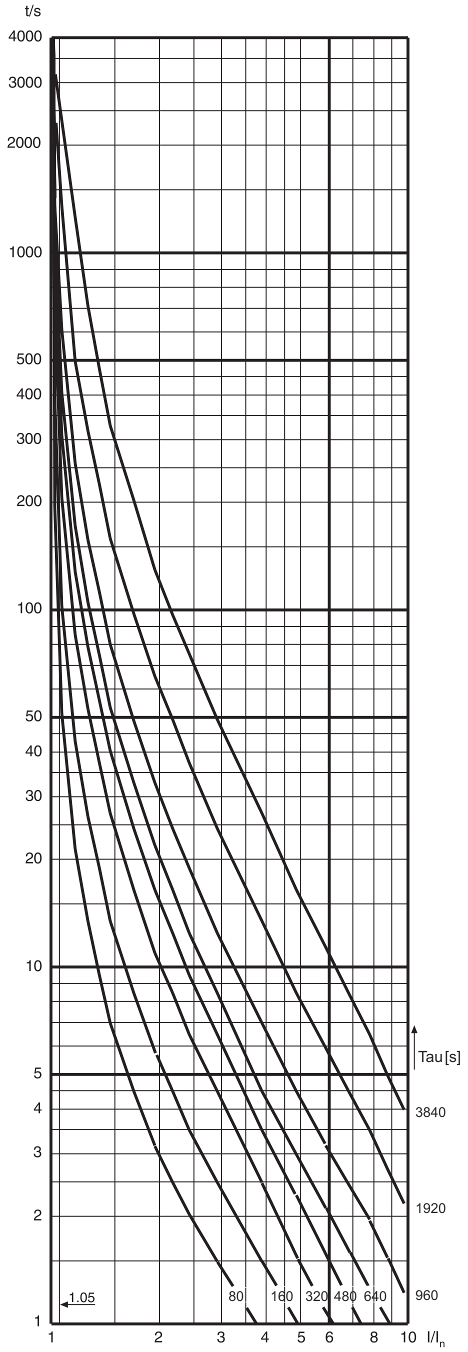


Figure 183: Trip curves at prior load 1 x FLC and p=100 %, Overload factor = 1.05.

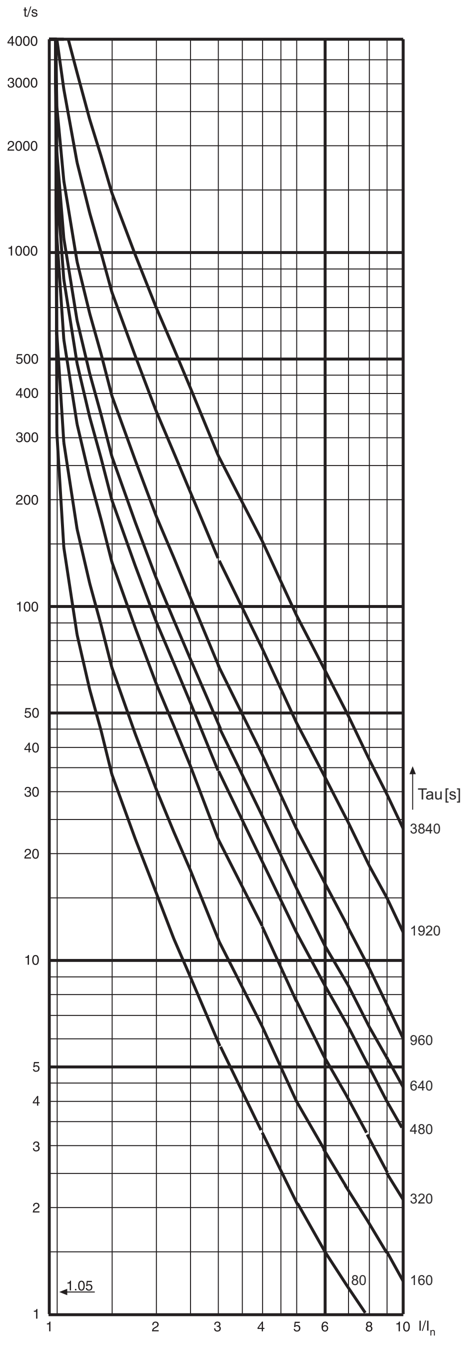


Figure 184: Trip curves at prior load 1 x FLC and p=50 %. Overload factor = 1.05.

4.1.11.5 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.

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 185*, 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 protection relay 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 start-up, the thermal level starts to decrease quite sharply, simulating the leveling out of the hot spots. Consequently, the probability of successive allowed start-ups 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.

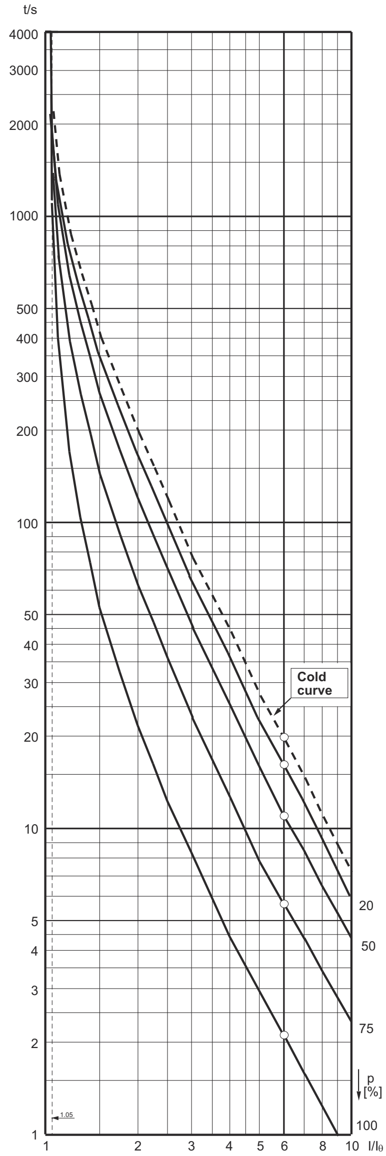


Figure 185: The influence of Weighting factor p at prior load 1xFLC, timeconstant = 640 s, and Overload factor = 1.05

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 21)

R_{R2}	Rotor negative sequence resistance
R_{R1}	Rotor positive sequence resistance

A conservative estimate for the setting can be calculated:

$$Negative\,Seq\ factor = \frac{175}{I_{LR}^2}$$

(Equation 22)

I_{LR}	Locked rotor current (multiple of set *Rated current*). The same as the start-up current at the beginning of the motor start-up.

For example, if the rated current of a motor is 230 A, start-up current is 5.7 x I_r,

$$Negative\,Seq\ factor = \frac{175}{5.7^2} = 5.4$$

(Equation 23)

Setting the thermal restart level

The restart disable level can be calculated as follows:

$$\theta_i = 100\% - \left(\frac{\text{startup time of the motor}}{\text{operate time when no prior load}} \times 100\% + \text{margin}\right)$$

(Equation 24)

For example, the motor start-up 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 start-up 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 *Alarm thermal value* 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.

4.1.11.6 Signals

Table 366: MPTTR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
START_EMERG	BOOLEAN	0=False	Signal for indicating the need for emergency start
AMB_TEMP	FLOAT32	0	The ambient temperature used in the calculation

Table 367: MPTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
ALARM	BOOLEAN	Thermal Alarm
BLK_RESTART	BOOLEAN	Thermal overload indicator, to inhibit restart

4.1.11.7 Settings

Table 368: MPTTR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Overload factor	1.00...1.20		0.01	1.05	Overload factor (k)
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
Negative Seq factor	0.0...10.0		0.1	0.0	Heating effect factor for negative sequence current
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

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
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
Env temperature mode	1=FLC Only 2=Use input 3=Set Amb Temp			1=FLC Only	Mode of measuring ambient temperature
Env temperature Set	-20.0...70.0	°C	0.1	40.0	Ambient temperature used when no external temperature measurement available

Table 369: MPTTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 370: MPTTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Current reference	0.30...2.00	xIn	0.01	1.00	Rated current (FLC) of the motor
Initial thermal Val	0.0...100.0	%	0.1	74.0	Initial thermal level of the motor

4.1.11.8 Monitored data

Table 371: MPTTR Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP_RL	FLOAT32	0.00...9.99		The calculated temperature of the protected object relative to the operate level
TEMP_AMB	FLOAT32	-99...999	°C	The ambient temperature used in the calculation
THERMLEV_ST	FLOAT32	0.00...9.99		Thermal level at beginning of motor startup
THERMLEV_END	FLOAT32	0.00...9.99		Thermal level at the end of motor startup situation

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
T_ENARESTART	INT32	0...99999	s	Estimated time to reset of block restart
MPTTR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
Therm-Lev	FLOAT32	0.00...9.99		Thermal level of protected object (1.00 is the operate level)

4.1.11.9 Technical data

Table 372: MPTTR Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	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 accuracy [1]	±2.0% of the theoretical value or ±0.50 s

4.1.11.10 Technical revision history

Table 373: MPTTR Technical revision history

Technical revision	Change
B	Added a new input AMB_TEMP. Added a new selection for the *Env temperature mode* setting "Use input".
C	Internal improvement.
D	Time constant stop range maximum value changed from 8000 s to 60000 s.
E	Internal improvement.

[1] Overload current > 1.2 × Operate level temperature

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

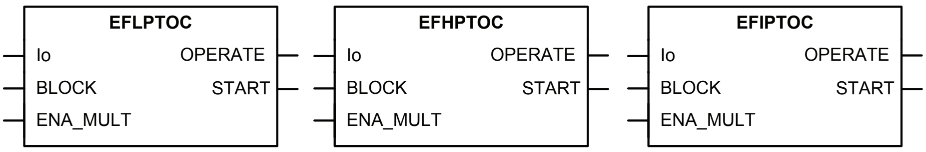


Figure 186: Function block

4.2.1.3 Functionality

The non-directional earth-fault protection 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 EFxPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

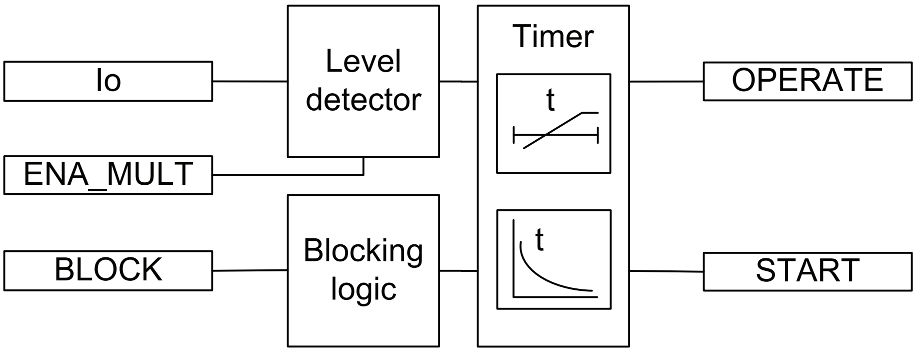


Figure 187: Functional module diagram

Level detector

The operating quantity can be selected with the setting *Io signal Sel*. The selectable options are "Measured Io" and "Calculated Io". 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.

The protection relay does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

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 *Chapter 11.2.1 IDMT curves for overcurrent protection* 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.2.1.5 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 374: Measurement modes supported by EFxPTOC stages

Measurement mode	EFLPTOC	EFHPTOC	EFIPTOC
RMS	x	x	
DFT	x	x	
Peak-to-Peak	x	x	x

For a detailed description of the measurement modes, see *Chapter 11.5 Measurement modes* in this manual.

4.2.1.6 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 protection relay 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 375: Timer characteristics supported by different stages

Operating curve type	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 *Chapter 11 General function block features* in this manual.

Table 376: Reset time characteristics supported by different stages

Reset curve type	EFLPTOC	EFHPTOC	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 EFIPTOC or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

4.2.1.7 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.

4.2.1.8 Signals

EFLPTOC Input signals

Table 377: EFLPTOC Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

EFHPTOC Input signals

Table 378: EFHPTOC Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

EFIPTOC Input signals

Table 379: EFIPTOC Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

EFLPTOC Output signals

Table 380: EFLPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

EFHPTOC Output signals

Table 381: EFHPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

EFIPTOC Output signals

Table 382: EFIPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.1.9 Settings

EFLPTOC Group settings

Table 383: EFLPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...5.000	xIn	0.005	0.010	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type

Table 384: EFLPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 385: EFLPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 386: EFLPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal

EFHPTOC Group settings

Table 387: EFHPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	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
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv. 5=ANSI Def. Time 9=IEC Norm. inv. 10=IEC Very inv. 12=IEC Ext. inv. 15=IEC Def. Time 17=Programmable			15=IEC Def. Time	Selection of time delay curve type

Table 388: EFHPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 389: EFHPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 390: EFHPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal

EFIPTOC Group settings

Table 391: EFIPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	1.00...40.00	xIn	0.01	1.00	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Operate delay time	20...200000	ms	10	20	Operate delay time

Table 392: EFIPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 393: EFIPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal

4.2.1.10 Monitored data

Table 394: EFLPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
EFLPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 395: EFHPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
EFHPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 396: EFIPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
EFIPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.1.11 Technical data

Table 397: EFxPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
	EFLPTOC	±1.5% of the set value or ±0.002 × I_n		
	EFHPTOC and EFIPTOC	±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 ,		Minimum	Typical	Maximum
	EFIPTOC: I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	16 ms 11 ms	19 ms 12 ms	23 ms 14 ms
	EFHPTOC and EFLPTOC: I_{Fault} = 2 × set *Start value*	23 ms	26 ms	29 ms
Reset time		Typically 40 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		
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		

4.2.1.12 Technical revision history

Table 398: EFIPTOC Technical revision history

Technical revision	Change
B	The minimum and default values changed to 40 ms for the *Operate delay time* setting
C	Minimum and default values changed to 20 ms for the *Operate delay time* setting Minimum value changed to 1.00 x In for the *Start value* setting
D	Added a setting parameter for the "Measured Io" or "Calculated Io" selection

Table continues on the next page

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...20

Technical revision	Change
E	Internal improvement
F	Internal improvement

Table 399: EFHPTOC Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting
C	Added a setting parameter for the "Measured Io" or "Calculated Io" selection
D	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting
E	Internal improvement
F	Internal improvement

Table 400: EFLPTOC Technical revision history

Technical revision	Change
B	The minimum and default values changed to 40 ms for the *Operate delay time* setting
C	*Start value* step changed to 0.005
D	Added a setting parameter for the "Measured Io" or "Calculated Io" selection
E	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting
F	Internal improvement
G	Internal improvement

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

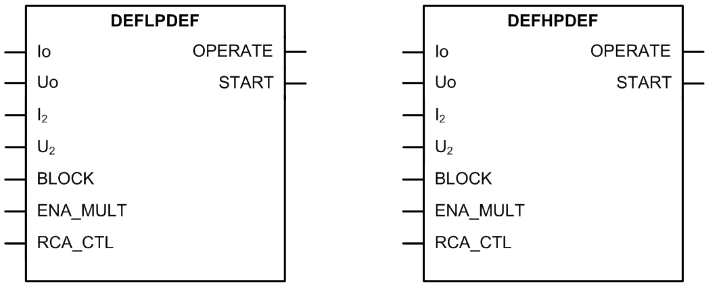


Figure 188: Function block

4.2.2.3 Functionality

The directional earth-fault protection 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 DEFxPDEF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

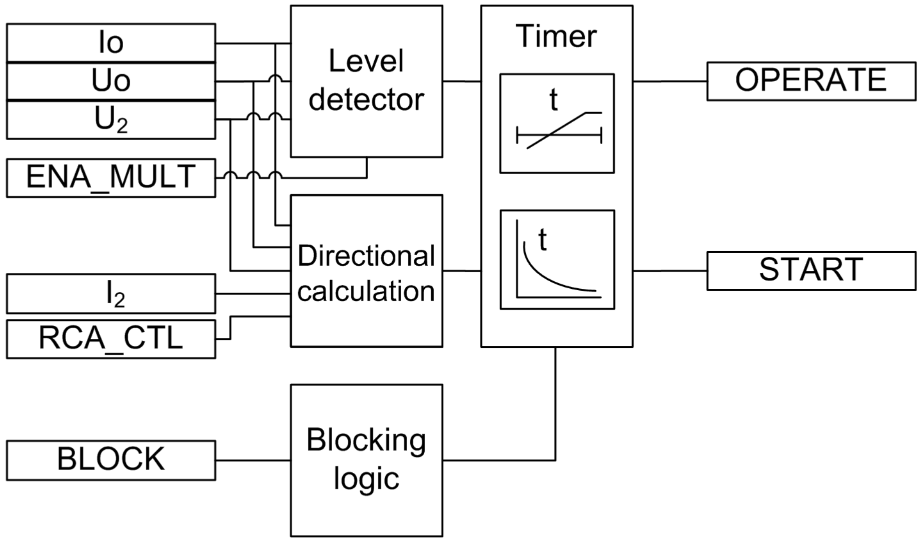


Figure 189: Functional module diagram

Level detector

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 the limits are exceeded, the level detector sends an enabling signal to the timer module. When the *Enable voltage limit* setting is set to "False", *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.

The operating quantity (residual current) can be selected with the setting *Io signal Sel*. The options are "Measured Io" and "Calculated Io". If "Measured Io" is selected, the current ratio for Io-channel is given in **Configuration** > **Analog inputs** > **Current (Io,CT)**. If "Calculated Io" is selected, the current ratio is obtained from the phase-current channels given in **Configuration** > **Analog inputs** > **Current (3I,CT)**.

The operating quantity (residual voltage) can be selected with the setting *Uo signal Sel.* The options are "Measured Uo" and "Calculated Uo". If "Measured Uo" is selected, the voltage ratio for Uo-channel is given in **Configuration** > **Analog inputs** > **Voltage (Uo,VT)**. If "Calculated Uo" is selected, the voltage ratio is obtained from the phase-voltage channels given in **Configuration** > **Analog inputs** > **Voltage (3U,VT)**.

Example 1: Io is measured with cable core CT (100/1 A) and Uo is measured from open-delta connected VTs (20/sqrt(3) kV : 100/sqrt(3) V : 100/3 V). In this case, "Measured Io" and "Measured Uo" are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios entered in Residual current Io: **Configuration** > **Analog inputs** > **Current (Io,CT)**: 100 A : 1 A. The Residual voltage Uo: **Configuration** > **Analog inputs** > **Voltage (Uo,VT)**: 11.547 kV : 100 V. The *Start value* of 1.0 × In corresponds to 1.0 * 100 A = 100 A in the primary. The *Voltage start value* of 1.0 × Un corresponds to 1.0 * 11.547 kV = 11.547 kV in the primary.

Example 2: Both Io and Uo are calculated from the phase quantities. Phase CT-ratio is 100 : 1 A and phase VT-ratio is 20/sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated Io" and "Calculated Uo" are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios entered in Residual current Io: **Configuration** > **Analog inputs** > **Current (3I,CT)**: 100 A : 1 A. The residual voltage Uo: **Configuration** > **Analog inputs** > **Voltage (3U,VT)**: 20.000 kV : 100 V. The *Start value* of 1.0 × In corresponds to 1.0 * 100 A = 100 A in the primary. The *Voltage start value* of 1.0 × Un corresponds to 1.0 * 20.000 kV = 20.000 kV in the primary.

If "Calculated Uo" is selected, the residual voltage nominal value is always phase-to-phase voltage. Thus, the valid maximum setting for residual Voltage start value is 0.577 x Un. The calculated Uo requires that all the three phase-to-earth voltages are connected to the protection relay. Uo cannot be calculated from the phase-to-phase voltages.

If the *Enable voltage limit* setting is set to "True", the magnitude of the polarizing quantity is checked even if the *Directional mode* was set to "Non-directional" or *Allow Non Dir* to "True". The protection relay does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

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 (measured or calculated) 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.

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 (see the connection diagram in the application manual). Similarly the polarity of the calculated Io and I_2 is also switched.

For defining the operation sector, there are five modes available through the *Operation mode* setting.

Table 401: 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| x sin (ANGLE) has a positive value and "reverse" when the value is negative. ANGLE is the angle difference between -Uo and Io.

Table continues on the next page

Operation mode	Description
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 directional operation can be selected with the *Directional mode* setting. The alternatives are "Non-directional", "Forward" and "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 directional information is invalid, that is, when the magnitude of the polarizing quantity is less than the value of the *Min operate voltage* setting.

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 equation for calculating the negative sequence voltage component need to be changed. The network rotating direction is defined with a system parameter *Phase rotation*. The calculation of the component is affected but the angle difference calculation remains the same. When the residual voltage is 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 protection relay using the parameter in the HMI menu: **Configuration** > **System** > **Phase rotation**.

The default parameter value is "ABC".

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 due the inaccuracies in the 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 *Chapter 4.2.2.8 Directional earth-fault characteristics* in this manual.

For definitions of different directional earth-fault characteristics, refer to general function block features information.

The directional calculation module calculates several values which are presented in the monitored data.

Table 402: 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, U2) and operating quantity (Io, I2).
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 x sin(ANGLE). If the Operation mode setting is "IoCos", I_OPER is calculated as follows I_OPER = Io x 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 *Chapter 11.2.1 IDMT curves for overcurrent protection* 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

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* setting, 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 the 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

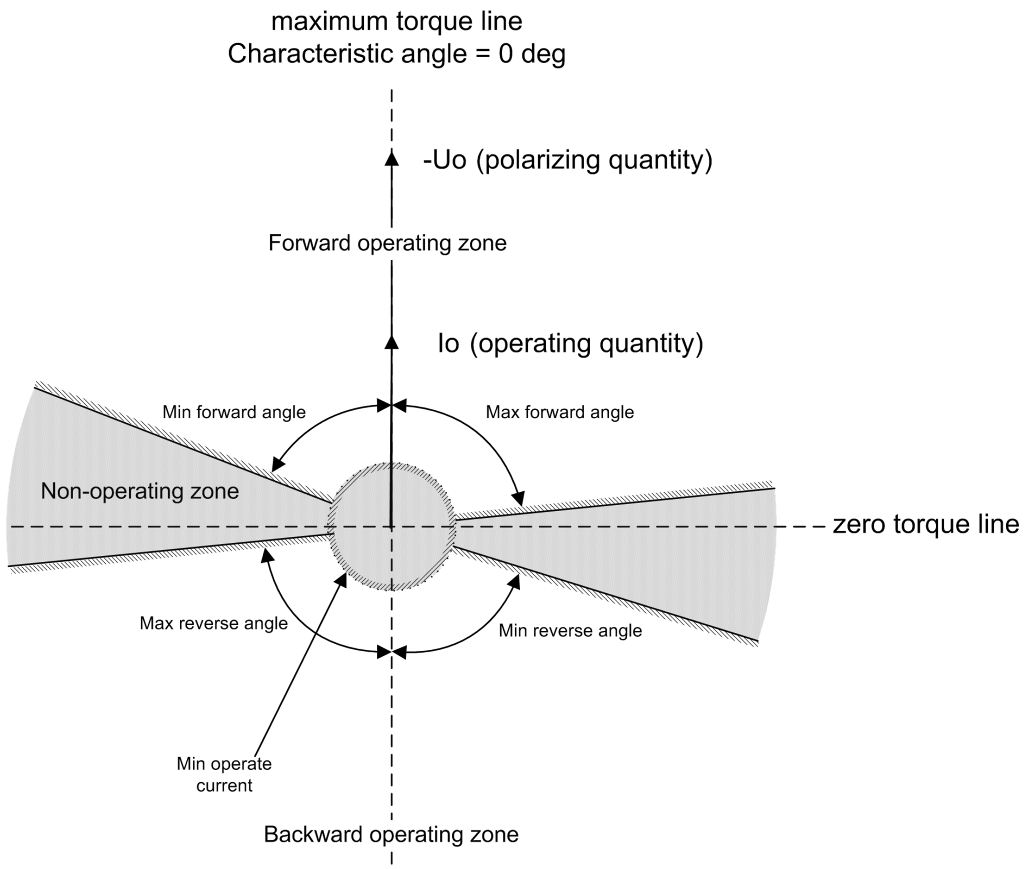


Figure 190: Definition of the relay characteristic angle, RCA=0 degrees in a compensated network

Example 2

The "Phase angle" mode is selected, solidly earthed network (ϕRCA = +60 deg)

=> *Characteristic angle* = +60 deg

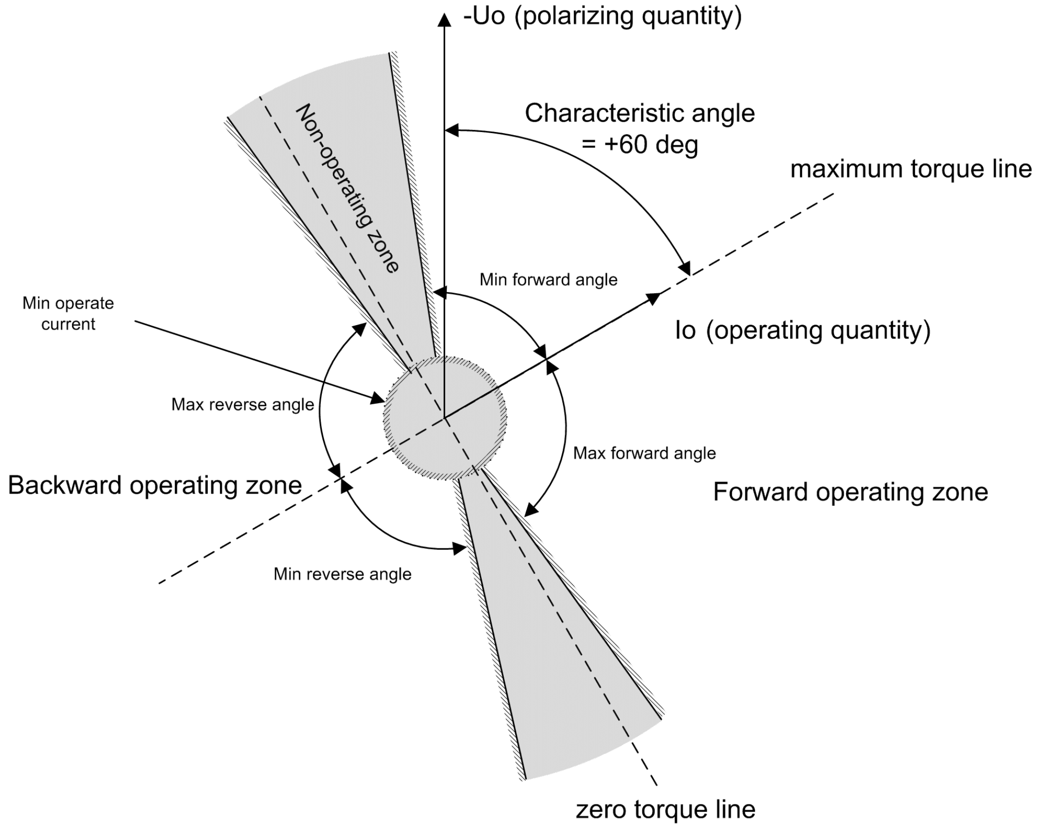


Figure 191: Definition of the relay characteristic angle, RCA=+60 degrees in a solidly earthed network

Example 3

The "Phase angle" mode is selected, isolated network (ϕRCA = -90 deg)

=> *Characteristic angle* = -90 deg

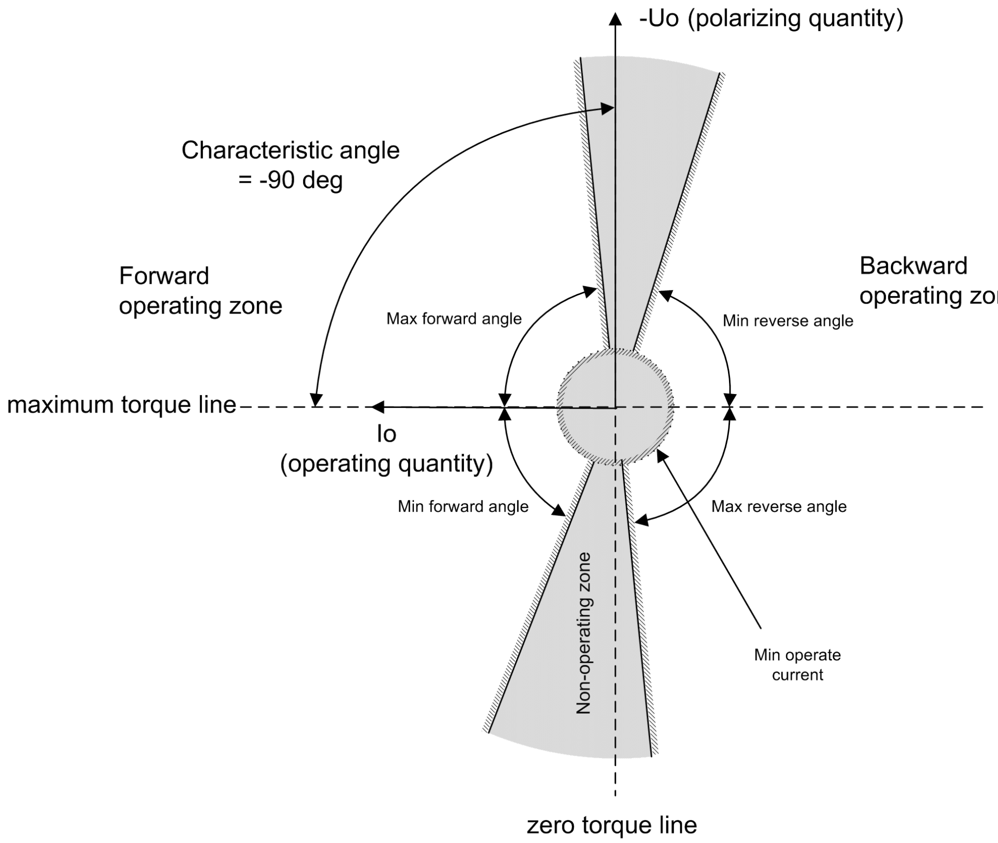


Figure 192: Definition of the relay characteristic angle, RCA=–90 degrees in an isolated network

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 193* 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 *Chapter 4.2.2.8 Directional earth-fault characteristics* .

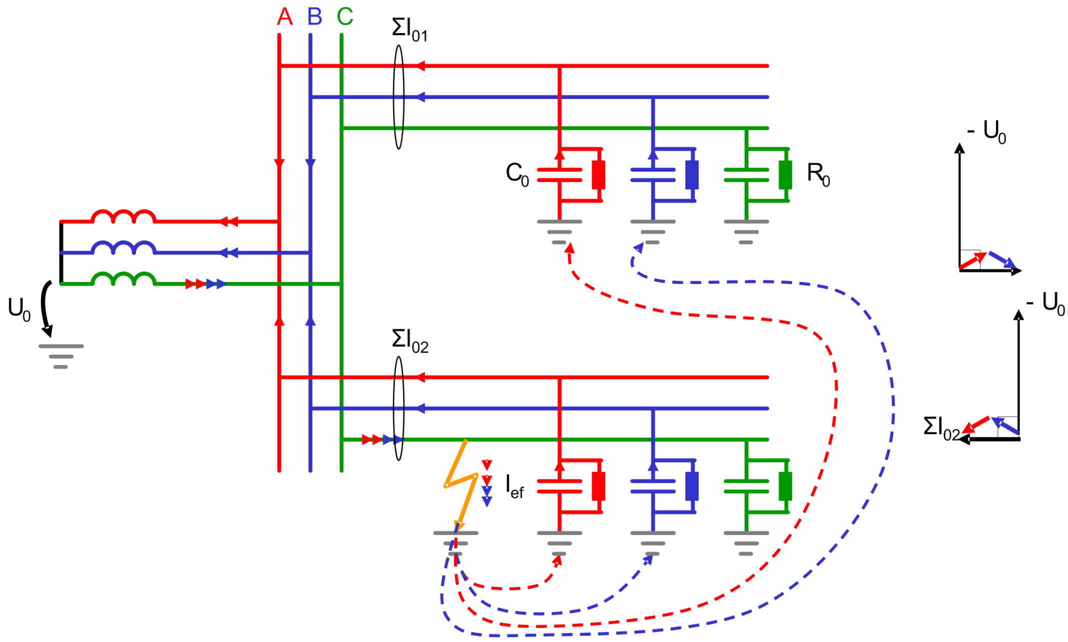


Figure 193: Earth-fault situation in an isolated network

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 protection 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 "IoCos" or "Phase angle". *Figure 194* illustrates a simplified equivalent circuit for a compensated network with an earth fault in phase C.

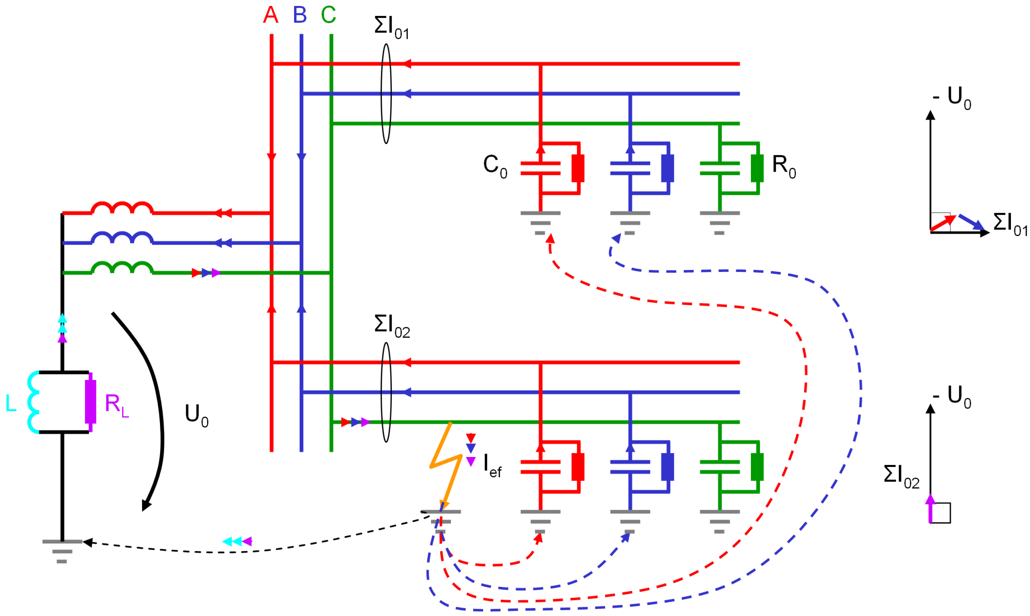


Figure 194: Earth-fault situation in a compensated network

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 protection 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 403 and Table 404.

Table 403: 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 404: *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").

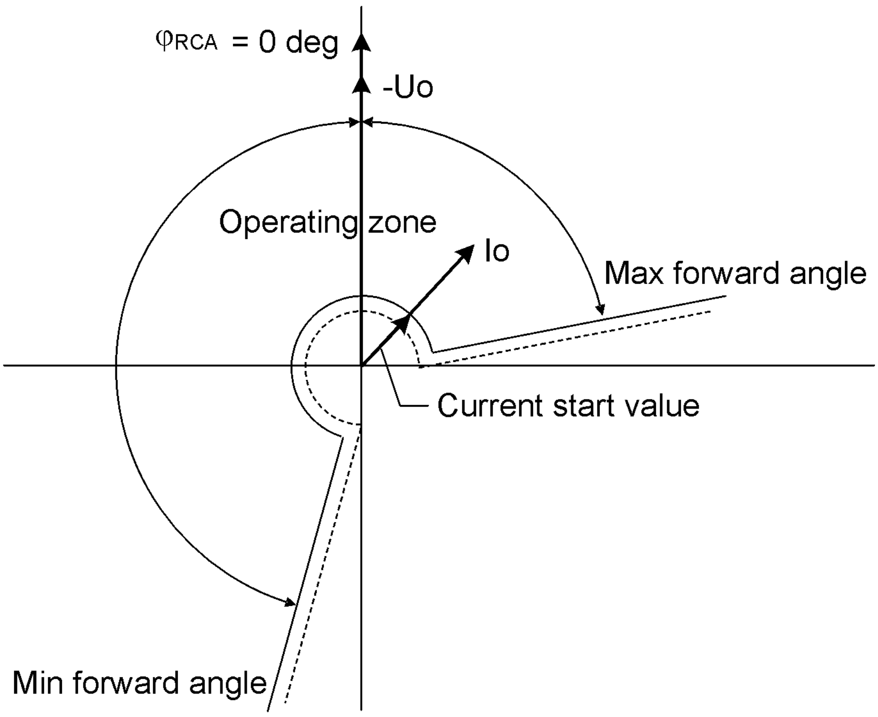


Figure 195: Extended operation area in directional earth-fault protection

4.2.2.6 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 405: Measurement modes supported by DEFxPDEF stages

Measurement mode	DEFLPDEF	DEFHPDEF
RMS	x	x
DFT	x	x
Peak-to-Peak	x	x

For a detailed description of the measurement modes, see *Chapter 11.5 Measurement modes* in this manual.

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 protection relay 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 406: Timer characteristics supported by different stages

Operating curve type	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 *Chapter 11 General function block features* in this manual.

Table 407: Reset time characteristics supported by different stages

Reset curve type	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 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.

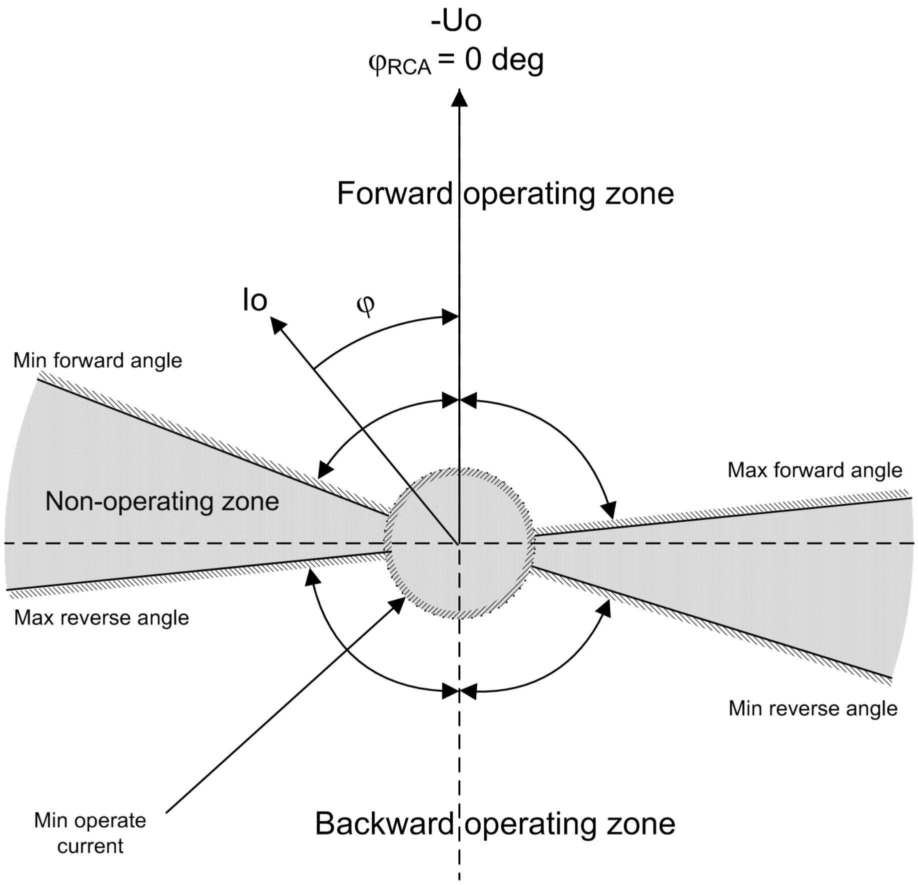


Figure 196: Configurable operating sectors in phase angle characteristic

Table 408: 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 409: Relay characteristic angle control in the IoSin and IoCos operation criteria

Operation mode:	RCA_CTL = "False"	RCA_CTL = "True"
IoSin	Actual operation criterion: Io-sin(φ)	Actual operation criterion: Io-cos(φ)
IoCos	Actual operation criterion: Io-cos(φ)	Actual operation criterion: Io-sin(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`

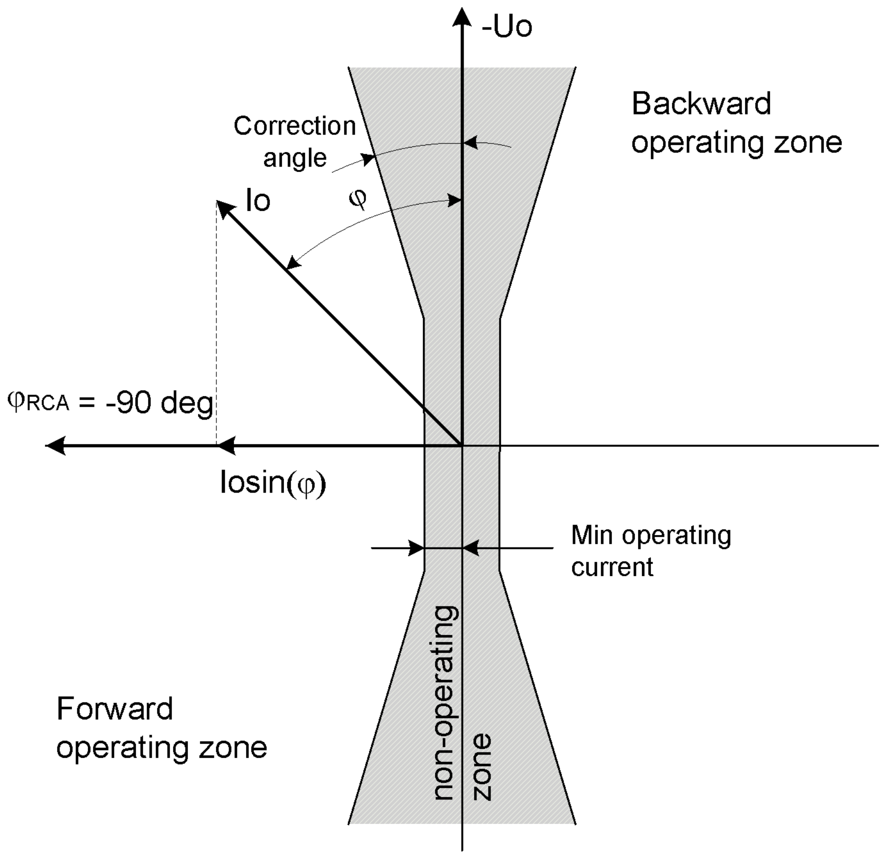


Figure 197: Operating characteristic Iosin(φ) in forward fault

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
```

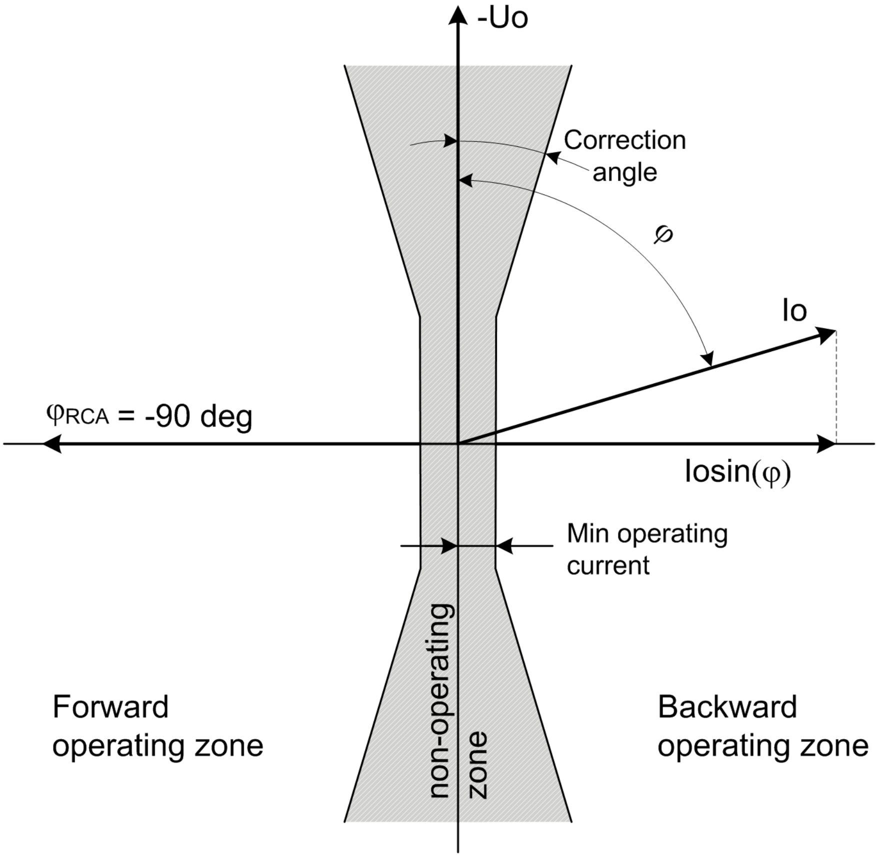


Figure 198: Operating characteristic Iosin(φ) in reverse fault

Example 3.

Iocos(φ) criterion selected, forward-type fault

`=> FAULT_DIR = 1`

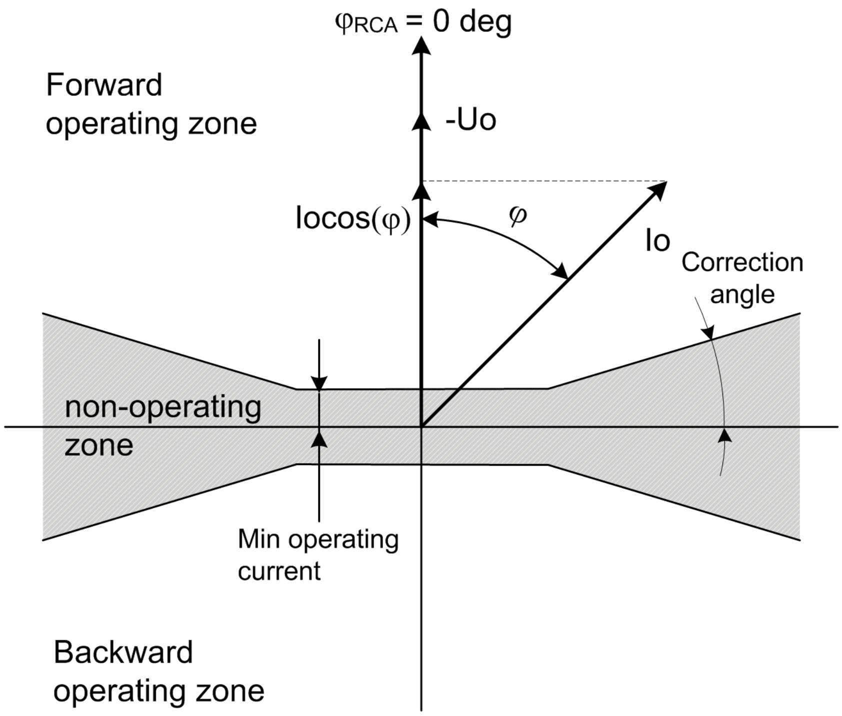


Figure 199: Operating characteristic Iocos(ϕ) in forward fault

Example 4.

Iocos(ϕ) criterion selected, reverse-type fault

```
=> FAULT_DIR = 2
```

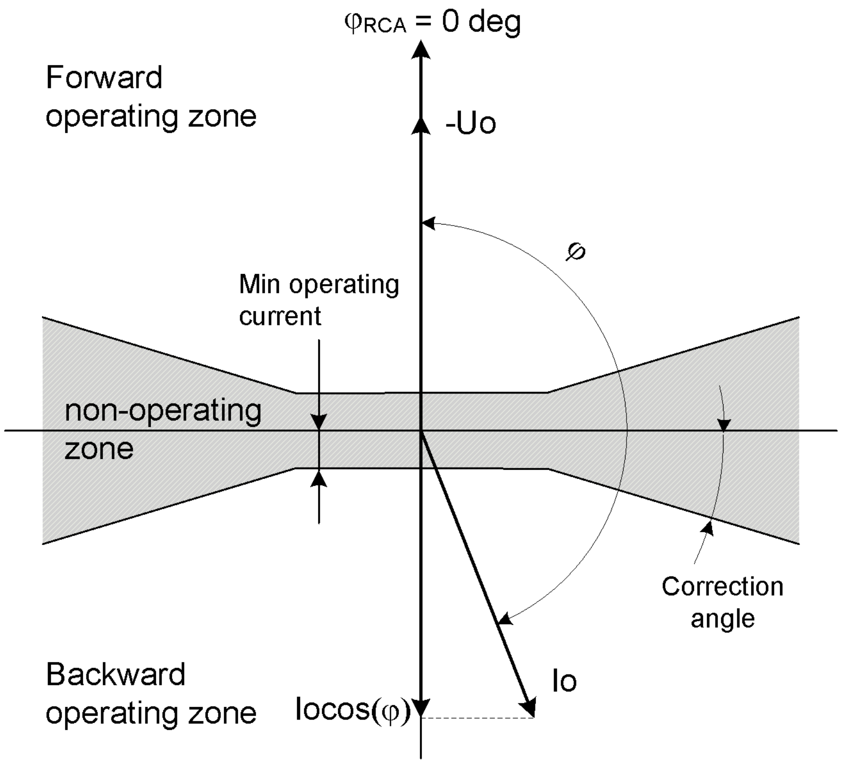


Figure 200: Operating characteristic Iocos(φ) in reverse fault

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.

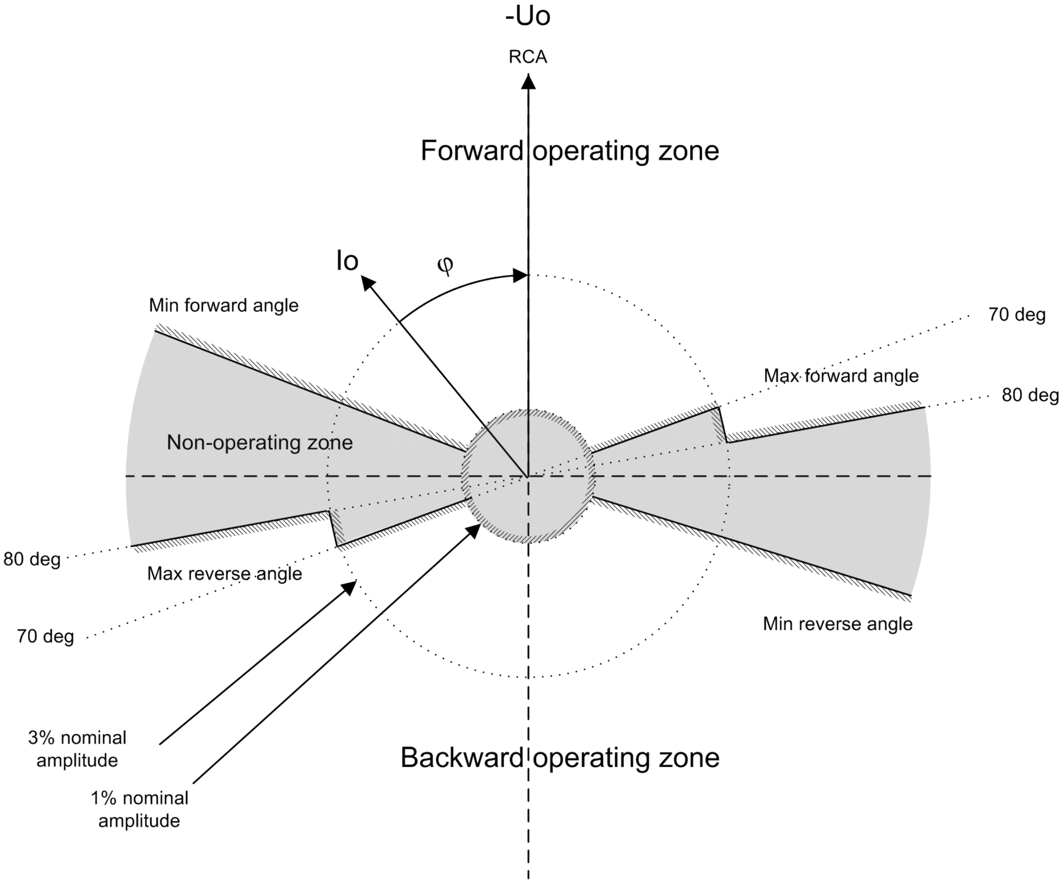


Figure 201: Operating characteristic for phase angle 80

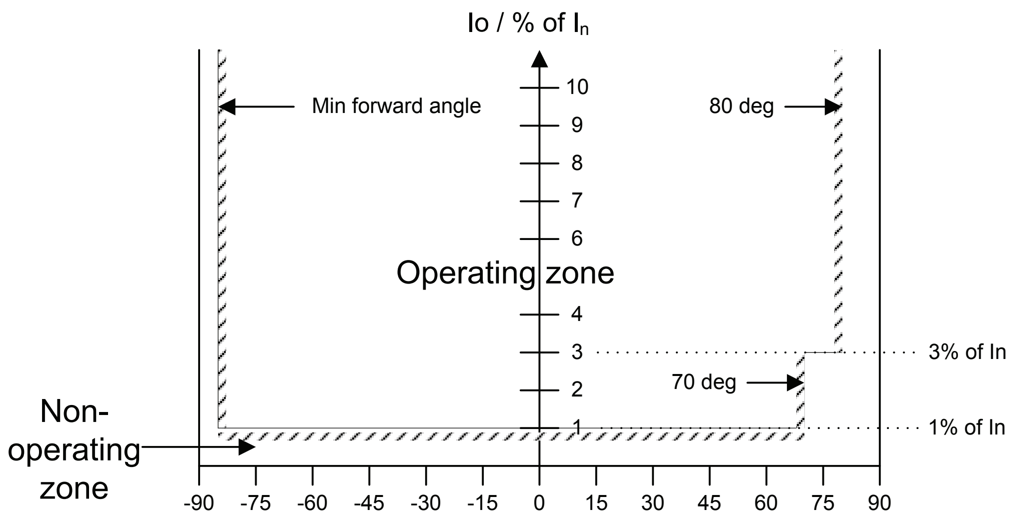


Figure 202: Phase angle 80 amplitude (Directional mode = Forward)

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.

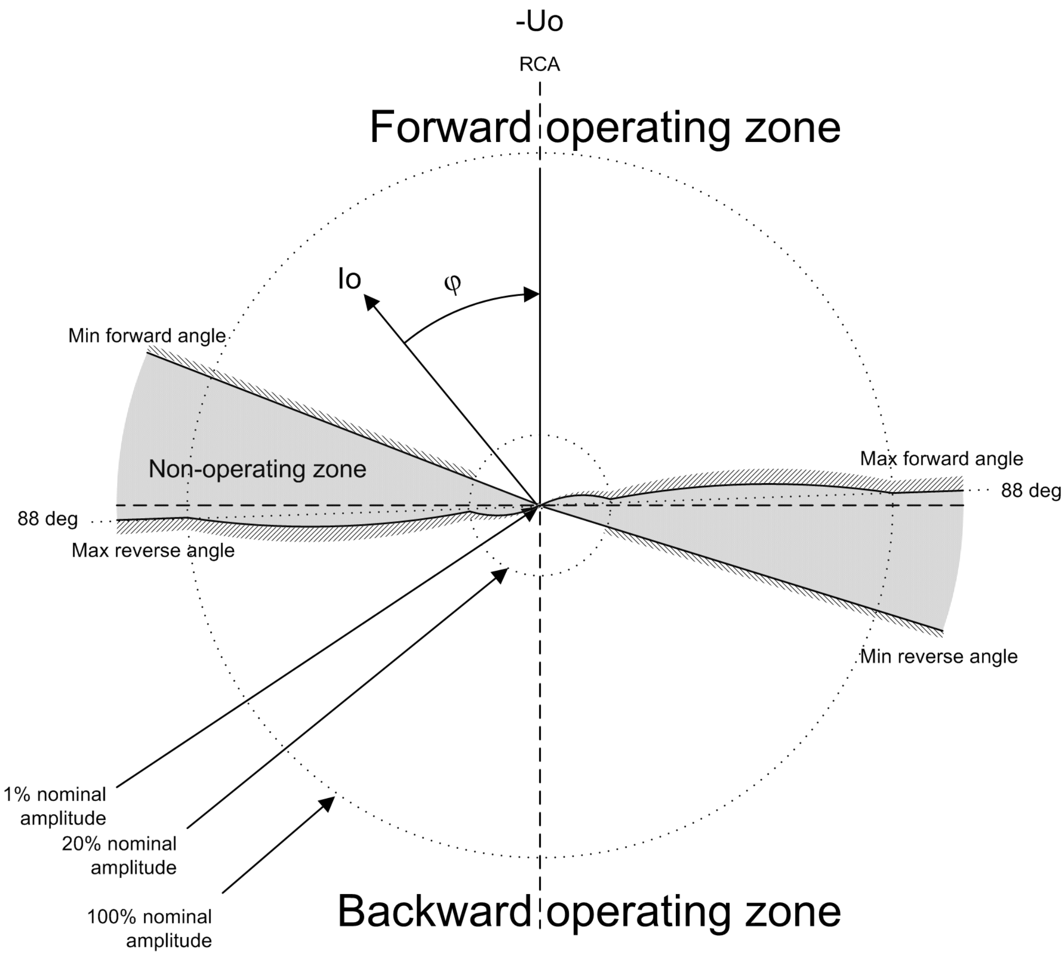


Figure 203: Operating characteristic for phase angle 88

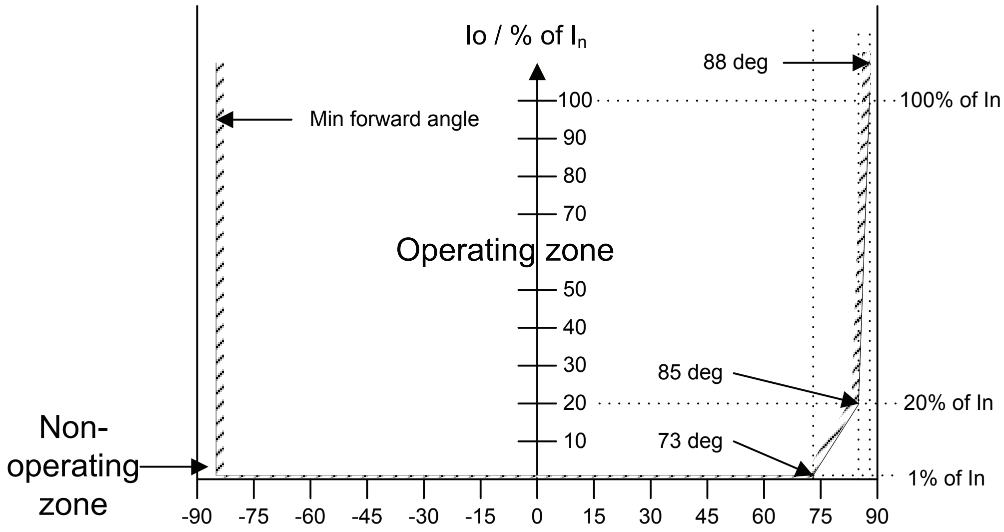


Figure 204: Phase angle 88 amplitude (Directional mode = Forward)

4.2.2.9 Signals

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 protection relay.

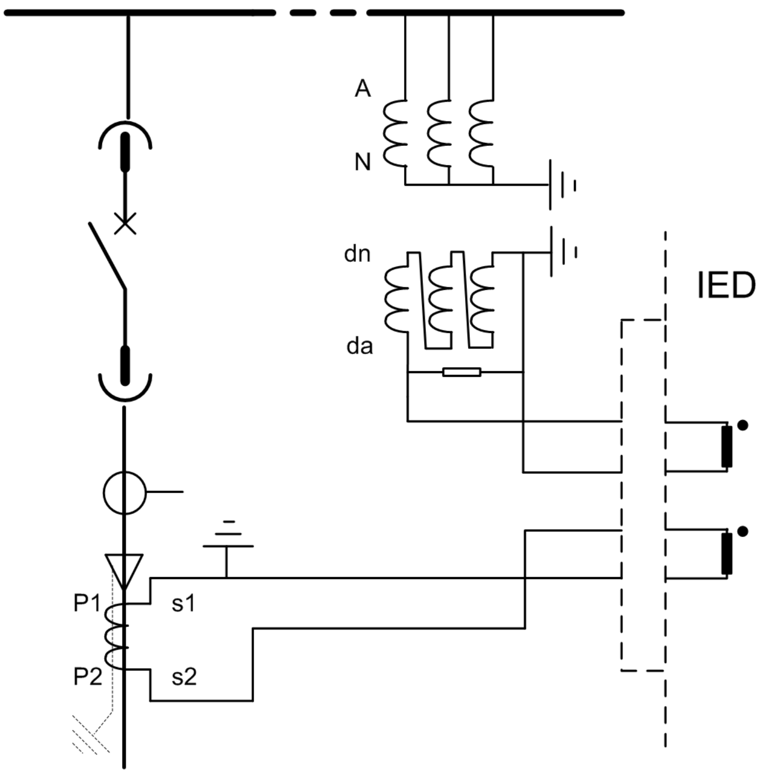


Figure 205: Connection of measuring transformers

DEFLPDEF Input signals

Table 410: DEFLPDEF Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

DEFHPDEF Input signals

Table 411: DEFHPDEF Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	Residual voltage

Table continues on the next page

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

DEFLPDEF Output signals

Table 412: DEFLPDEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

DEFHPDEF Output signals

Table 413: DEFHPDEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.2.11 Settings

DEFLPDEF Group settings

Table 414: DEFLPDEF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...5.000	xIn	0.005	0.010	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv.			15=IEC Def. Time	Selection of time delay curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type				
Operate delay time	50...200000	ms	10	50	Operate delay time
Characteristic angle	-179...180	deg	1	-90	Characteristic angle
Max forward angle	0...180	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...180	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...180	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...180	deg	1	80	Minimum phase angle in reverse direction
Voltage start value	0.010...1.000	xUn	0.001	0.010	Voltage start value

Table 415: DEFLPDEF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Operation mode	1=Phase angle 2=IoSin 3=IoCos 4=Phase angle 80 5=Phase angle 88			1=Phase angle	Operation criteria
Enable voltage limit	0=False 1=True			1=True	Enable voltage limit

Table 416: DEFLPDEF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 417: DEFLPDEF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	50...60000	ms	1	50	Minimum operate time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Min operate current	0.005...1.000	xIn	0.001	0.005	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage
Correction angle	0.0...10.0	deg	0.1	0.0	Angle correction
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal
Uo signal Sel	1=Measured Uo 2=Calculated Uo			1=Measured Uo	Selection for used Uo signal
Pol quantity	3=Zero seq. volt. 4=Neg. seq. volt.			3=Zero seq. volt.	Reference quantity used to determine fault direction

DEFHPDEF Group settings

Table 418: DEFHPDEF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	0.01	0.10	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv.			15=IEC Def. Time	Selection of time delay curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=ANSI Def. Time 15=IEC Def. Time 17=Programmable				
Operate delay time	40...200000	ms	10	40	Operate delay time
Characteristic angle	-179...180	deg	1	-90	Characteristic angle
Max forward angle	0...180	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...180	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...180	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...180	deg	1	80	Minimum phase angle in reverse direction
Voltage start value	0.010...1.000	xUn	0.001	0.010	Voltage start value

Table 419: DEFHPDEF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Operation mode	1=Phase angle 2=IoSin 3=IoCos 4=Phase angle 80 5=Phase angle 88			1=Phase angle	Operation criteria
Enable voltage limit	0=False 1=True			1=True	Enable voltage limit

Table 420: DEFHPDEF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 421: DEFHPDEF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	40...60000	ms	1	40	Minimum operate time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Min operate current	0.005...1.000	xIn	0.001	0.005	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage
Correction angle	0.0...10.0	deg	0.1	0.0	Angle correction
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal
Uo signal Sel	1=Measured Uo 2=Calculated Uo			1=Measured Uo	Selection for used Uo signal
Pol quantity	3=Zero seq. volt. 4=Neg. seq. volt.			3=Zero seq. volt.	Reference quantity used to determine fault direction

4.2.2.12 Monitored data

Table 422: DEFLPDEF Monitored data

Name	Type	Values (Range)	Unit	Description
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between operating angle

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
				and characteristic angle
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
I_OPER	FLOAT32	0.00...40.00	xIn	Calculated operating current
DEFLPDEF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 423: DEFHPDEF Monitored data

Name	Type	Values (Range)	Unit	Description
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
I_OPER	FLOAT32	0.00...40.00	xIn	Calculated operating current
DEFHPDEF	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Name	Type	Values (Range)	Unit	Description
		5=off		

4.2.2.13 Technical data

Table 424: DEFxPDEF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
	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]		Minimum	Typical	Maximum
	DEFHPDEF I_{Fault} = 2 × set *Start value*	42 ms	46 ms	49 ms
	DEFLPDEF I_{Fault} = 2 × set *Start value*	58 ms	62 ms	66 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<30 ms		
Operate time accuracy in definite time mode [4]		±1.0% of the set value or ±20 ms		

Table continues on the next page

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.

Characteristic	Value
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

4.2.2.14 Technical revision history

Table 425: DEFHPDEF Technical revision history

Technical revision	Change
B	Maximum value changed to 180 deg for the Max forward angle setting
C	Added a setting parameter for the "Measured Io" or "Calculated Io" selection and setting parameter for the "Measured Uo", "Calculated Uo" or "Neg. seq. volt." selection for polarization. *Operate delay time* and *Minimum operate time* changed from 60 ms to 40 ms. The sector default setting values are changed from 88 degrees to 80 degrees.
D	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.
E	Unit added to calculated operating current output (I_OPER).
F	Added setting *Pol quantity*.

Table 426: DEFLPDEF Technical revision history

Technical revision	Change
B	Maximum value changed to 180 deg for the *Max forward angle* setting. *Start value* step changed to 0.005
C	Added a setting parameter for the "Measured Io" or "Calculated Io" selection and setting parameter for the "Measured Uo", "Calculated Uo" or "Neg. seq. volt." selection for polarization. The sector default setting values are changed from 88 degrees to 80 degrees.
D	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.
E	Unit added to calculated operating current output (I_OPER).
F	Added setting *Pol quantity*. Minimum value for *Operate delay time* and *Minimum operate time* changed from “60 ms” to “50 ms”. Default value for *Operate delay time* and *Mini-*

[4] Start time of the function also included.
[3] Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20.

Technical revision	Change
	mum operate time changed from “60 ms” to “50 ms”.

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

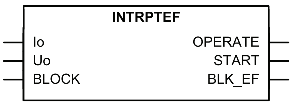


Figure 206: Function block

4.2.3.3 Functionality

The transient/intermittent earth-fault protection function 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.

The operating time characteristics are according to definite time (DT).

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

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 INTRPTEF can be described with a module diagram. All the modules in the diagram are explained in the next sections.

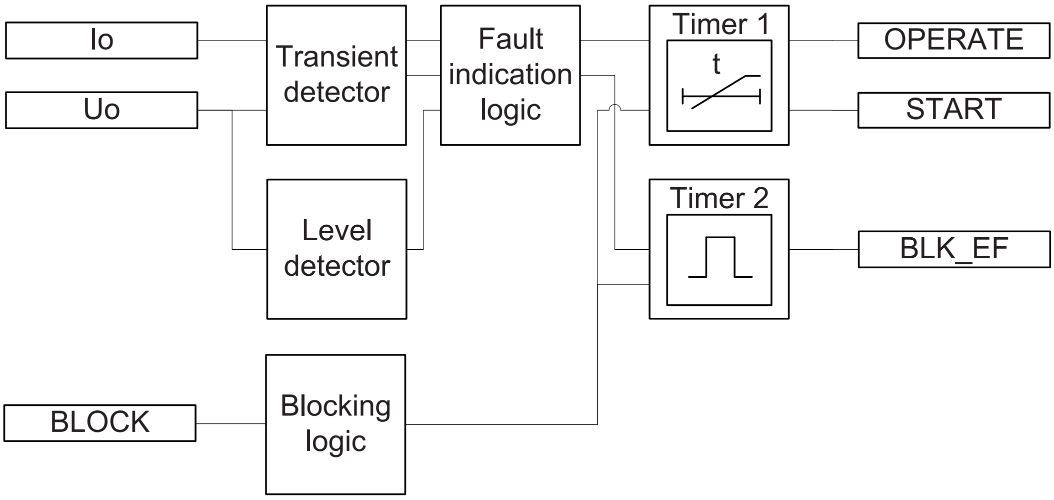


Figure 207: Functional module diagram

Level detector

The residual voltage can be selected from the *Uo signal Sel* setting. The options are "Measured Uo" and "Calculated Uo". If "Measured Uo" is selected, the voltage ratio for Uo-channel is given in the global setting **Configuration** > **Analog inputs** > **Voltage (Uo,VT)**. If "Calculated Uo" is selected, the voltage ratio is obtained from phase-voltage channels given in the global setting **Configuration** > **Analog inputs** > **Voltage (3U,VT)**.

Example 1: Uo is measured from open-delta connected VTs (20/sqrt(3) kV : 100/ sqrt(3) V : 100/3 V). In this case, "Measured Uo" is selected. The nominal values for residual voltage is obtained from VT ratios entered in Residual voltage Uo: **Configuration** > **Analog inputs** > **Voltage (Uo,VT)**: 11.547 kV :100 V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 11.547 kV = 11.547 kV in the primary.

Example 2: Uo is calculated from phase quantities. The phase VT-ratio is 20/sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated Uo" is selected. The nominal values for residual current and residual voltage are obtained from VT ratios entered in Residual voltage Uo: **Configuration** > **Analog inputs** > **Voltage (3U,VT)**: 20.000 kV : 100 V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 20.000 kV = 20.000 kV in the primary.

If "Calculated Uo" is selected, the residual voltage nominal value is always phase-to-phase voltage. Thus, the valid maximum setting for residual voltage start value is 0.577 × Un. Calculated Uo requires that all three phase-to-earth voltages are connected to the protection relay. Uo cannot be calculated from the phase-to-phase voltages.

Transient detector

The Transient detector module is used for detecting transients in the residual current and residual voltage signals.

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, then a value of 0.7×10 A = 7 A could be used. The same setting is also 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 in order 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, basic earth-fault protection (based on fundamental frequency phasors) should always be used in parallel with the 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 *Directional mode* setting "Forward" is used, the protection operates when the fault is in the protected feeder. When *Directional mode* setting "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 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*, the Timer 1 is activated. 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 Timer 1 is kept activated as long as transients are occurring during the drop-off time defined by setting *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 the *Reset delay time* elapses. After `OPERATE` activation, `START` and `OPERATE` signals are reset as soon as Uo falls below *Voltage start value*.

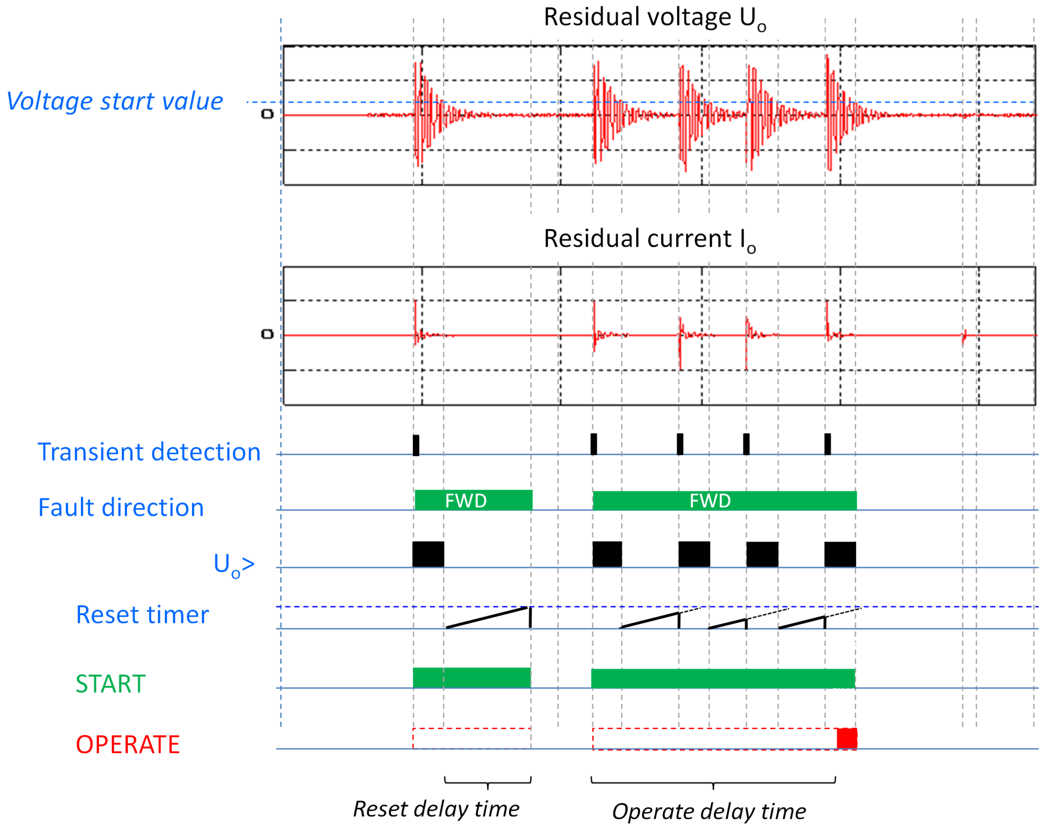


Figure 208: Example of INTRPTEF operation in ”Transient EF” mode in the faulty feeder

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 with the *Operate delay time*
- and 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

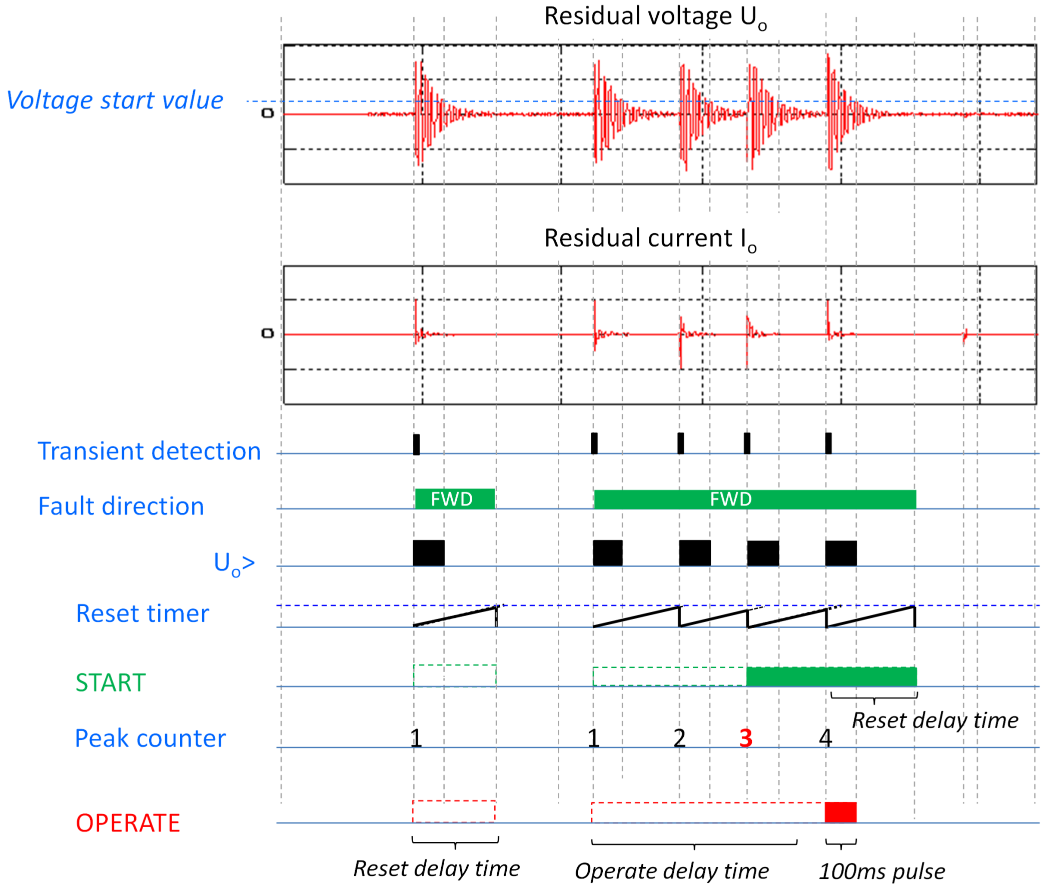


Figure 209: Example of INTRPTEF operation in "Intermittent EF" mode in the faulty feeder, Peak counter limit=3

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.

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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.2.3.5 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 210*. 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.

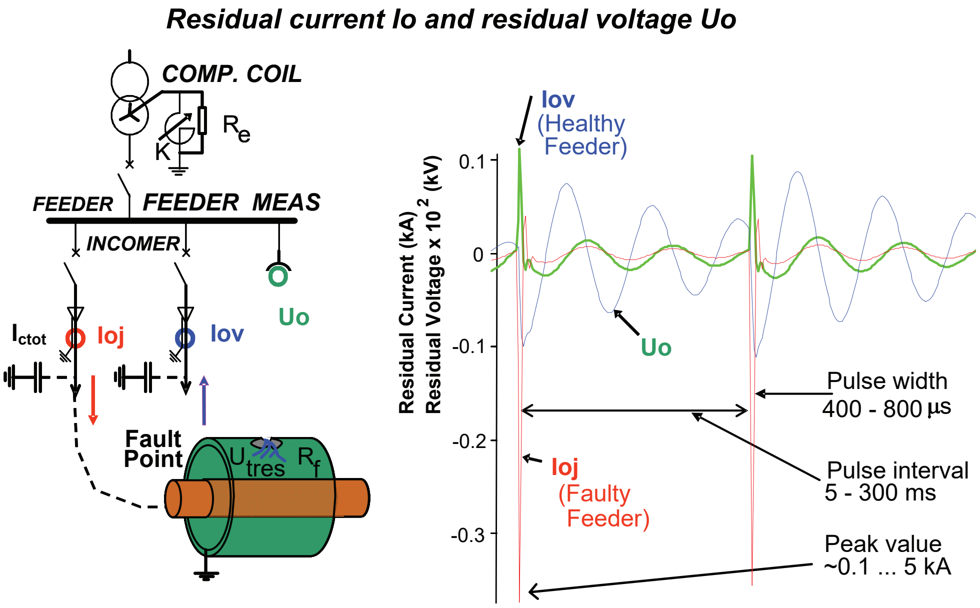


Figure 210: Typical intermittent earth-fault characteristics

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.

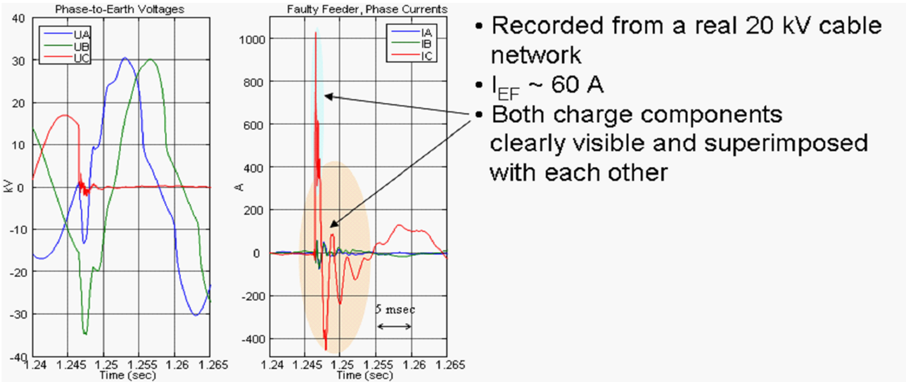


Figure 211: Example of earth-fault transients, including discharge and charge transient components, when a permanent fault occurs in a 20 kV network in phase C

4.2.3.6 Signals

Table 427: INTRPTEF Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 428: INTRPTEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
BLK_EF	BOOLEAN	Block signal for EF to indicate opposite direction peaks

4.2.3.7 Settings

Table 429: INTRPTEF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Directional mode	1=Non-directional			2=Forward	Directional mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Forward 3=Reverse				
Operate delay time	40...1200000	ms	10	500	Operate delay time
Voltage start value	0.05...0.50	xUn	0.01	0.20	Voltage start value

Table 430: INTRPTEF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Intermittent EF 2=Transient EF			1=Intermittent EF	Operation criteria
Uo signal Sel	1=Measured Uo 2=Calculated Uo			1=Measured Uo	Selection for used Uo signal

Table 431: INTRPTEF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	40...60000	ms	1	500	Reset delay time
Peak counter limit	2...20		1	2	Min requirement for peak counter before start in IEF mode
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current for transi-ent detector

4.2.3.8 Monitored data

Table 432: INTRPTEF Monitored data

Name	Type	Values (Range)	Unit	Description
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
INTRPTEF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.3.9 Technical data

Table 433: INTRPTEF Technical data

Characteristic	Value
Operation accuracy (Uo criteria with transient protection)	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × U_o
Operate time accuracy	±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

4.2.3.10 Technical revision history

Table 434: INTRPTEF Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting
C	The *Minimum operate current* setting is added. Correction in IEC 61850 mapping: DO BlkEF renamed to InhEF. Minimum value changed from 0.01 to 0.10 (default changed from 0.01 to 0.20) for the *Voltage start value* setting. Minimum value changed from 0 ms to 40 ms for the *Reset delay time* setting.
D	Voltage start value description changed from "Voltage start value for transient EF" to "Voltage start value" since the start value is effective in both operation modes. Added support for calculated Uo. Uo source (measured/calculated) can be selected with "Uo signal Sel". *Voltage start value* setting minimum changed from 0.10 to 0.05.
E	*Min operate current* setting scaling corrected to RMS level from peak level.

4.2.4 Admittance-based earth-fault protection EFPADM

4.2.4.1 Identification

Function 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

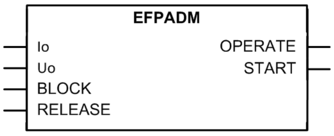


Figure 212: Function block

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 25)

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 Io and Uo. 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.

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 EFPADM can be described using a module diagram. All the modules in the diagram are explained in the next sections.

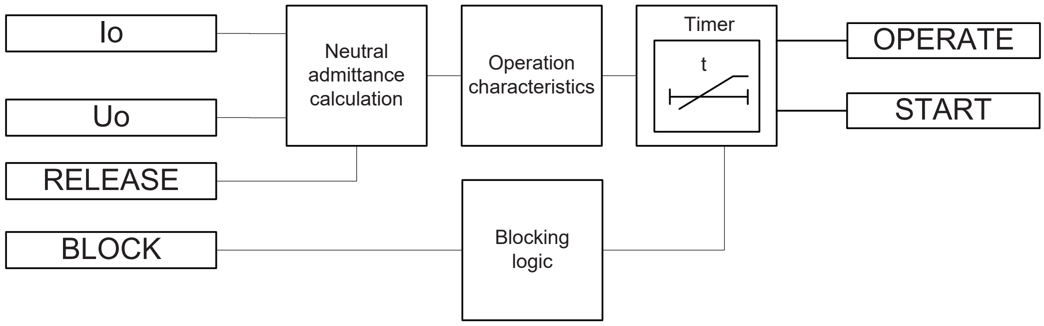


Figure 213: Functional module diagram

Neutral admittance calculation

The residual current can be selected from the *Io signal Sel* setting. The setting options are "Measured Io" and "Calculated Io". If "Measured Io" is selected, the current ratio for Io-channel is given in **Configuration** > **Analog inputs** > **Current (Io,CT)**. If "Calculated Io" is selected, the current ratio is obtained from phase-current channels given in **Configuration** > **Analog inputs** > **Current (3I,CT)**.

Respectively, the residual voltage can be selected from the *Uo signal Sel* setting. The setting options are "Measured Uo" and "Calculated Uo". If "Measured Uo" is selected, the voltage ratio for Uo-channel is given in **Configuration** > **Analog inputs** > **Voltage (Uo,VT)**. If "Calculated Uo" is selected, the voltage ratio is obtained from phase-voltage channels given in **Configuration** > **Analog inputs** > **Voltage (3U,VT)**.

Example 1: Uo is measured from open-delta connected VTs (20/sqrt(3) kV : 100/sqrt(3) V:100/3 V). In this case, "Measured Uo" is selected. The nominal values for residual voltage is obtained from the VT ratios entered in Residual voltage Uo : **Configuration** > **Analog inputs** > **Voltage (Uo,VT)**: 11.547 kV : 100 V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 11.547 kV = 11.547 kV in the primary.

Example 2: Uo is calculated from phase quantities. The phase VT-ratio is 20/sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated Uo" is selected. The nominal value for residual voltage is obtained from the VT ratios entered in Residual voltage Uo : **Configuration** > **Analog inputs** > **Voltage (3U,VT)** : 20.000kV : 100V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 20.000 kV = 20.000 kV in the primary.

In case, if "Calculated Uo" is selected, the residual voltage nominal value is always phase-to-phase voltage. Thus, the valid maximum setting for residual voltage start value is 0.577 × Un. The calculated Uo requires that all three phase-to-earth voltages are connected to the protection relay. Uo cannot be calculated from the phase-to-phase voltages.

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 × Un 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 from fault initiation. 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"

$$\underline{Y}o = \frac{\underline{I}o_{fault}}{-\underline{U}o_{fault}}$$

(Equation 26)

Admittance Clc mode = "Delta"

$$\underline{Y}o = \frac{\underline{I}o_{fault} - \underline{I}o_{prefault}}{-(\underline{U}o_{fault} - \underline{U}o_{prefault})} = \frac{\Delta \underline{I}o}{-\Delta \underline{U}o}$$

(Equation 27)

$\underline{Y}o$	Calculated neutral admittance [Siemens]
$\underline{I}o_{fault}$	Residual current during the fault [Amperes]
$\underline{U}o_{fault}$	Residual voltage during the fault [Volts]
$\underline{I}o_{prefault}$	Prefault residual current [Amperes]
$\underline{U}o_{prefault}$	Prefault residual voltage [Volts]
$\Delta \underline{I}o$	Change in the residual current due to fault [Amperes]
$\Delta \underline{U}o$	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 certain values during forward and reverse faults.

Fault in reverse direction, that is, outside the protected feeder.

$$\underline{Y}o = -\underline{Y}_{Fdtot}$$

(Equation 28)

$$\approx -j \cdot \frac{I_{eFd}}{U_{ph}}$$

(Equation 29)

$\underline{Y}_{Fdtot}$	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 28 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 214*.

The result of *Equation 28* 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.

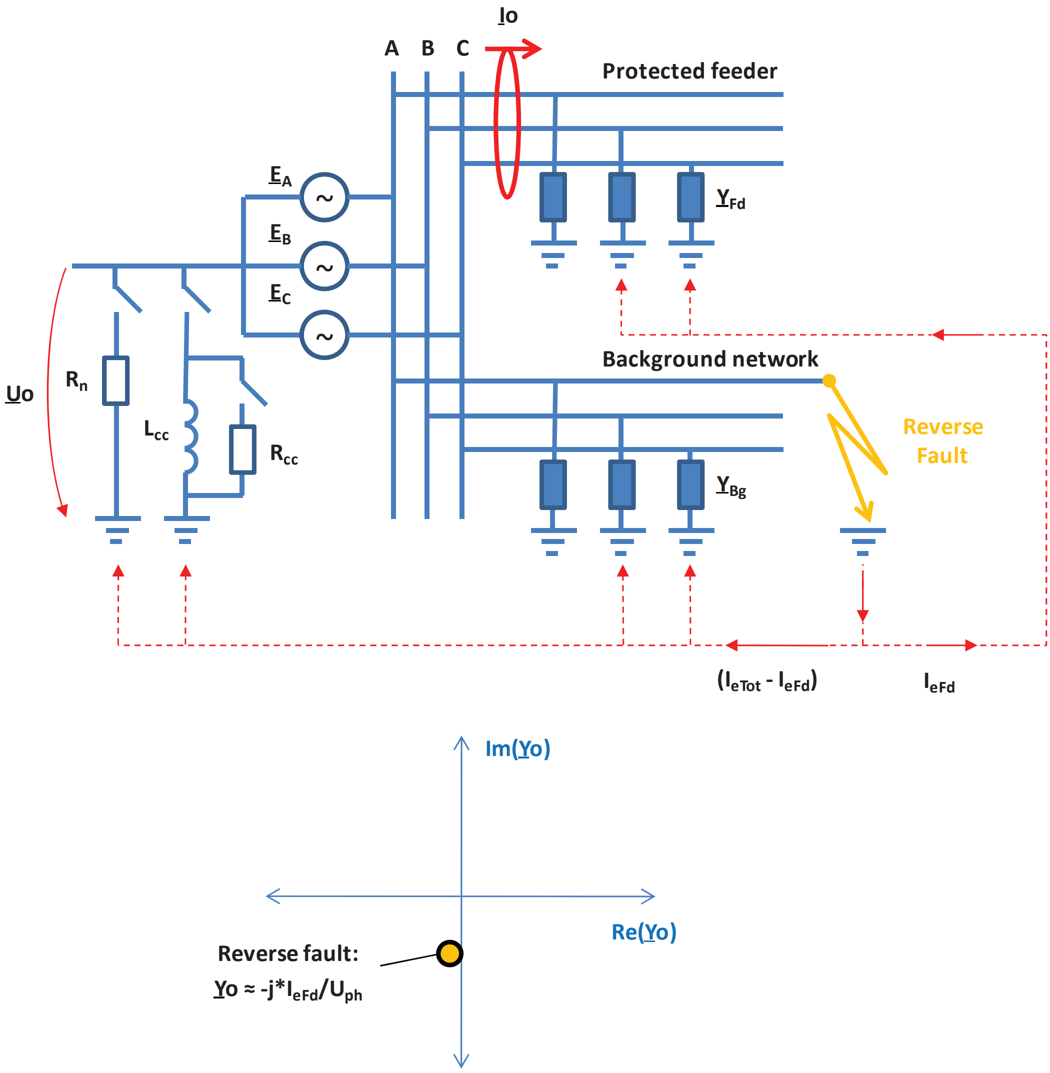


Figure 214: Admittance calculation during a reverse fault

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 Ω), the theoretical value for the measured admittance during an earth fault in the reverse direction, that is, outside the protected feeder, can be calculated.

$$\underline{Yo} \approx -j \cdot \frac{I_{eFd}}{U_{ph}} = -j \cdot \frac{10A}{15/\sqrt{3}kV} = -j \cdot 1.15 \text{ milliSiemens}$$

(Equation 30)

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 31)

$$\approx j \cdot \left(\frac{I_{eTot} - I_{eFd}}{U_{ph}} \right)$$

(Equation 32)

Compensated network:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{CC}$$

(Equation 33)

$$\approx \frac{I_{Rcc} + j \cdot \left(I_{eTot} \cdot (1-K) - I_{eFd} \right)}{U_{ph}}$$

(Equation 34)

High-resistance earthed network:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{Rn}$$

(Equation 35)

$$\approx \frac{I_{Rn} + j \cdot \left(I_{eTot} - I_{eFd} \right)}{U_{ph}}$$

(Equation 36)

$\underline{Y}_{Bgtot}$	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 31 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 215*.

Equation 33 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 215*.

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 35 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 215*.

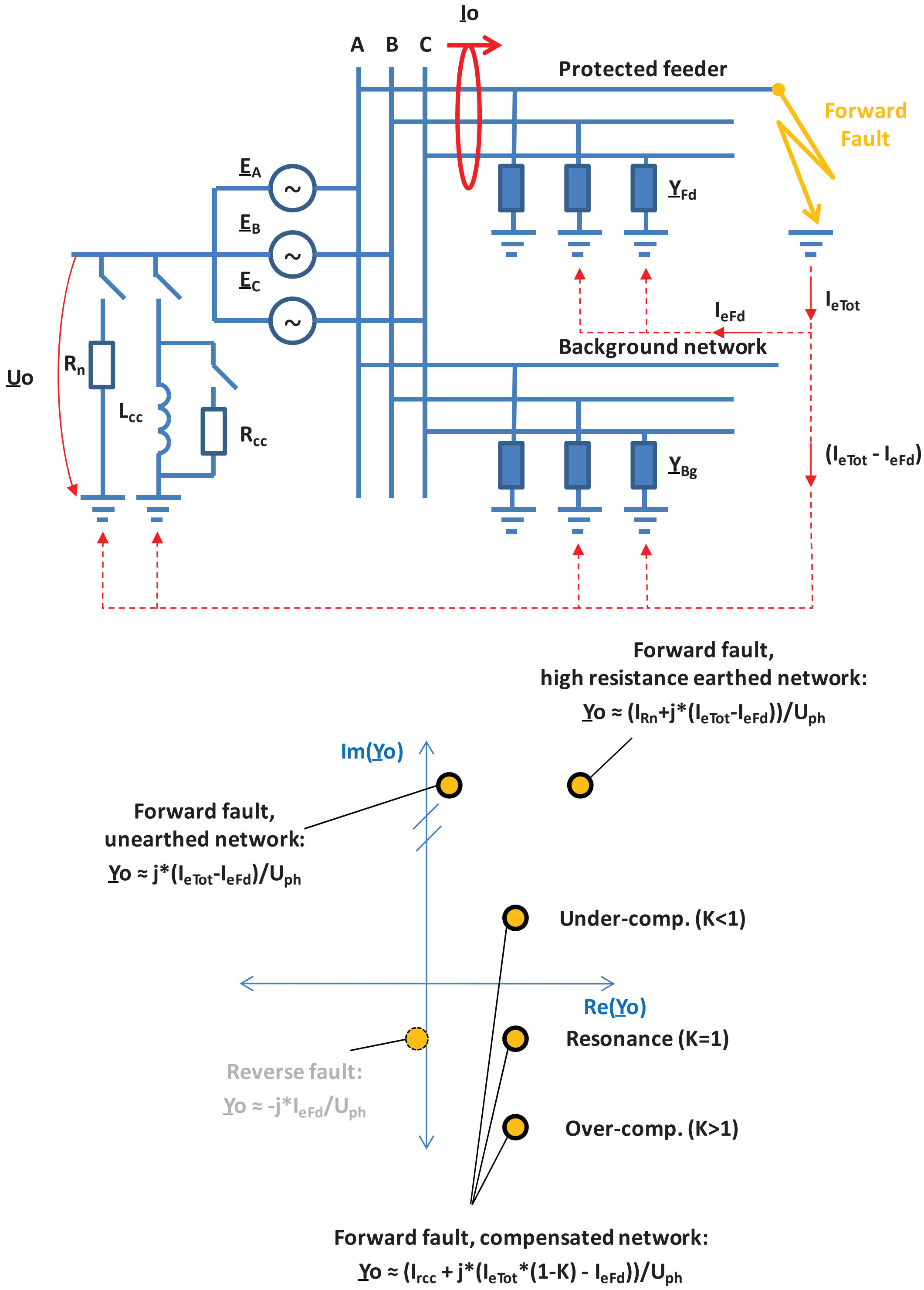


Figure 215: Admittance calculation during a forward fault

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 Ω) and the magnitude of the network is 100 A (Rf = 0 Ω). 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 37)

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.

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.

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.

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.

Table 435: 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 216, *Figure 217* and *Figure 218* 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 *Chapter 4.2.4.5 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 primary milliSiemens (mS). The conversion equation for the admittance from secondary to primary is:

$$Y_{pri} = Y_{sec} \cdot \frac{ni_{CT}}{nu_{VT}}$$

(Equation 38)

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.

$$Y_{pri} = 5.00\ milliSiemens \cdot \frac{100/1A}{11547/100V} = 4.33\ milliSiemens$$

(Equation 39)

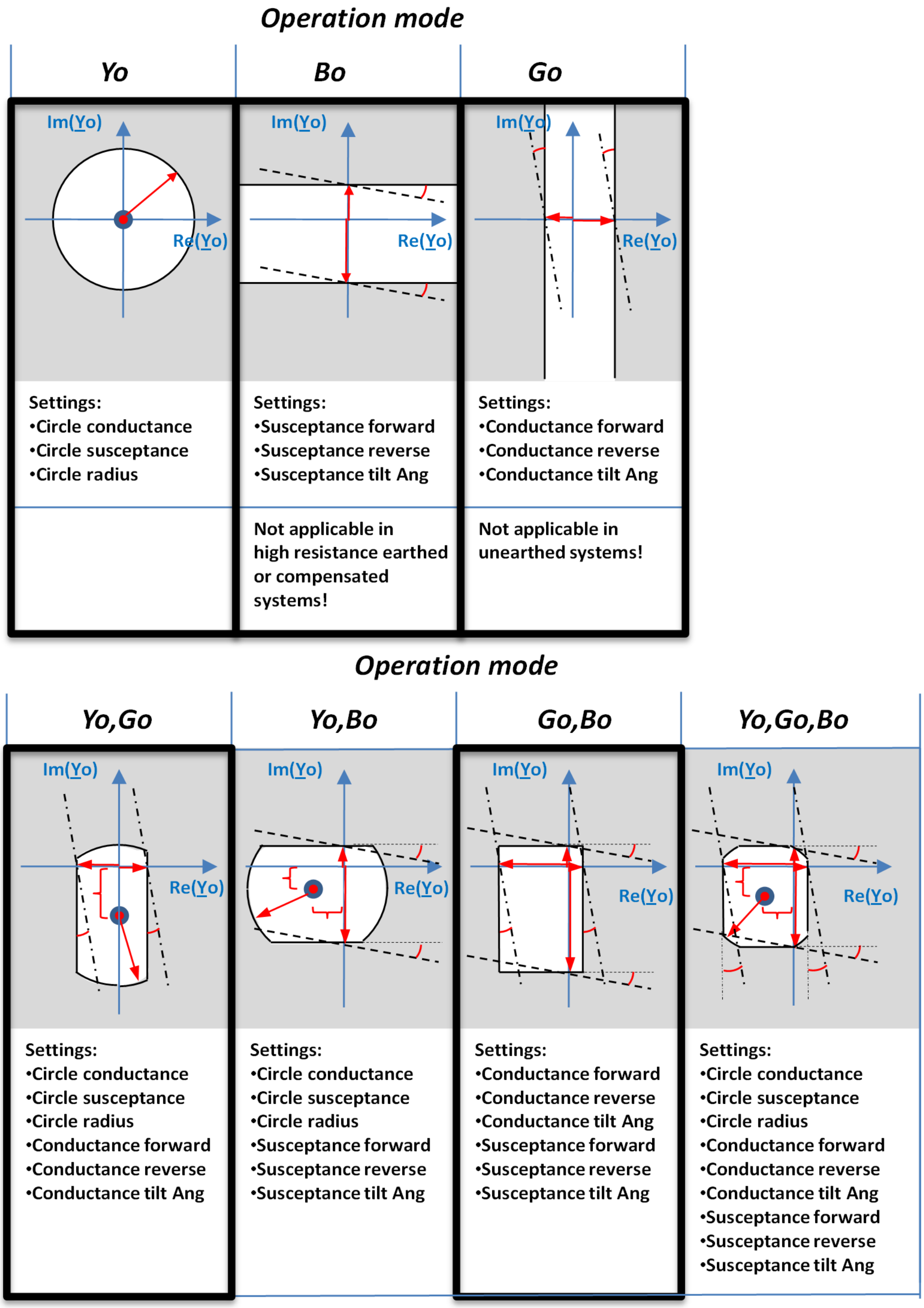


Figure 216: Admittance characteristic with different operation modes when Directional mode = "Non-directional"

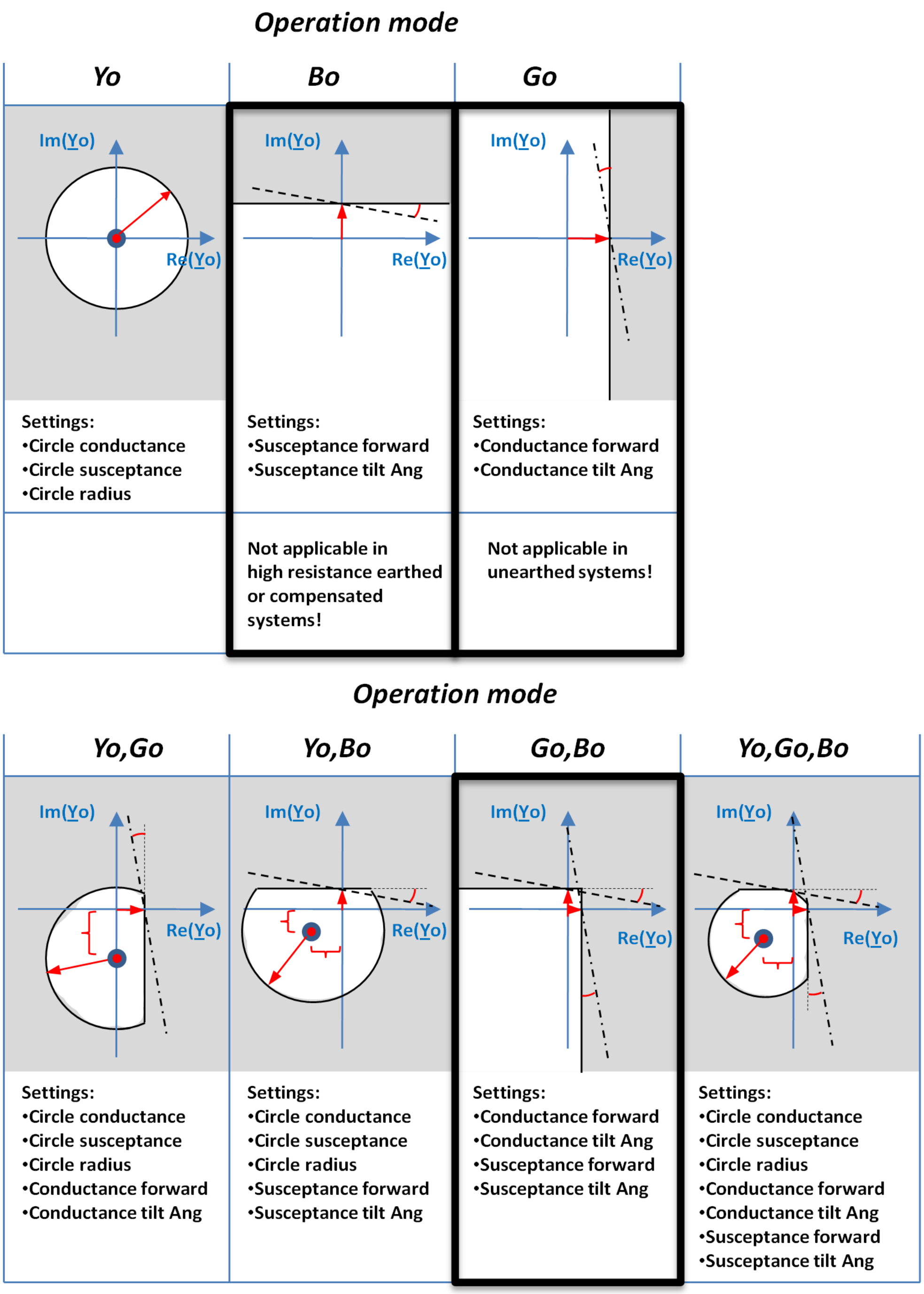


Figure 217: Admittance characteristic with different operation modes when Directional mode = "Forward"

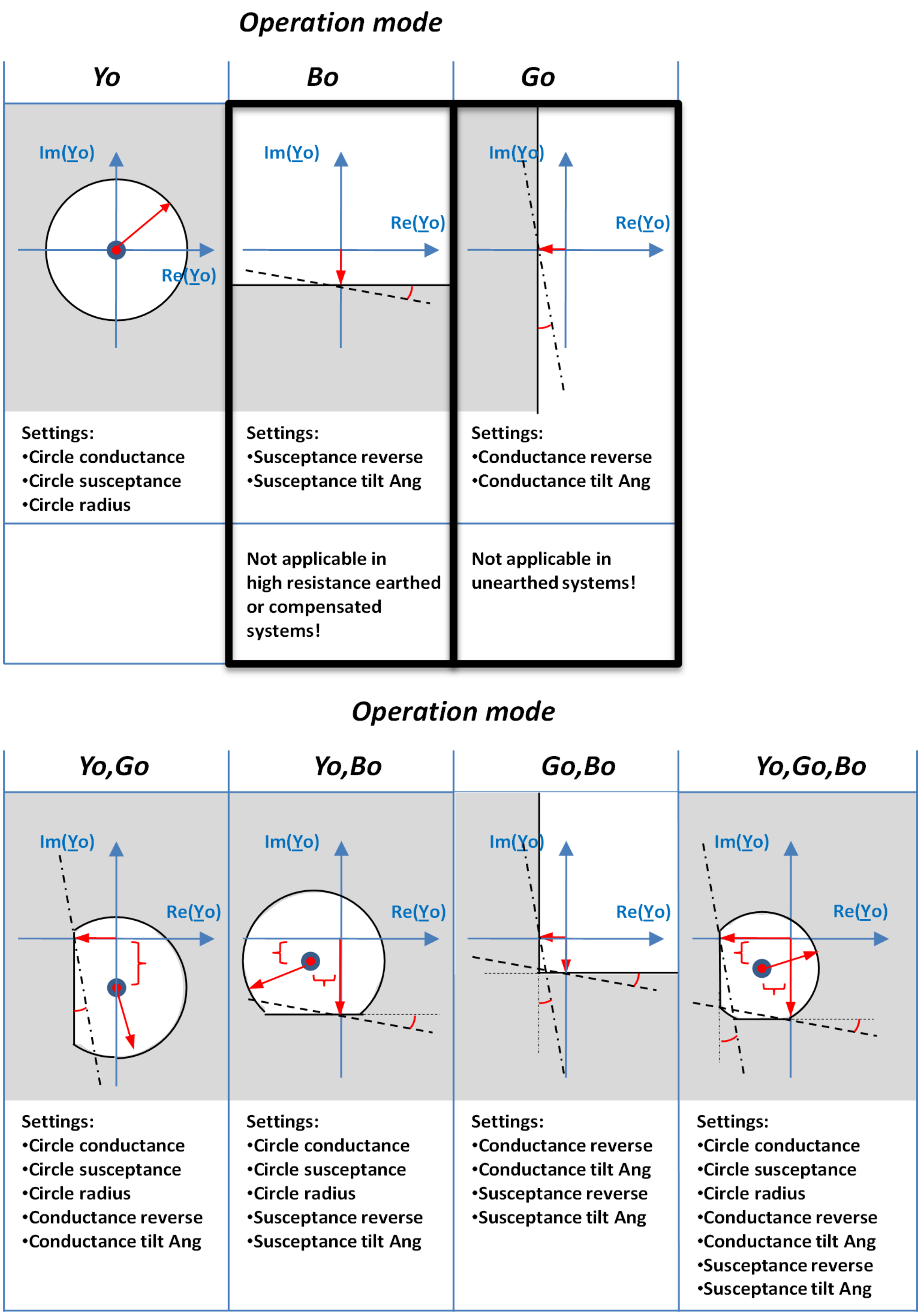


Figure 218: Admittance characteristic with different operation modes when Directional mode = "Reverse"

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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

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 primary milliSiemens.

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.

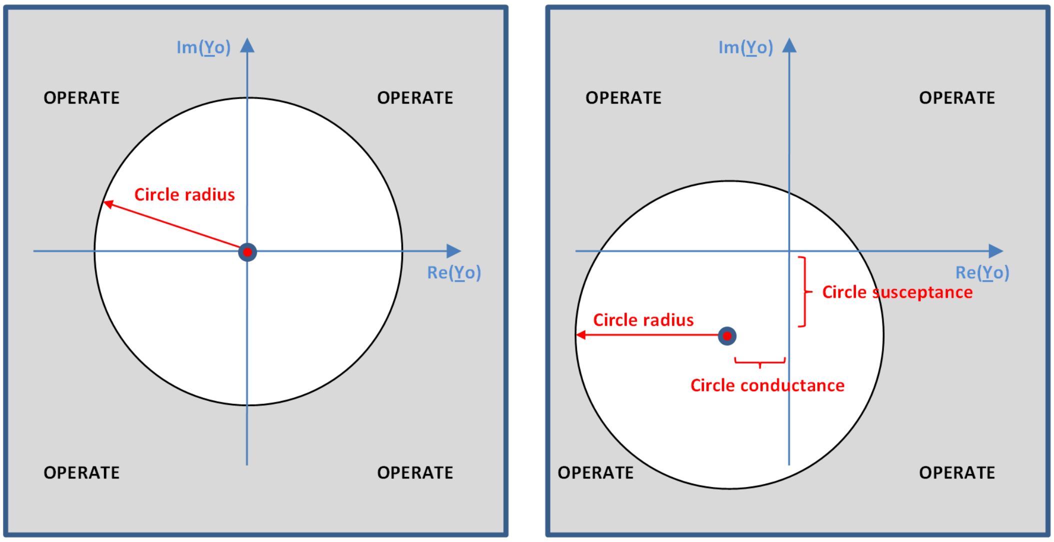


Figure 219: Overadmittance characteristic. Left figure: classical origin-centered admittance circle. Right figure: admittance circle is set off from the origin.

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*.

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.

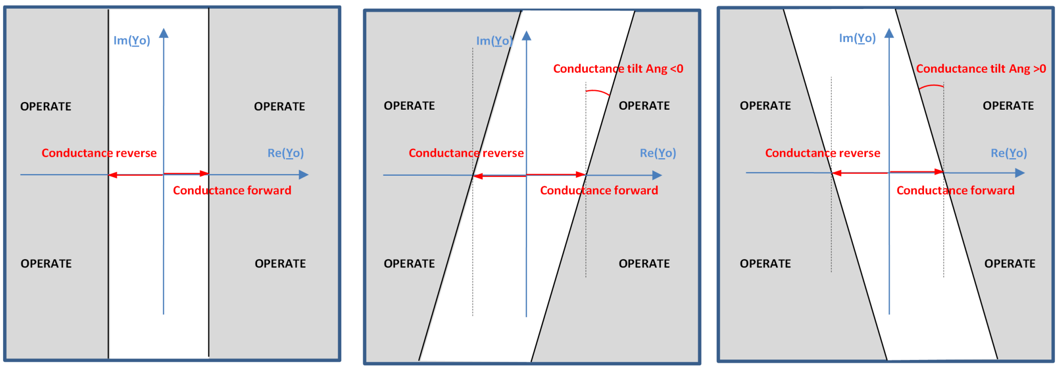


Figure 220: Non-directional overconductance characteristic. Left figure: classical non-directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

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.

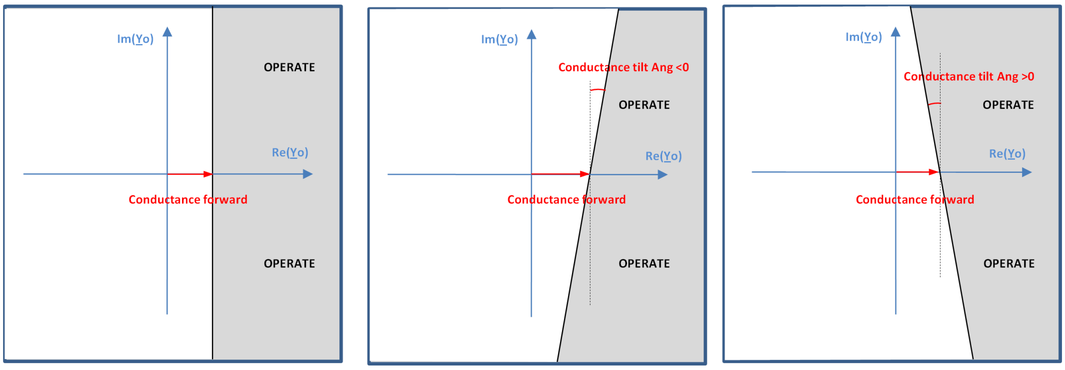


Figure 221: Forward directional overconductance characteristic. Left figure: classical forward directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

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 to compensated networks.

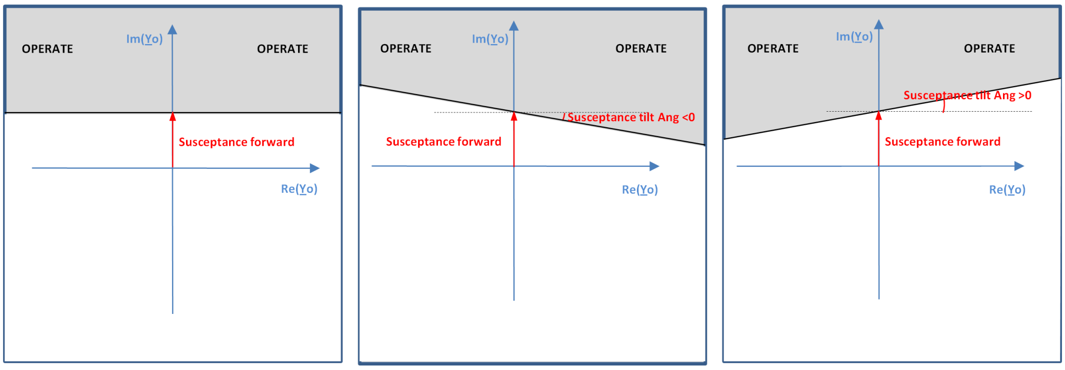


Figure 222: Forward directional oversusceptance characteristic. Left figure: classical forward directional oversusceptance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

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*.

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.

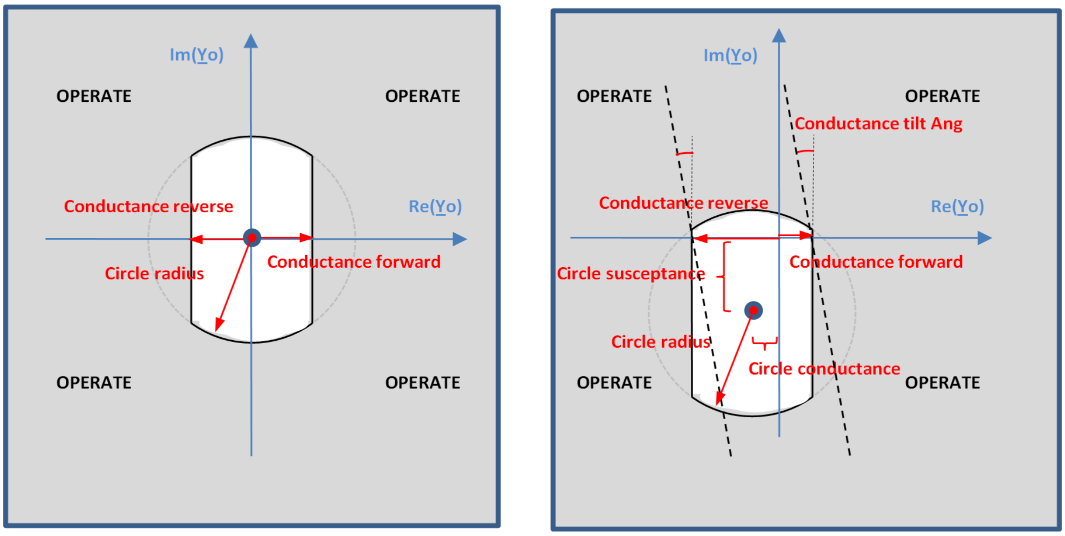


Figure 223: Combined overadmittance and overconductance characteristic. Left figure: classical origin-centered admittance circle combined with two overconductance boundary lines. Right figure: admittance circle is set off from the origin.

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 224*.

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 225*.

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*.

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.

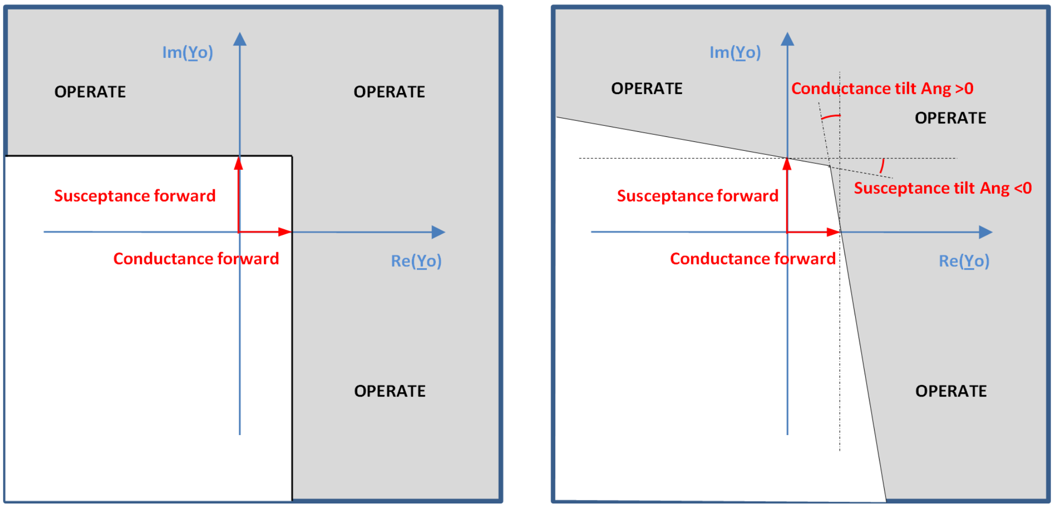


Figure 224: Combined forward directional overconductance and forward directional oversusceptance characteristic. Left figure: the Conductance tilt Ang and Susceptance tilt Ang settings equal zero degrees. Right figure: the setting Conductance tilt Ang > 0 degrees and the setting Susceptance tilt Ang < 0 degrees.

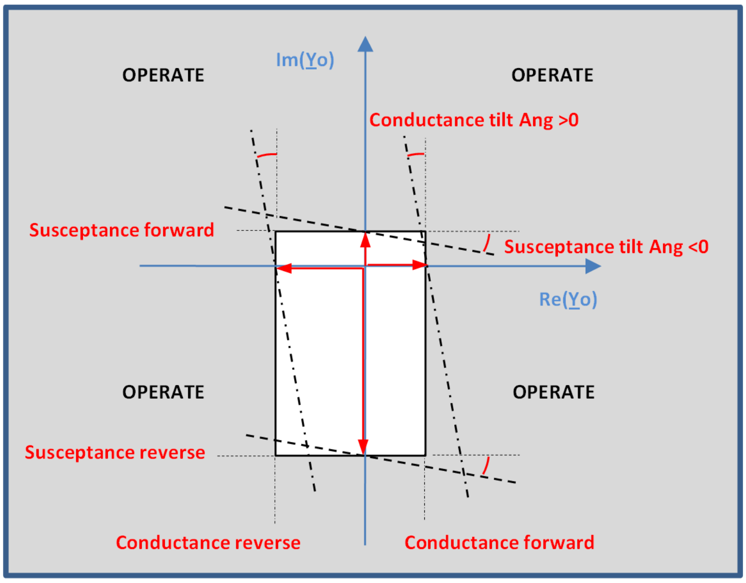


Figure 225: Combined non-directional overconductance and non-directional oversusceptance characteristic

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.

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.

4.2.4.6 Application

Admittance-based earth-fault protection provides a selective earth-fault protection 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.

Residual overvoltage condition is used as a start condition for the admittance-based earth-fault protection. 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 admittance-based earth-fault 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 226 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 fulfill the requirements for the sensitivity of the protection in terms of fault resistance.

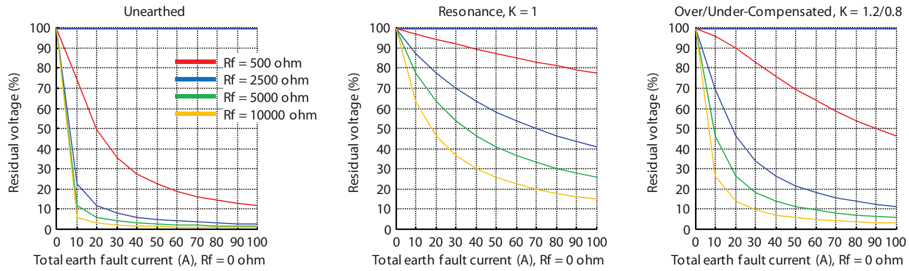


Figure 226: Influence of fault resistance on the residual voltage magnitude in 10 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

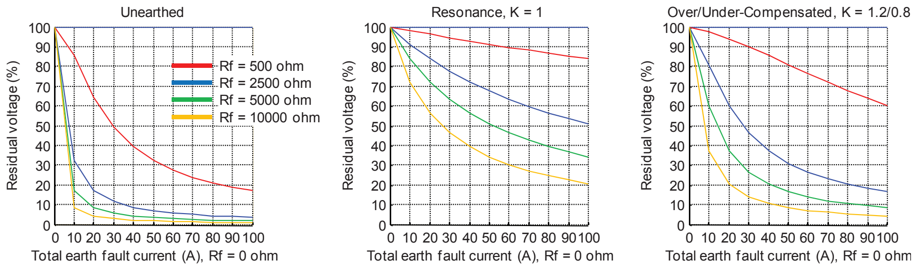


Figure 227: Influence of fault resistance on the residual voltage magnitude in 15 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

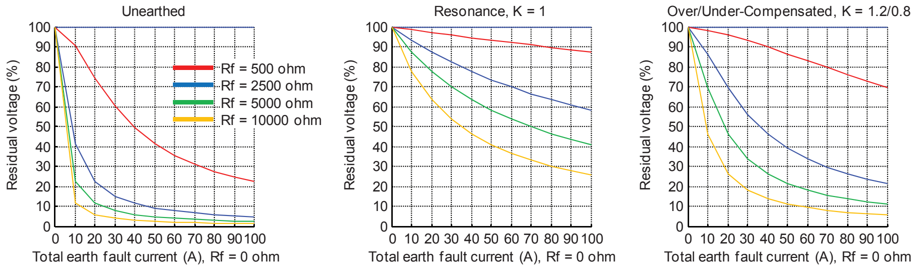


Figure 228: Influence of fault resistance on the residual voltage magnitude in 20 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to 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 (at 15 kV), which is connected in parallel to the coil during the fault after a 1.0 second delay.

Solution: As a start condition for the admittance-based earth-fault 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 × Un

According to *Figure 227*, 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.

$$\underline{Y}_{Fdtot} = \frac{10A}{15kV/\sqrt{3}} \approx j \cdot 1.15 \text{ mS}$$

(Equation 40)

A parallel resistor current of 15 A can be converted into admittance.

$$G_{cc} = \frac{15A}{15kV/\sqrt{3}} \approx 1.73 \text{ mS}$$

(Equation 41)

According to *Equation 28*, during an outside fault EFPADM measures the following admittance:

$$\underline{Y}o = -\underline{Y}_{Fdtot} \approx -j \cdot 1.15 \text{ mS}$$

(Equation 42)

According to *Equation 31*, during an inside fault EFPADM measures the admittance after the connection of the parallel resistor:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{CC} \approx (1.73 + j \cdot B) \text{ mS}$$

(Equation 43)

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 ("Box"-characteristics) 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 229*. 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/VT-errors, 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

By default, 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

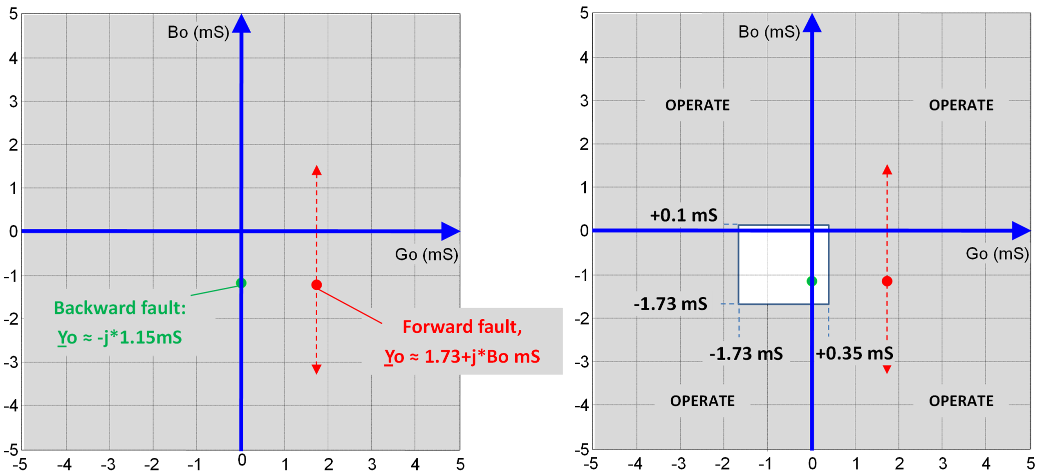


Figure 229: Admittances of the example

4.2.4.7 Signals

Table 436: EFPADM Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RELEASE	BOOLEAN	0=False	External trigger to release neutral admittance protection

Table 437: EFPADM Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.4.8 Settings

Table 438: EFPADM Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.01...2.00	xUn	0.01	0.15	Voltage start value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Operation mode	1=Yo 2=Go 3=Bo 4=Yo, Go 5=Yo, Bo 6=Go, Bo 7=Yo, Go, Bo			1=Yo	Operation criteria
Operate delay time	60...200000	ms	10	60	Operate delay time
Circle radius	0.05...500.00	mS	0.01	1.00	Admittance circle radius
Circle conductance	-500.00...500.00	mS	0.01	0.00	Admittance circle midpoint, conductance
Circle susceptance	-500.00...500.00	mS	0.01	0.00	Admittance circle midpoint, susceptance
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

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
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

Table 439: EFPADM Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Conductance tilt Ang	-30...30	deg	1	0	Tilt angle of conductance boundary line
Susceptance tilt Ang	-30...30	deg	1	0	Tilt angle of susceptance boundary line

Table 440: EFPADM Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 441: EFPADM Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Admittance Clc mode	1=Normal 2=Delta			1=Normal	Admittance calculation mode
Reset delay time	0...60000	ms	1	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal
Uo signal Sel	1=Measured Uo 2=Calculated Uo			1=Measured Uo	Selection for used Uo signal

4.2.4.9 Monitored data

Table 442: EFPADM Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
FAULT_DIR	Enum	0=unknown		Detected fault direction

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		1=forward 2=backward 3=both		
COND_RES	FLOAT32	-1000.00...1000.00	mS	Real part of calculated neutral admittance
SUS_RES	FLOAT32	-1000.00...1000.00	mS	Imaginary part of calculated neutral admittance
EFPADM	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.4.10 Technical data

Table 443: 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]	Minimum	Typical	Maximum
	56 ms	60 ms	64 ms
Reset time	40 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,…		

4.2.5 Rotor earth-fault protection MREFPTOC

4.2.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Rotor earth-fault protection	MREFPTOC	Io>R	64R

1 $U_o = 1.0 \times U_n$.
2 Includes the delay of the signal output contact, results based on statistical distribution of 1000 measurements.

4.2.5.2 Function block

Figure 230: 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.

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 MREFPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

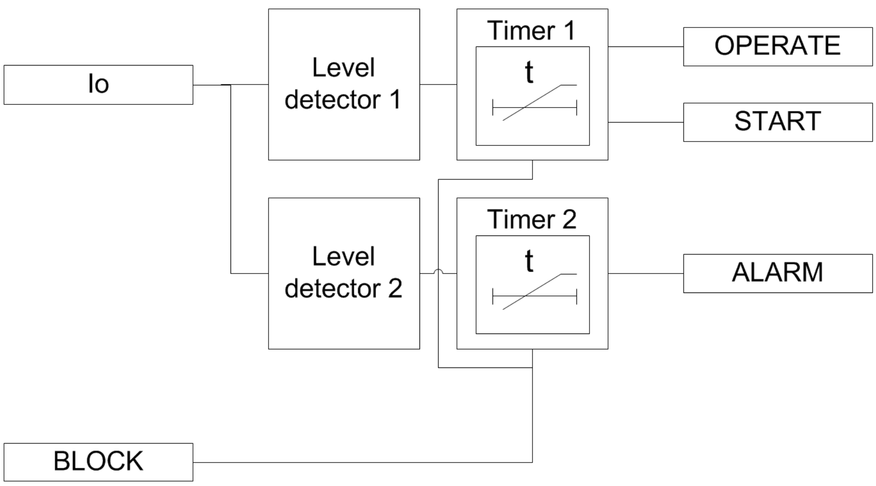


Figure 231: Functional module diagram

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 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 232*. The injected voltage is 100 V AC via the coupling capacitors. A coupling capacitor prevents a DC current leakage through the injection device.

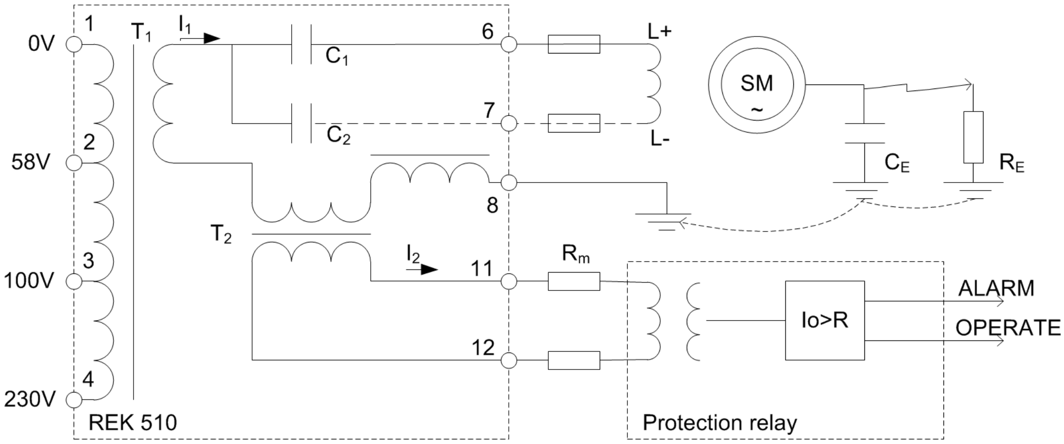


Figure 232: Principle of the rotor earth-fault protection with the current injection device

The 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 233*.

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.

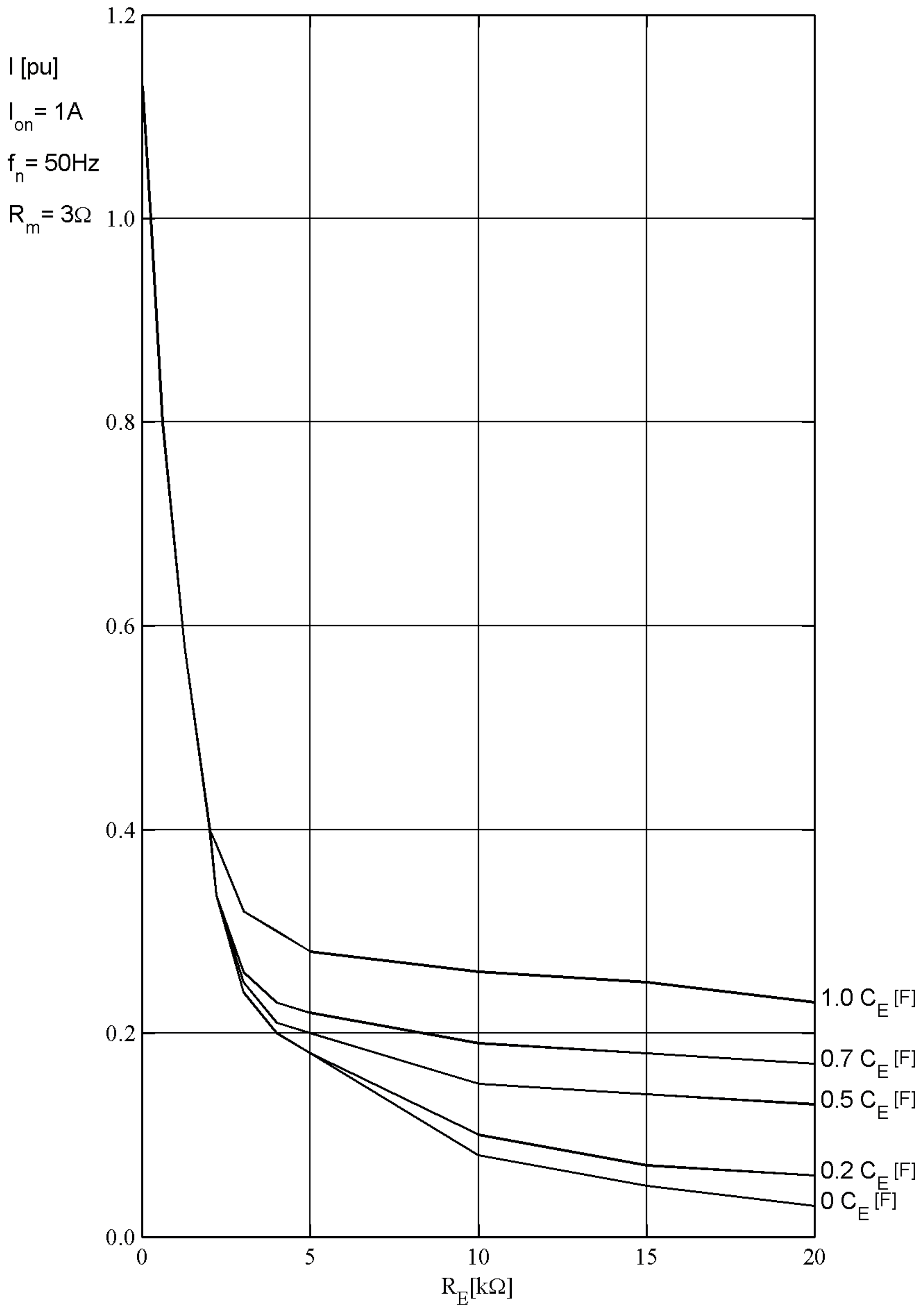


Figure 233: Measured current as a function of the rotor earth-fault resistance with various field-to-earth capacitance values with the measuring circuit resistance Rm = 3.0 Ω, fn = 50 Hz. Only one coupling capacitor is used.

4.2.5.6 Signals

Table 444: MREFPTOC Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 445: MREFPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Alarm

4.2.5.7 Settings

Table 446: MREFPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate start value	0.010...2.000	xIn	0.001	0.010	Operate start value
Alarm start value	0.010...2.000	xIn	0.001	0.010	Alarm start value
Operate delay time	40...20000	ms	1	500	Operate delay time
Alarm delay time	40...200000	ms	1	10000	Alarm delay time

Table 447: MREFPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 448: MREFPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Alm reset delay time	0...60000	ms	1	20	Alarm reset delay time

4.2.5.8 Monitored data

Table 449: MREFPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
MREFPTOC	Enum	1=on 2=blocked		Status

Name	Type	Values (Range)	Unit	Description
		3=test 4=test/blocked 5=off		

4.2.5.9 Technical data

Table 450: MREFPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the current measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1, 2]	I_{Fault} = 1.2 × set *Start value*	Minimum	Typical	Maximum
		30 ms	34 ms	38 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 × f_n, where n = 2, 3, 4, 5,…		

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

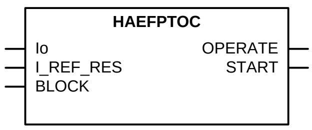


Figure 234: Function block

4.2.6.3 Functionality

The harmonics-based earth-fault protection function HAEFPTOC is used instead of a traditional earth-fault protection in networks where a fundamental frequency component of the earth-fault current is low due to compensation.

1 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.

By default, HAEFPTOC is used as a standalone mode. Substation-wide application can be achieved using horizontal communication where the detection of a faulty feeder is done by comparing the harmonics earth-fault current measurements.

The function starts when the harmonics 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 protection relays, the function operates according to the DT characteristic.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

4.2.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of HAEFPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

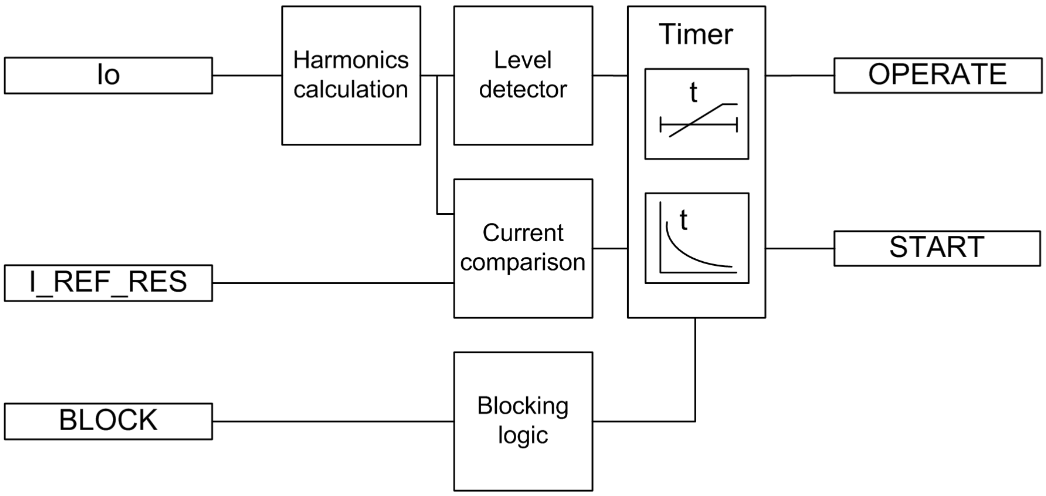


Figure 235: Functional module diagram

Harmonics calculation

This module feeds the measured residual current to the high-pass filter, where the frequency range is limited to start from two times 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 harmonics current, is fed to the Level detector and Current comparison modules.

The harmonics current I_HARM_RES is available in the monitored data view. The value is also sent over horizontal communication to the other protection relays on the parallel feeders configured in the protection scheme.

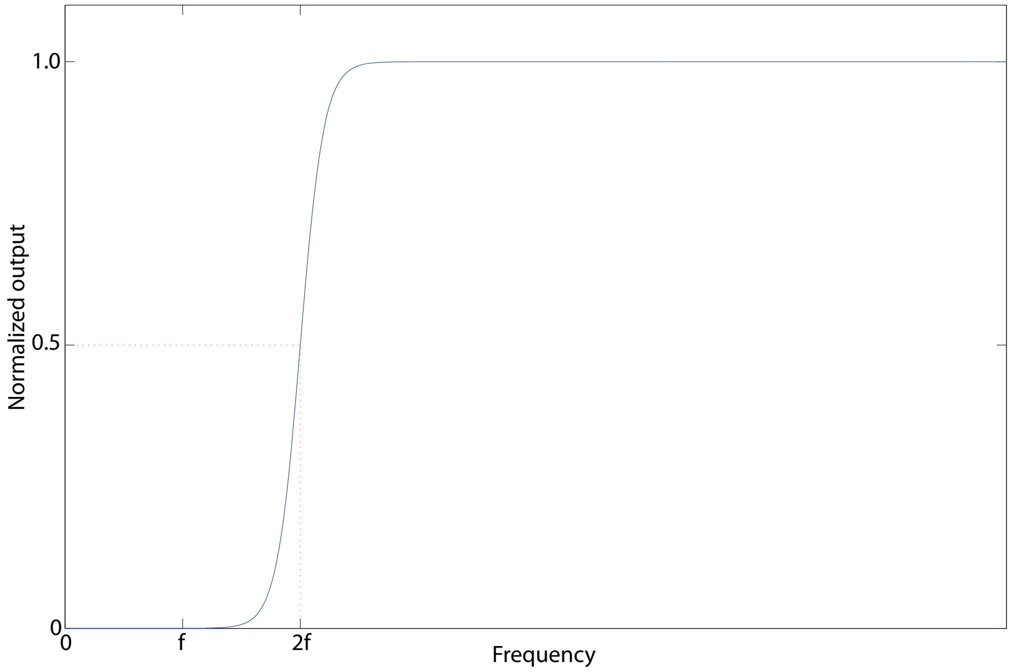


Figure 236: High-pass filter

Level detector

The harmonics current is compared to the *Start value* setting. If the value exceeds the value of the *Start value* setting, Level detector sends an enabling signal to the Timer module.

Current comparison

The maximum of the harmonics 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 harmonics current is higher than `I_REF_RES`, the enabling signal is sent to Timer.

If the locally measured harmonics current is lower than `I_REF_RES`, the fault is not in that feeder. The detected situation blocks Timer internally, and simultaneously also the `BLKD_I_REF` output is activated.

The module also supervises the communication channel validity which is reported to the Timer.

Timer

The `START` output is activated when Level detector sends the enabling signal. Functionality and the time characteristics depend on the selected value of the *Enable reference use* setting.

Table 451: 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	When using the 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.

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 for some reason fails, the function switches to use the *Operation curve type* setting, and 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 too fast an operation time.

In case of a communication failure, the start duration may change substantially depending on the user 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.

If a drop-off situation happens, that is, a fault suddenly disappears before the operation 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. If the drop-off situation continues, the reset timer is reset and the `START` output is deactivated.

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

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 *Chapter 11.2.1 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, which can be either according to DT or IDMT. The value is available in the monitored data view.

More information can be found in *Chapter 11 General function block features*.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.2.6.5 Application

During an earth fault, HAEFPTOC calculates the maximum current for the current feeder. The value is sent over an analog GOOSE to other protection relays of the busbar in the substation. At the configuration level, all the 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 harmonics current. If I_REF_RES exceeds the locally measured harmonics current, the operation of HAEFPTOC is blocked.

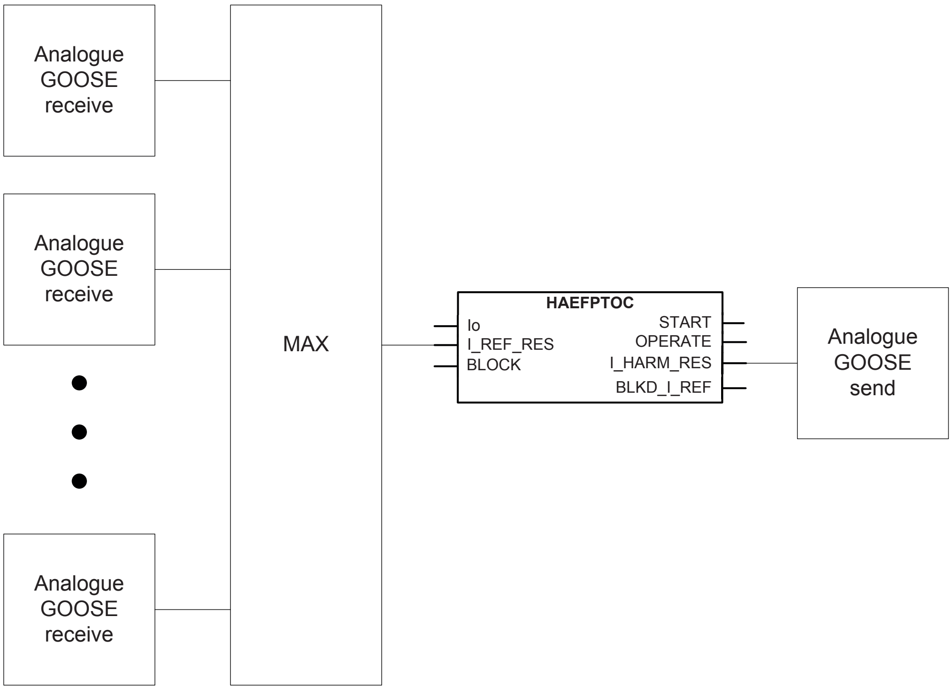


Figure 237: Protection scheme based on the analog GOOSE communication with three analog GOOSE receivers

4.2.6.6 Signals

Table 452: HAEFPTOC Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
I_REF_RES	FLOAT32	0.0	Reference current

Table 453: HAEFPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.6.7 Settings

Table 454: HAEFPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	0.01	0.10	Start value
Time multiplier	0.05...15.000		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	100...200000	ms	10	600	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type

Table 455: HAEFPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	100...200000	ms	10	500	Minimum operate time for IDMT curves
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Enable reference use	0=False 1=True			0=False	Enable using current reference from other IEDs instead of stand-alone

Table 456: HAEFPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 457: HAEFPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

4.2.6.8 Monitored data

Table 458: HAEFPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
I_HARM_RES	FLOAT32	0.0...30000.0	A	Calculated harmonics current
BLKD_I_REF	BOOLEAN	0=False 1=True		Current comparison status indicator
HAEFPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.6.9 Technical data

Table 459: HAEFPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±5% of the set value or ±0.004 × I_n
Start time ,	Typically 77 ms
Reset time	Typically 40 ms
Reset ratio	Typically 0.96

Table continues on the next page

[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 measurements.

[2] Includes the delay of the signal output contact.

Characteristic	Value
Operate time accuracy in definite time mode [3]	±1.0% of the set value or ±20 ms
Operate time accuracy in IDMT mode	±5.0% of the set value or ±20 ms
Suppression of harmonics	-50 dB at $f = f_n$
	-3 dB at $f = 13 \times f_n$

4.2.7 Wattmetric-based earth-fault protection WPWDE

4.2.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Wattmetric-based earth-fault protection	WPWDE	Po> ->	32N

4.2.7.2 Function block

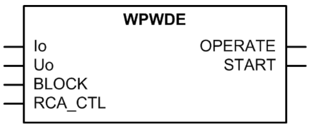


Figure 238: Function block

4.2.7.3 Functionality

The wattmetric-based earth-fault protection function WPWDE can be used to detect earth faults in unearthed networks, compensated networks (Petersen coil-earthed networks) or networks with a high-impedance earthing. 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.

WPWDE measures the earth-fault power 3UoIoCosφ and gives an operating signal when the residual current Io, residual voltage Uo and the earth-fault power exceed the set limits and the angle (φ) between the residual current and the residual voltage is inside the set operating sector, that is, forward or backward sector. 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-based 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.

WPWDE contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

3 Start time of the function also included.
4 Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 2...20.

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".

For WPWDE, certain notations and definitions are used.

Residual voltage Uo = (UA+UB+UC)/3 = U $_0$, where U $_0$ = zero-sequence voltage

Residual current Io = -(IA+IB+IC) = 3×- I $_0$, where I $_0$ = zero-sequence current

The minus sign (-) is needed to match the polarity of calculated and measured residual currents.

The operation of WPWDE can be described with a module diagram. All the modules in the diagram are explained in the next sections.

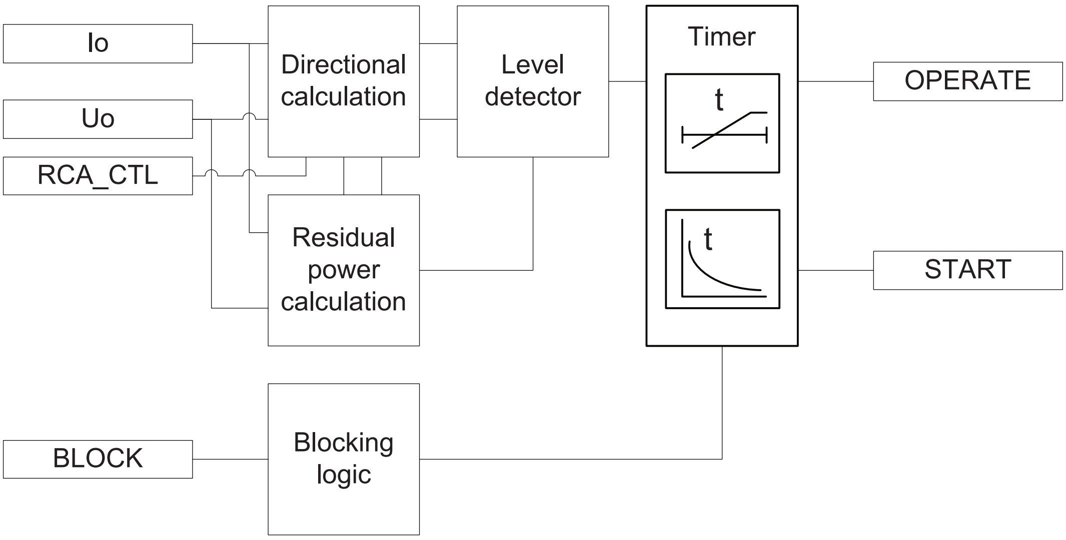


Figure 239: Function module diagram

Directional calculation

The Directional calculation module monitors the angle between the operating quantity (residual current Io) and polarizing quantity (residual voltage Uo). The operating quantity can be selected with the setting *Io signal Sel*. The selectable options are “Measured Io” and “Calculated Io”. The polarizing quantity can be selected with the setting *Pol signal Sel*. The selectable options are “Measured Uo” and “Calculated Uo”. When the angle between operating quantity and polarizing quantity after considering the *Characteristic angle* setting is in the operation sector, the module sends an enabling signal to 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 Io and polarizing quantity Uo, and the value (ANGLE) is available in the monitored data view.

In the phasor diagrams representing the operation of WPWDE, the polarity of the polarizing quantity (residual voltage Uo) is reversed. Reversing is done by switching the polarity of the residual current measuring channel (See the connection diagram in the application manual).

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°.

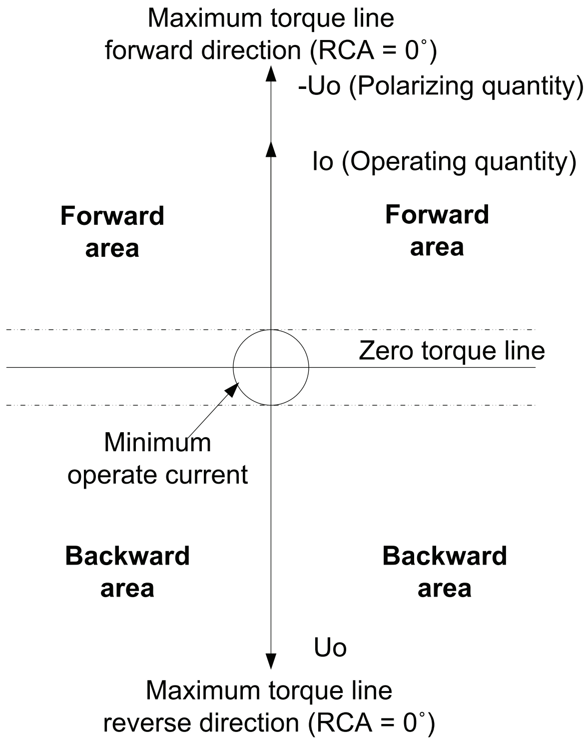


Figure 240: Definition of the relay characteristic angle

The phase angle difference is calculated based on the *Characteristic angle* setting (also known as Relay Characteristic Angle (RCA) or Relay Base Angle 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°, and in case of a compensated network, the *Characteristic angle* setting is set to 0°. In general, *Characteristic angle* is selected so that it is close to the expected fault angle value, which results in maximum sensitivity. *Characteristic angle* can be set anywhere between -179° to +180°. Thus, the effective phase angle (ϕ) for calculating the residual power considering characteristic angle is according to the equation.

$$\phi = \left(\angle(-Uo) - \angle Io - Characteristic\ angle \right)$$

(Equation 44)

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.

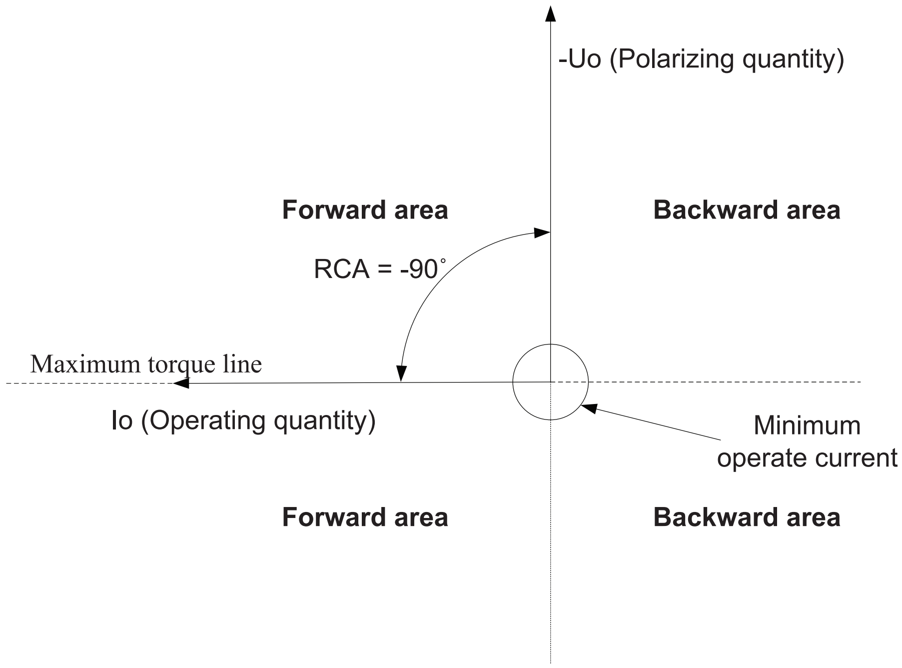


Figure 241: Definition of relay characteristic angle, RCA = -90° in an isolated network

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	Recommended characteristic angle
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 `FAULT_DIR` (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:

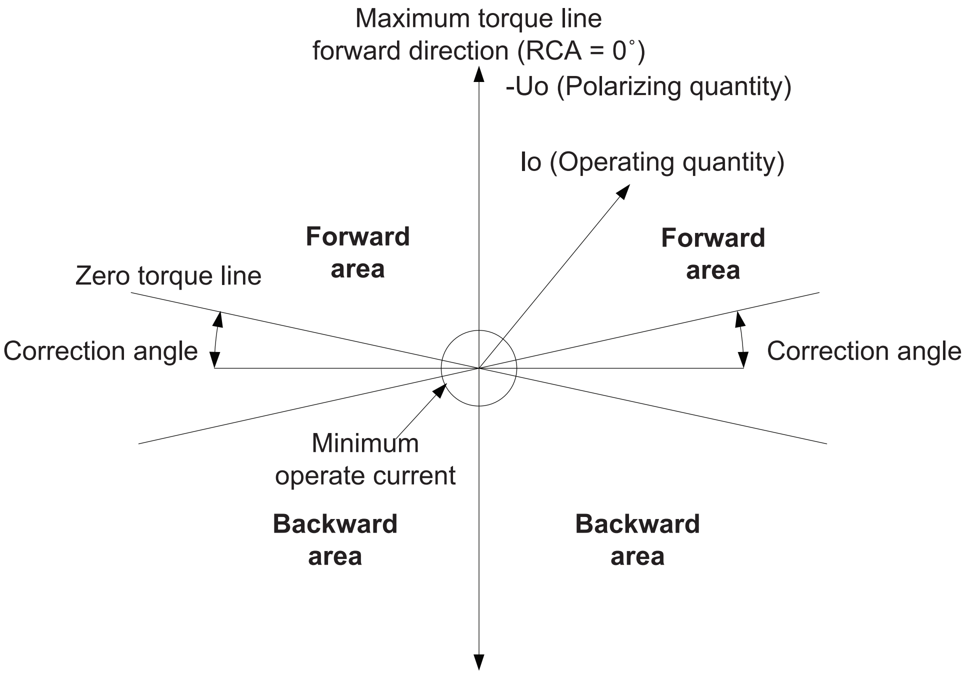


Figure 242: Definition of correction angle

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 3UoIoCosϕ. 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. The power is given in relation to nominal power calculated as Pn = Un × In, where Un and In are obtained from the entered voltage transformer and current transformer ratios entered, and depend on the *Io signal Sel* and *Uo signal Sel* settings.

Level detector

Level detector compares the magnitudes of the measured operating quantity (residual current Io), polarizing quantity (residual voltage Uo) and calculated residual power to the set *Current start value* (×In), *Voltage start value* (×Un) and *Power start value* (×Pn) respectively. When all three quantities exceed the limits, Level detector enables the Timer module.

When calculating the setting values for Level detector, it must be considered that the nominal values for current, voltage and power depend on whether the residual quantities are measured from a dedicated measurement channel or calculated from phase quantities, as defined in the *Io signal Sel* and *Uo signal Sel* settings.

For residual current Io, if "Measured Io" is selected, the nominal values for primary and secondary are obtained from the current transformer ratio entered for residual current channel **Configuration** > **Analog inputs** > **Current (Io, CT)**. If "Calculated Io" is selected, the nominal values for primary and secondary are obtained from the current transformer ratio entered for phase current channels **Configuration** > **Analog inputs** > **Current (3I, CT)**.

For residual voltage Uo, if "Measured Uo" is selected, the nominal values for primary and secondary are obtained from the voltage transformer ratio entered for residual voltage channel **Configuration** > **Analog inputs** > **Voltage (Uo, VT)**. If "Calculated Uo" is selected, the nominal values for primary and secondary are obtained from the voltage transformer ratio entered for phase voltage channels **Configuration** > **Analog inputs** > **Voltage (3U, VT)**.

Calculated Uo requires that all three phase-to-earth voltages are connected to the protection relay. Uo cannot be calculated from the phase-to-phase voltages.

As nominal power is the result of the multiplication of the nominal current and the nominal voltage Pn = Un × In, the calculation of the setting value for *Power start value* (×Pn) depends on whether Io and Uo are measured or calculated from the phase quantities.

Table 460: Measured and calculated Io and Uo

	Measured Io	Calculated Io
Measured Uo	Pn = (Uo, VT) × (Io, CT)	Pn = (Uo, VT) × (3I, CT)
Calculated Uo	Pn = (3U, VT) × (Io, CT)	Pn = (3U, VT) × (3I, CT)

Example 1. Io is measured with cable core CT (100/1A) and Uo is measured from open delta-connected VTs (20/sqrt(3) kV:100/sqrt(3) V:100/3 V). In this case, "Measured Io" and "Measured Uo" are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios.

Residual current Io: **Configuration** > **Analog inputs** > **Current (Io, CT)**: 100 A:1 A

Residual voltage Uo: **Configuration** > **Analog inputs** > **Current (Uo, VT)**: 11.547 kV:100 V

Residual Current start value of 1.0 × In corresponds then 1.0 × 100 A = 100 A in primary

Residual Voltage start value of 1.0 × Un corresponds then 1.0 × 11.547 kV = 11.547 kV in primary

Residual Power start value of 1.0 × Pn corresponds then 1.0 × 11.547 kV × 100 A = 1154.7kW in primary

Example 2. Both Io and Uo are calculated from phase quantities. Phase CT-ratio is 100:1 A and Phase VT-ratio 20/sqrt(3) kV:100/sqrt(3) V. In this case "Calculated Io" and "Calculated Uo" are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios entered in:

Residual current Io: **Configuration** > **Analog inputs** > **Current (3I, CT)**: 100 A:1 A

Residual voltage Uo: **Configuration** > **Analog inputs** > **Current (3U, VT)**: 20.000 kV:100 V

Residual Current start value of 1.0 × In corresponds then 1.0 × 100 A = 100 A in primary

Residual Voltage start value of 1.0 × Un corresponds then 1.0 × 20.000 kV = 20.000 kV in primary

Residual Power start value of 1.0 × Pn corresponds then 1.0 × 20.000 kV × 100 A = 2000kW in primary

If "Calculated Uo" is selected for the *Uo signal Sel* setting, the nominal value for residual voltage Un is always phase-to-phase voltage. Thus, the valid maximum setting for residual *Voltage start value* is 0.577 × Un, which corresponds to full phase-to-earth voltage in primary.

Timer

Once activated, 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 operating 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.

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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

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 45)

t[s]	operation time in seconds
k	set value of *Time multiplier*
P_{ref}	set value of *Reference power*
P_{cal}	calculated residual power

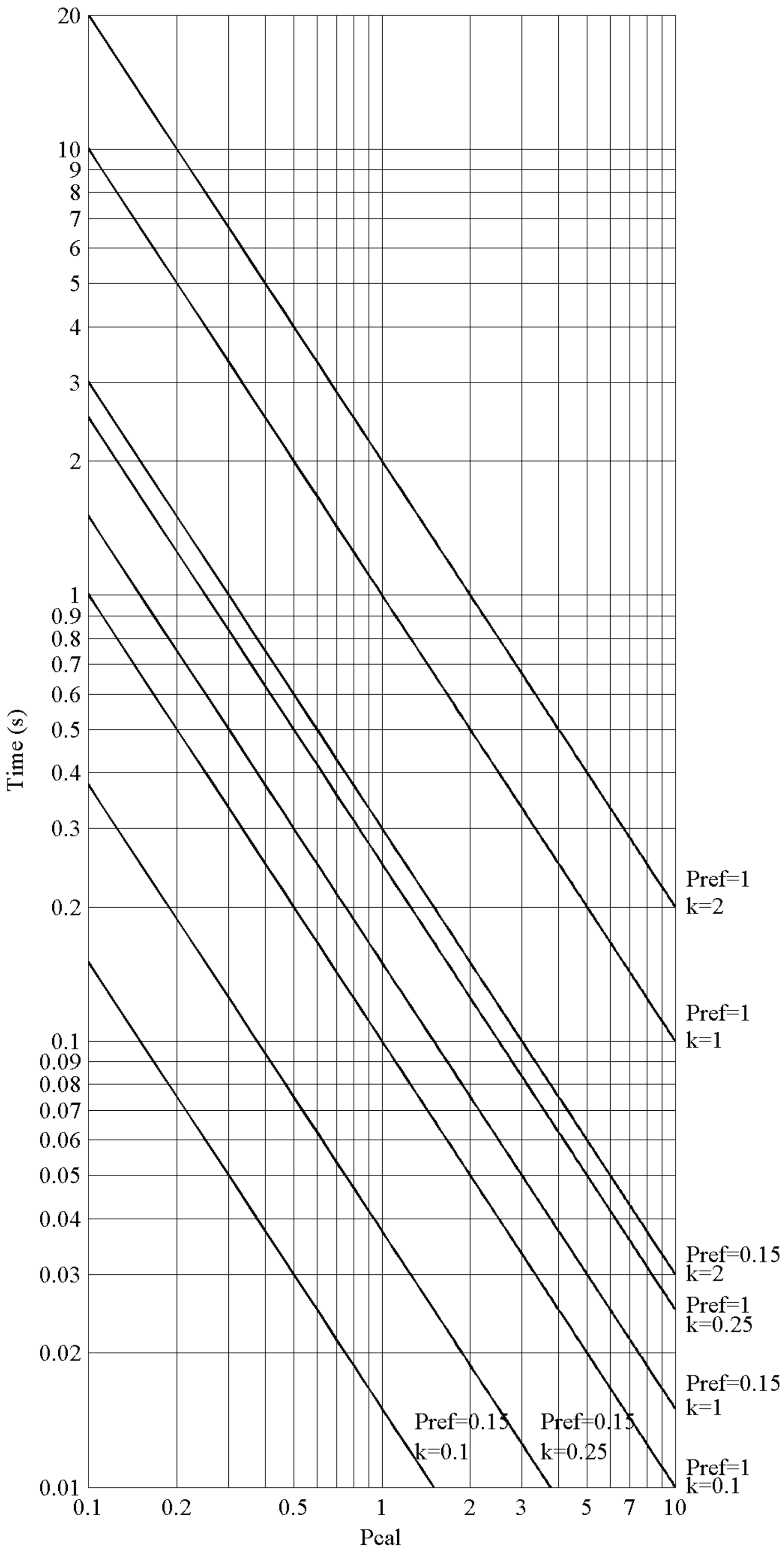


Figure 243: Operation time curves for wattmetric IDMT for S ref set at 0.15 xPn

4.2.7.6 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.

4.2.7.7 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 3UoIoCosφ (φ is the angle between the polarizing quantity and operating quantity compensated with a relay characteristic angle).

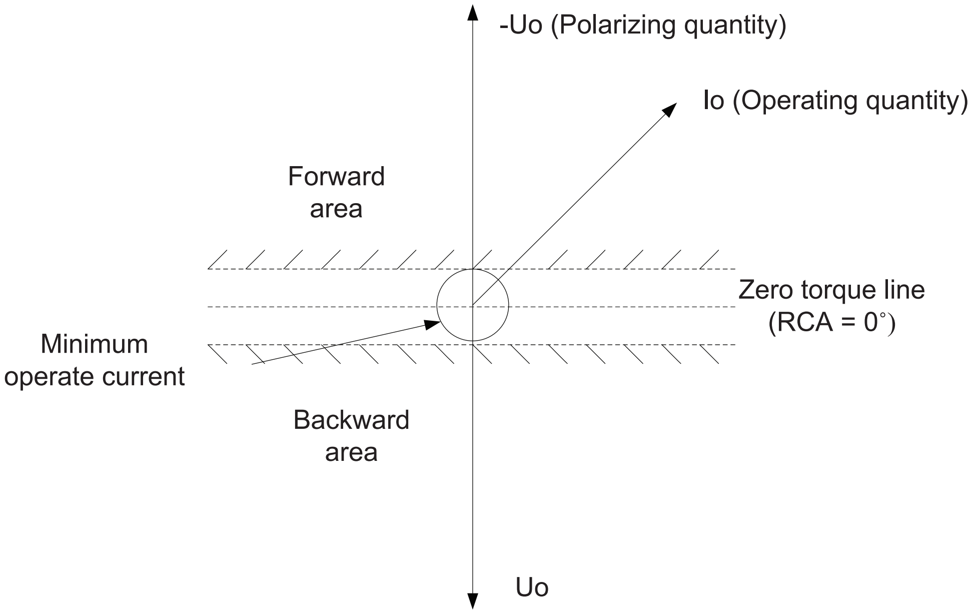


Figure 244: Characteristics of wattmetric protection

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.

A typical network with the wattmetric protection is 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).

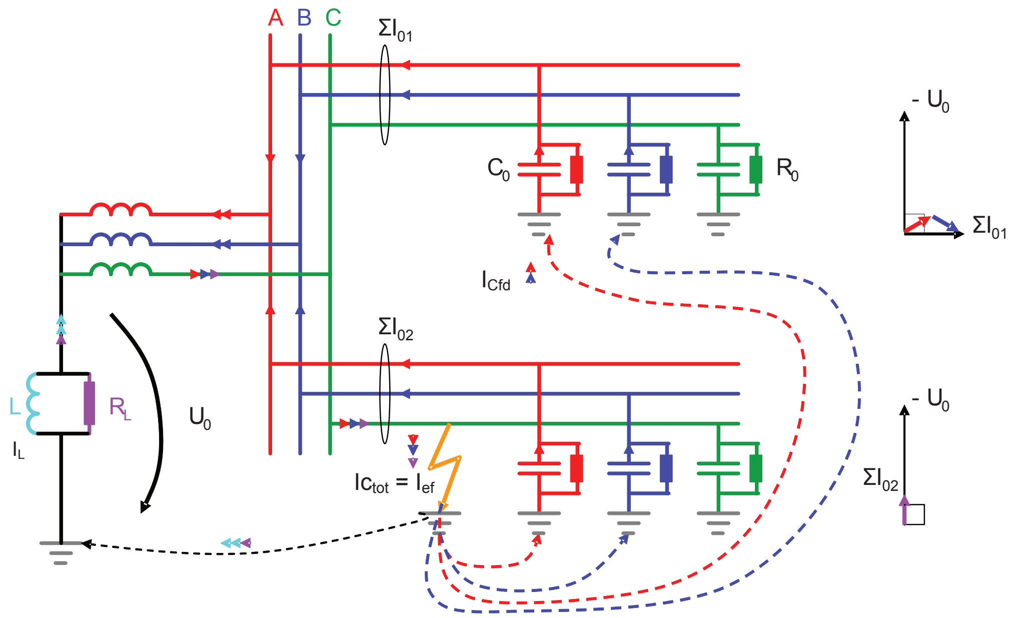


Figure 245: Typical radial compensated network employed with wattmetric protection

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.

It is highly recommended that core balance current transformers are used for measuring Io when using the wattmetric method. When a low transformation ratio is used, the current transformer can suffer accuracy problems and even a distorted secondary current waveform with some core balance current transformers. 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 current transformer 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, when the network is only coupled to earth via the capacitances between the phase conductors and earth, the characteristic angle is chosen as -90°.

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 0°. Often the magnitude of an 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 0°.

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.

The 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.

4.2.7.8 Signals

Table 461: WPWDE Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

Table 462: WPWDE Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.7.9 Settings

Table 463: WPWDE Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Directional mode	2=Forward 3=Reverse			2=Forward	Directional mode
Current start value	0.010...5.000	xIn	0.001	0.010	Minimum operate residual current for deciding fault direction
Voltage start value	0.010...1.000	xUn	0.001	0.010	Start value for residual voltage
Power start value	0.003...1.000	xPn	0.001	0.003	Start value for residual active power
Reference power	0.050...1.000	xPn	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	5=ANSI Def. Time 15=IEC Def. Time			15=IEC Def. Time	Selection of time delay curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	20=Wattmetric IDMT				
Operate delay time	60...200000	ms	10	60	Operate delay time for definite time

Table 464: WPWDE Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 465: WPWDE Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used current measurement mode
Correction angle	0.0...10.0	deg	0.1	2.0	Angle correction
Min operate current	0.010...1.000	xIn	0.001	0.010	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage
Reset delay time	0...60000	ms	1	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal
Uo signal Sel	1=Measured Uo 2=Calculated Uo			1=Measured Uo	Selection for used polarization signal

4.2.7.10 Monitored data

Table 466: WPWDE Monitored data

Name	Type	Values (Range)	Unit	Description
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
DIRECTION	Enum	0=unknown 1=forward		Direction information

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		2=backward 3=both		
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
RES_POWER	FLOAT32	-160.000...160.000	xPn	Calculated residual active power
WPWDE	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.7.11 Technical data

Table 467: WPWDE Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Current and voltage: ±1.5% of the set value or ±0.002 × I_n Power: ±3% of the set value or ±0.002 × P_n
Start time [1, 2]	Typically 63 ms
Reset time	Typically 40 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode [3]	±1.0% of the set value or ±20 ms
Operate time accuracy in IDMT mode	±5.0% of the set value or ±20 ms
Suppression of harmonics	-50 dB at f = n × f_n, where n = 2,3,4,5,…

4.2.8 Multifrequency admittance-based earth-fault protection MFADPSDE

1 Io varied during the test, U_o = 1.0 × U_n = phase-to-earth voltage during earth fault in compensated or unearthed 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.
3 Start time of the function also included.

4.2.8.1 Identification

Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Multifrequency admittance-based earth-fault protection	MFADPSDE	Io> ->Y	67YN

4.2.8.2 Function block

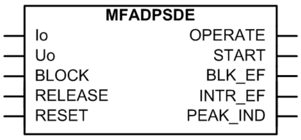


Figure 246: Function block

4.2.8.3 Functionality

The multifrequency admittance-based earth-fault protection function 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 multifrequency 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 (DEFxPDEF), Watt/Varmetric (WPWDE) and neutral admittance (EFPADM).

MFADPSDE is capable of detecting faults with dominantly fundamental frequency content as well as 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. The inbuilt transient detector can be used to identify restriking or intermittent earth faults, and discriminate them from permanent or 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).

The function contains a blocking functionality to block function outputs, timers or the function itself.

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 MFADPSDE can be described using a module diagram. All the modules in the diagram are explained in the following sections.

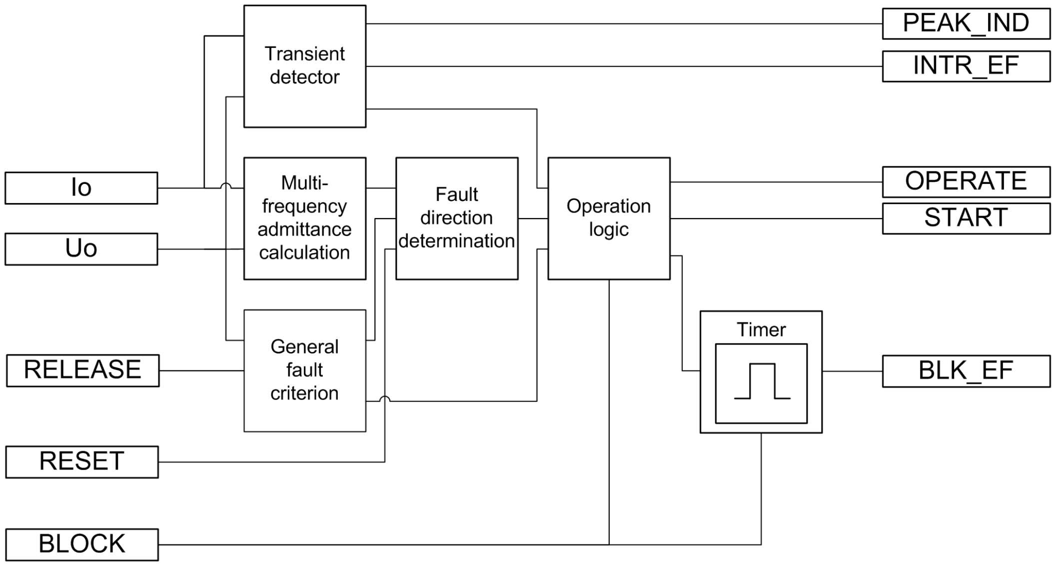


Figure 247: Functional module diagram

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.

$$\overline{U_0^1} = \left(\overline{U_A^1} + \overline{U_B^1} + \overline{U_C^1}\right) / 3$$

(Equation 46)

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 utilizing 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 protection relay.

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 47)

$\overline{Y_0^1}$ The fundamental frequency neutral admittance phasor.

$\overline{I_0^1}$ The fundamental frequency zero-sequence current phasor $(= (\overline{I_A^1} + \overline{I_B^1} + \overline{I_C^1}) / 3)$

$\overline{U_0^1}$ The fundamental frequency zero-sequence voltage phasor $(= (\overline{U_A^1} + \overline{U_B^1} + \overline{U_C^1}) / 3)$

G_o^1 The fundamental frequency conductance, $\mathrm{Re}\left(\overline{Y_0^1}\right)$

B_o^1 The fundamental frequency susceptance, $\mathrm{Im}\left(\overline{Y_0^1}\right)$

Harmonic susceptance

$$\mathrm{Im}\left[\overline{Y_0^n}\right] = \mathrm{Im}\left[\frac{3 \cdot \overline{I_0^n}}{-\overline{U_0^n}}\right] = j \cdot B_o^n$$

(Equation 48)

where n = 2, 3, 5, 7 and 9

$\overline{Y_0^n}$ The nth harmonic frequency neutral admittance phasor.

$\overline{I_0^n}$ The nth harmonic frequency zero-sequence current phasor.

$\overline{U_0^n}$ The nth harmonic frequency zero-sequence voltage phasor.

B_o^n The nth harmonic frequency susceptance, $\mathrm{Im}\left(\overline{Y_0^n}\right)$

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.

$$\overline{Y}_{osum} = \text{Re}\left[\overline{Y_0^1}\right] + j \cdot \text{Im}\left[\overline{Y_0^1} + \sum_{n=2}^{9} \overline{Y_0^n}\right] = G_o^1 + j \cdot B_{osum}$$

(Equation 49)

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 248*. 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 50)

$$\overline{Y}_{osum\_CPS}(t_2) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2)$$

(Equation 51)

$$\overline{Y}_{osum\_CPS}(t_3) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2) + \overline{Y}_{osum}(t_3)$$

(Equation 52)

$$\overline{Y}_{osum\_CPS}(t_4) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2) + \overline{Y}_{osum}(t_3) + \overline{Y}_{osum}(t_4)$$

(Equation 53)

$$\overline{Y}_{osum\_CPS}(t_5) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2) + \overline{Y}_{osum}(t_3) + \overline{Y}_{osum}(t_4) + \overline{Y}_{osum}(t_5)$$

(Equation 54)

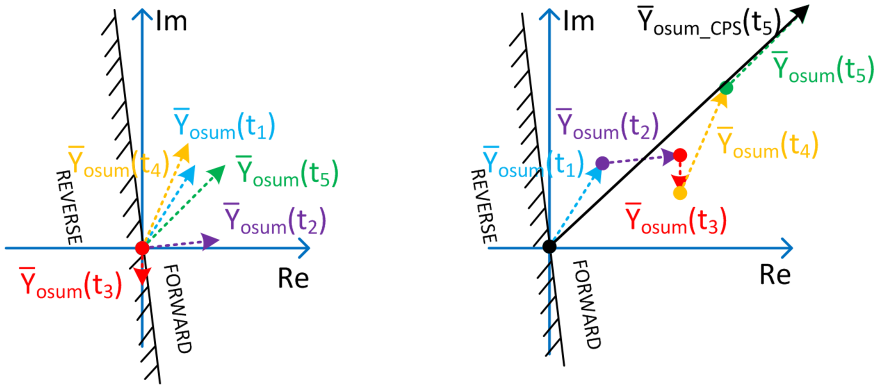


Figure 248: Principle of Cumulative Phasor Summing (CPS)

The CPS technique provides a stable directional phasor quantity despite individual phasors varying 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.

Harmonic components provide a more distinctive directional determination in compensated networks than the fundamental frequency component. The higher the 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 249*. 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 250*, 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 $\mathrm{Im}(\overline{Yo})$ 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 $\mathrm{Im}(\overline{Yo})$ 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 no harmonic components are 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 $\mathrm{Im}(\overline{Yo})$ axis (as phasor 4).

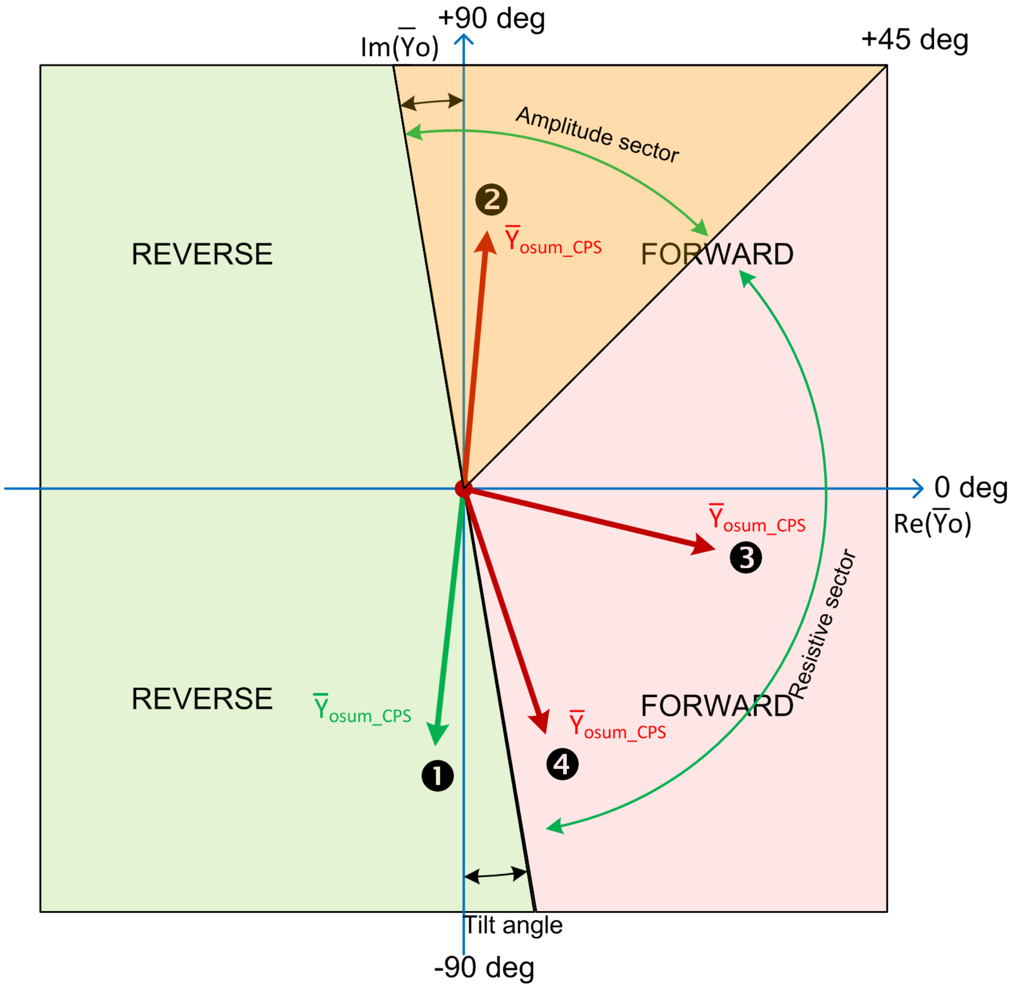


Figure 249: Directional characteristic of MFADPSDE

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 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 MFADPSDE includes also a `RESET` input, which can be utilized 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 55)

$\overline{Y^1_{o\ stab}}$	The stabilized fundamental frequency admittance estimate, which is result from fundamental frequency admittance calculation utilizing the Cumulative Phasor Summing (CPS) technique.
$\overline{I^1_{0\,CPS}}$	The fundamental frequency zero-sequence current phasor calculated utilizing the Cumulative Phasor Summing (CPS) technique.
$\overline{U^1_{0\,CPS}}$	The fundamental frequency zero-sequence voltage phasor calculated utilizing the Cumulative Phasor Summing (CPS) technique.
G^1_{ostab}	The real-part of stabilized fundamental frequency conductance estimate.
B^1_{ostab}	The imaginary part of stabilized fundamental frequency susceptance estimate.

$$\overline{I^1_{o\,stab}} = (G^1_{ostab} + j \cdot B^1_{ostab}) \cdot U_{baseres} = I^1_{oCosstab} + j \cdot I^1_{oSinstab}$$

(Equation 56)

$\overline{I^1_{o\,stab}}$	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.
$\overline{I^1_{o\,Cosstab}}$	The real-part of stabilized fundamental frequency residual current estimate.
$\overline{I^1_{o\,Sinstab}}$	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 Ω). Another advantage of the method is that it is capable of estimating correct current magnitude also during intermittent or restriking faults.

The setting *Min operate current* defines the minimum operate current.

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 250*). 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.

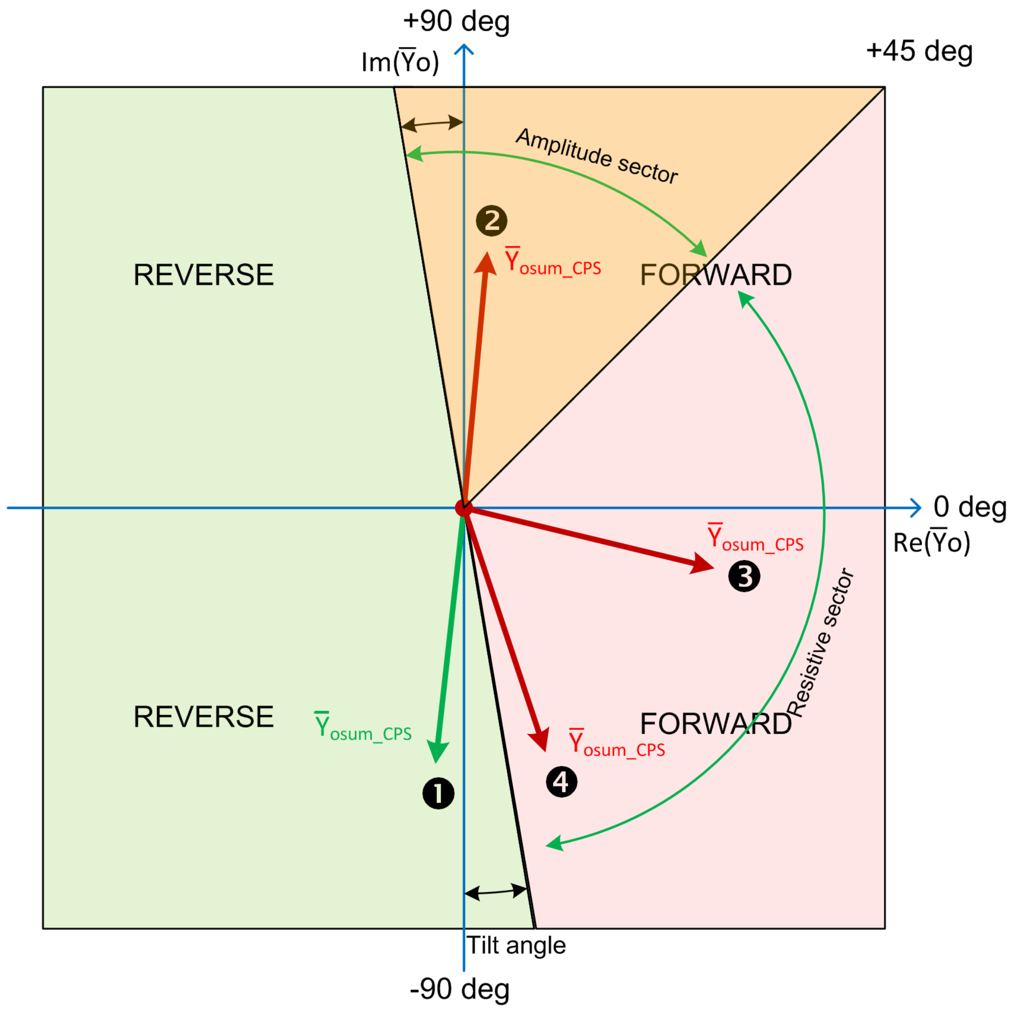


Figure 250: Illustration of amplitude and resistive current sectors if Operating quantity is set "Adaptive" and Directional mode is set "Forward"

The setting rules for current thresholds are given below.

In case the "Adaptive" operating quantity is selected, the setting *Min operate current* should be set to value:

$$[pu] < p \cdot IRtot$$

(Equation 57)

IRtot	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 251*.

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.

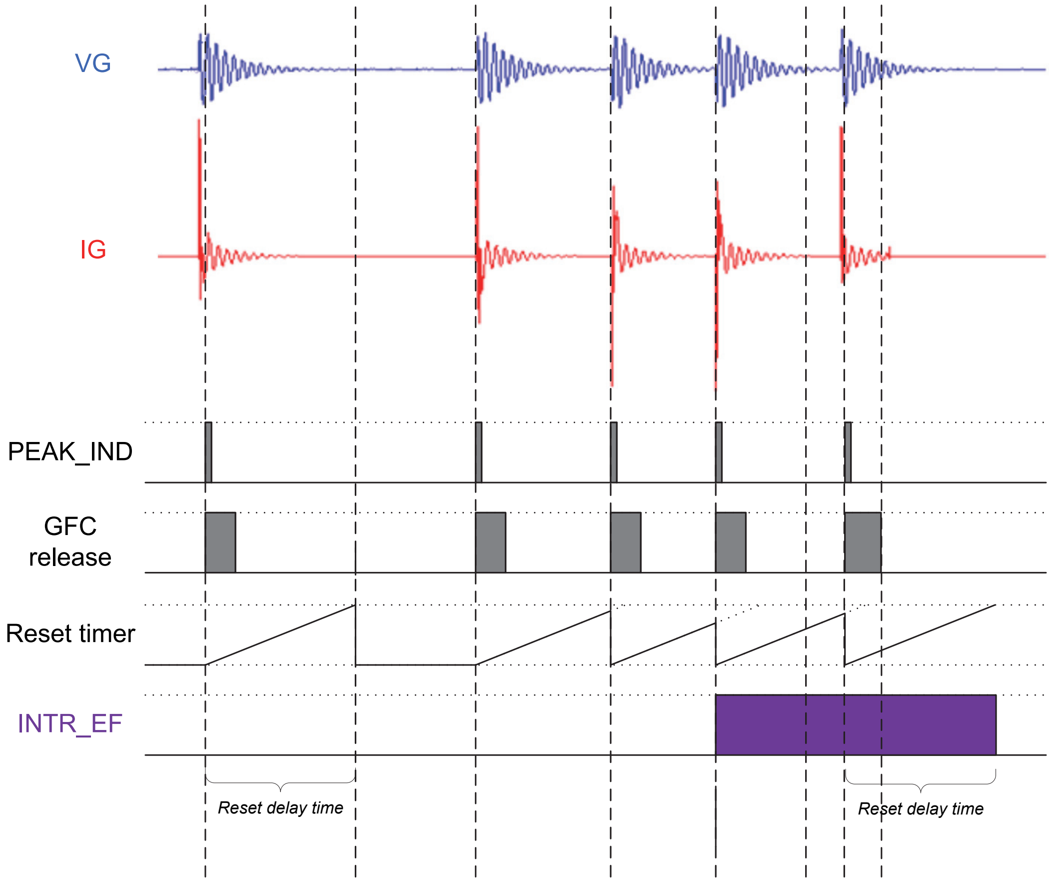


Figure 251: Example of operation of Transient detector: indication of detected transient by PEAK_IND output and detection of restriking or intermittent earth fault by INTR_EF output (setting Peak counter limit = 3)

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 the set *Min operate current* level

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.

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.

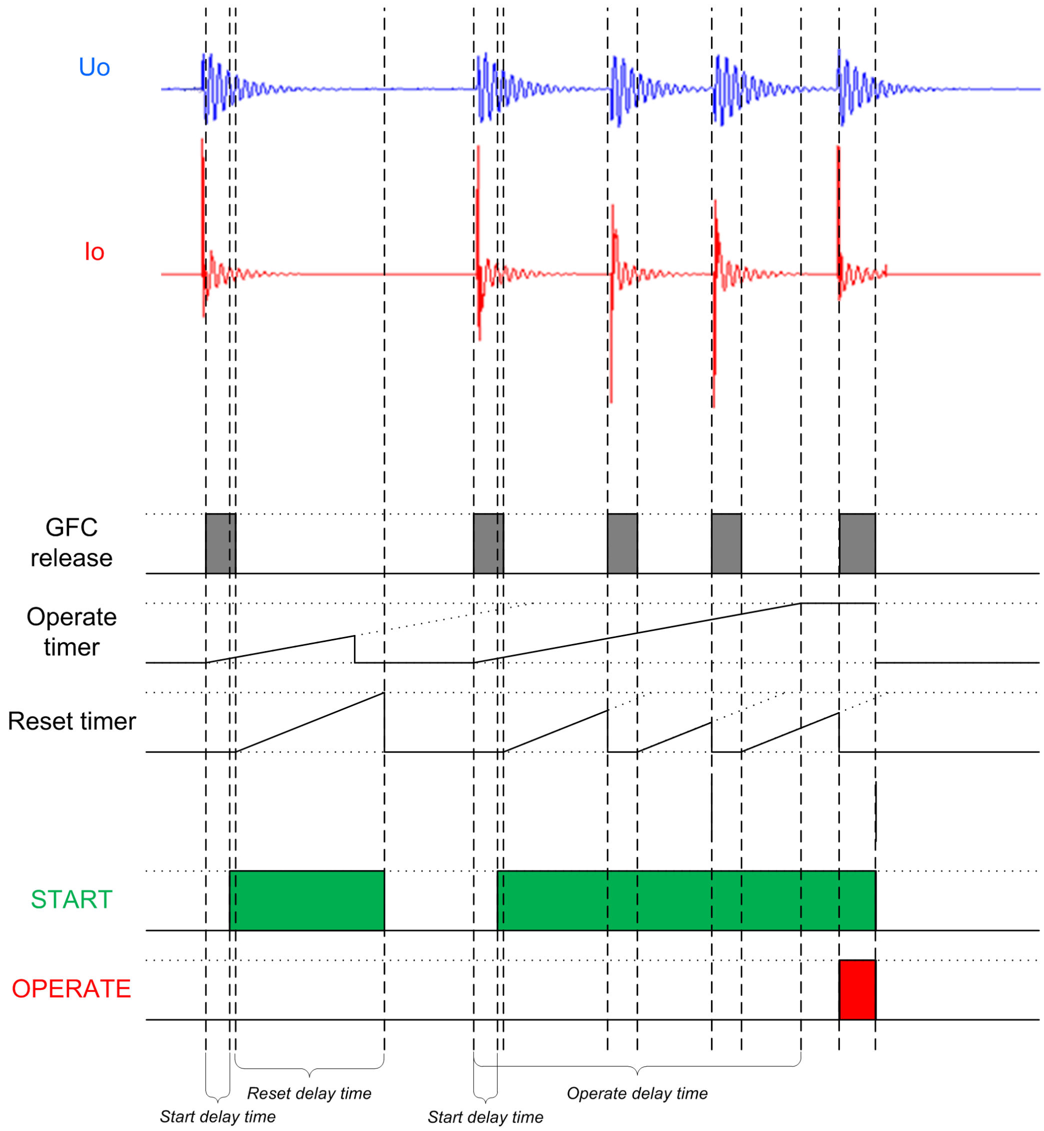


Figure 252: Operation in “General EF” mode

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 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 the set *Min operate current* level

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.

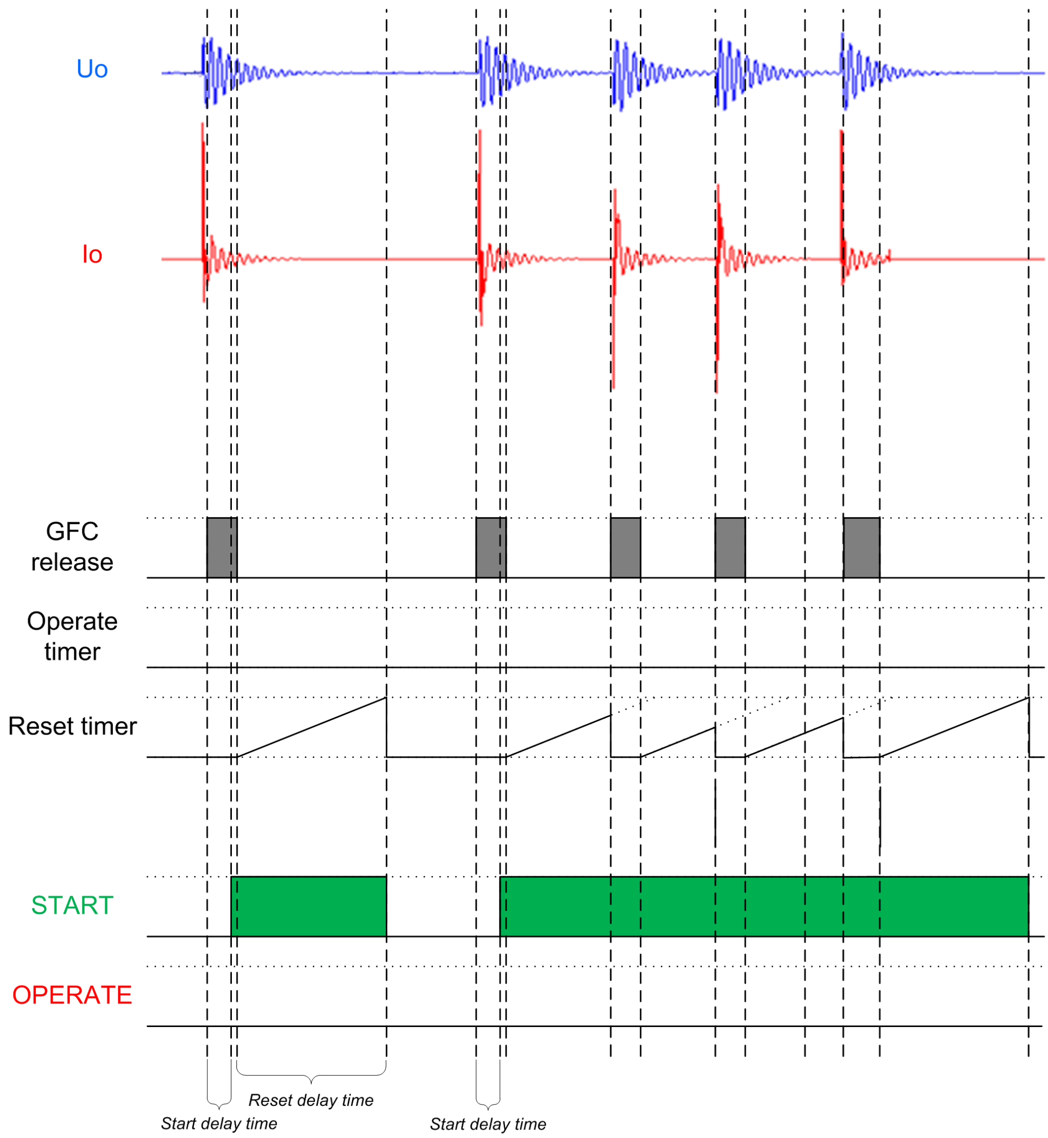


Figure 253: Operation in “Alarming EF” mode

Operation mode “Intermittent EF” is dedicated for detecting restriking or intermittent earth faults. A required number of intermittent earth fault transients set with the *Peak counter limit* setting must be detected for operation. 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 the 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 the set *Min operate current* level

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.

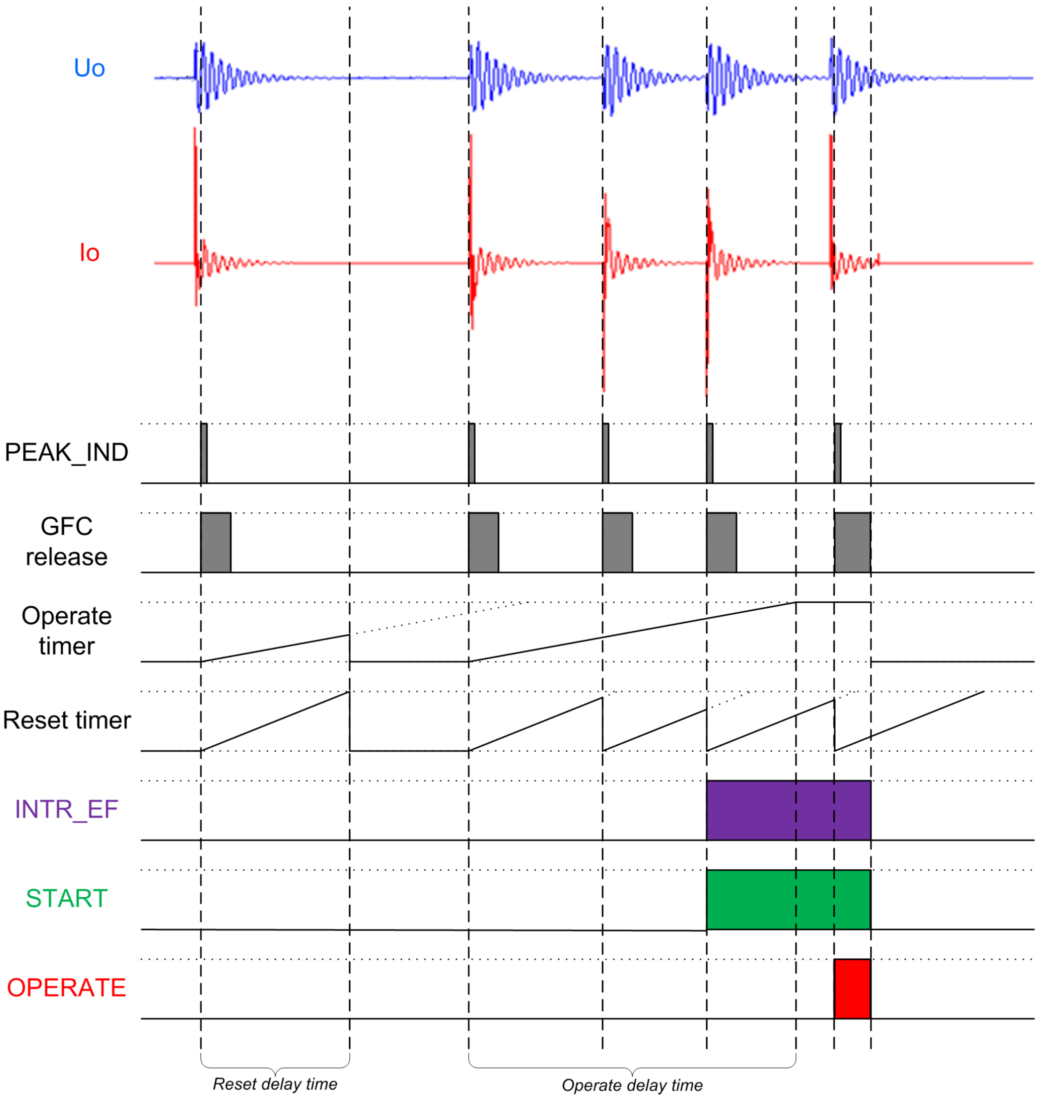


Figure 254: Operation in "Intermittent EF" mode, Peak counter limit = 3

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

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.

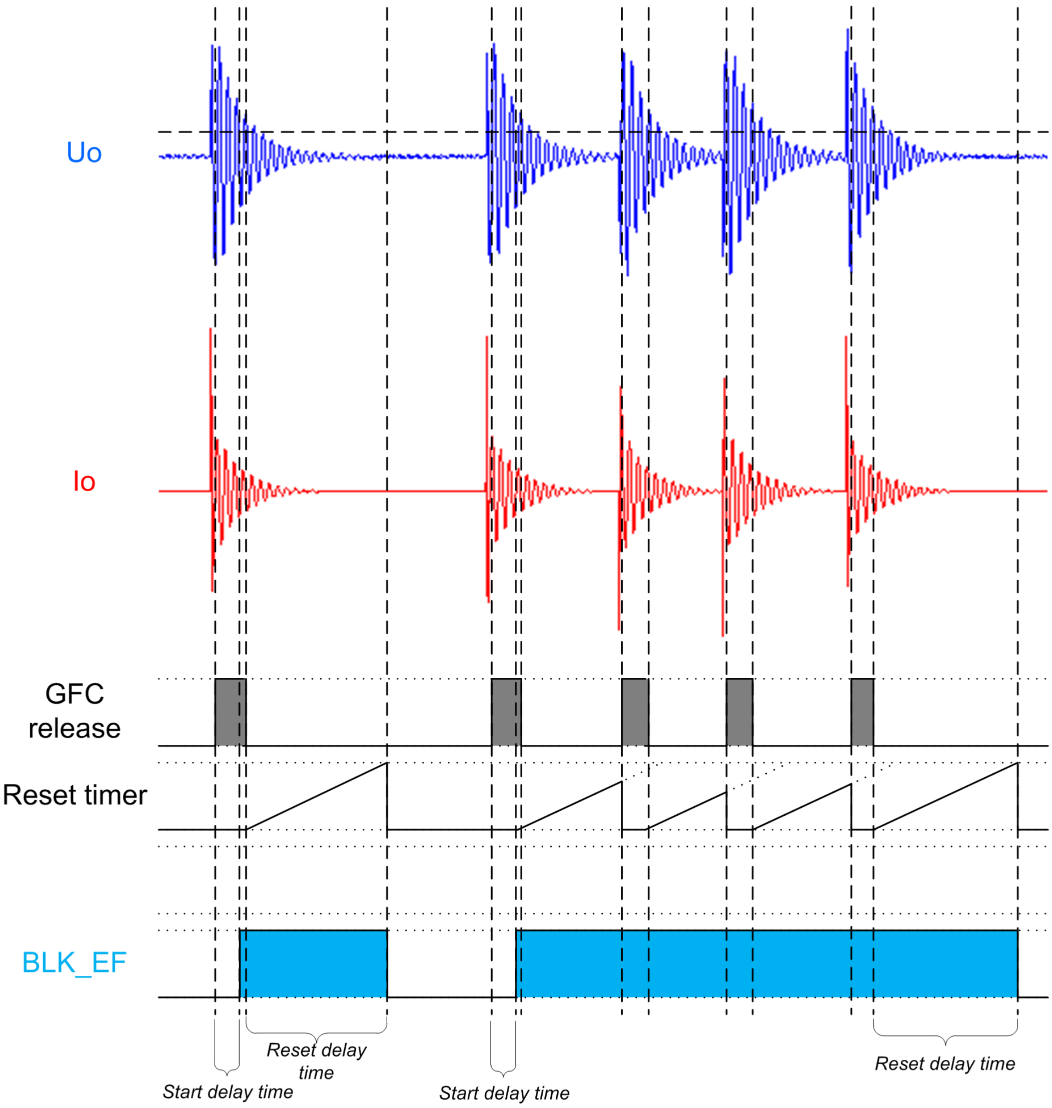


Figure 255: Activation of BLK_EF output (indication that fault is located opposite to the set operate direction)

4.2.8.5 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 (DEFxPDEF), Watt/Varmetric (32N) and neutral admittance (21YN).

MFADPSDE is capable of detecting faults with dominantly fundamental frequency content as well as 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 transient 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.

4.2.8.6 Signals

Table 468: MFADPSDE Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	Residual voltage

Table continues on the next page

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RELEASE	BOOLEAN	0=False	External trigger to release neutral admittance protection
RESET	BOOLEAN	0=False	External trigger to reset direction calculation

Table 469: MFADPSDE Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
BLK_EF	BOOLEAN	Block signal for EF to indicate opposite direction peaks
INTR_EF	BOOLEAN	Intermittent earth-fault indication
PEAK_IND	BOOLEAN	Current transient detection indication

4.2.8.7 Settings

Table 470: MFADPSDE Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Directional mode	2=Forward 3=Reverse			2=Forward	Directional mode
Voltage start value	0.01...1.00	xUn	0.01	0.10	Voltage start value
Operate delay time	60...1200000	ms	10	500	Operate delay time

Table 471: MFADPSDE Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operating quantity	1=Adaptive 2=Amplitude			1=Adaptive	Operating quantity selection
Min operate current	0.005...5.000	xIn	0.001	0.010	Minimum operate current
Tilt angle	2.0...20.0	deg	0.1	5.0	Characteristic tilt angle

Table 472: MFADPSDE Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Intermittent EF			3=General EF	Operation criteria

Parameter	Values (Range)	Unit	Step	Default	Description
	3=General EF 4=Alarming EF				

Table 473: MFADPSDE Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal
Uo signal Sel	1=Measured Uo 2=Calculated Uo			1=Measured Uo	Selection for used Uo signal
Peak counter limit	2...20		1	2	Peak counter limit for restriking EF
Start delay time	30...60000	ms	1	30	Start delay time
Reset delay time	0...60000	ms	1	500	Reset delay time
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity

4.2.8.8 Monitored data

Table 474: MFADPSDE Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
MFADPSDE	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.8.9 Technical data

Table 475: MFADPSDE Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × U_n
Start time [1]	Typically 35 ms
Reset time	Typically 40 ms
Operate time accuracy	±1.0% of the set value or ±20 ms

4.3 Differential protection

[1] Includes the delay of the signal output contact, results based on statistical distribution of 1000 measurements.

4.3.1 Stabilized and instantaneous differential protection for machines MPDIF

4.3.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Stabilized and instantaneous differ-ential protection for machines	MPDIF	3dI>M/G	87M/G

4.3.1.2 Function block

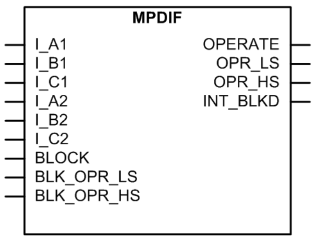


Figure 256: Function block

4.3.1.3 Functionality

The stabilized and instantaneous differential protection for machines function MPDIF is a unit protection function. The possibility of internal failures of the machine 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.

4.3.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MPDIF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

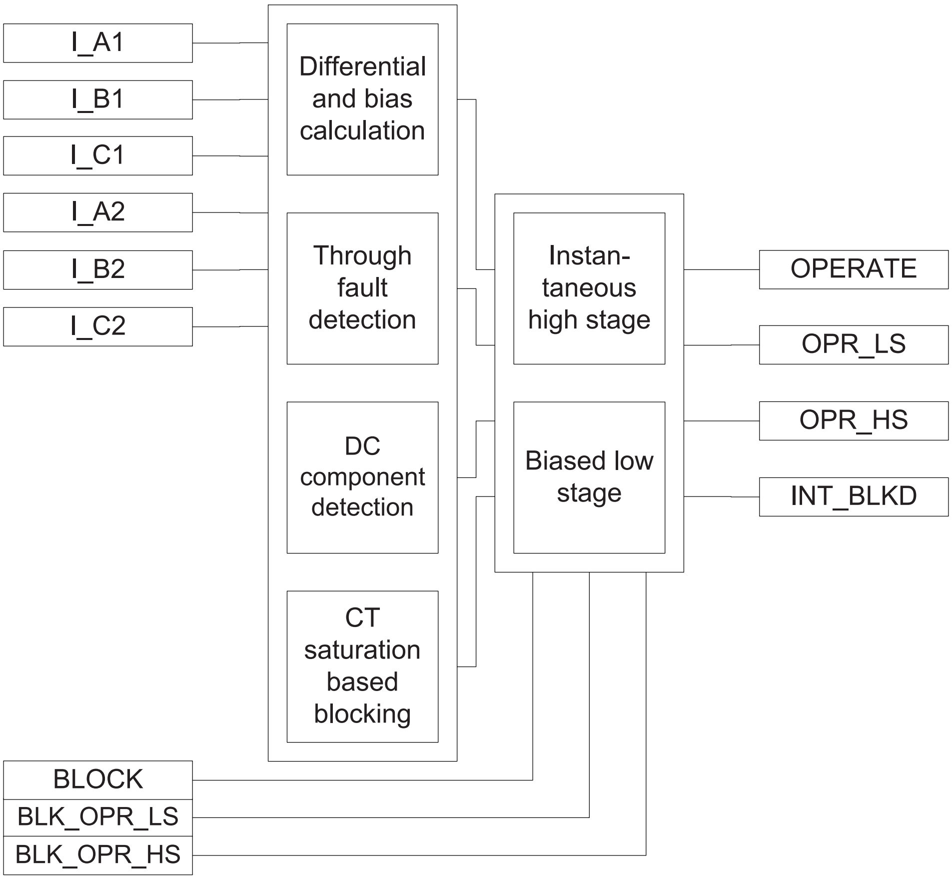


Figure 257: Functional module diagram

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 58)

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 59)

The module calculates the bias current for all three phases.

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.

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 operating 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:

$$Low\,operate\,value = I_{d1}$$

(Equation 60)

The *Slope section 2* and *Slope section 3* settings are determined correspondingly:

$$Slope\,section\,2 = \frac{I_{d2}}{I_{b2}} \cdot 100\%$$

(Equation 61)

$$Slope\,section\,3 = \frac{I_{d3}}{I_{b3}} \cdot 100\%$$

(Equation 62)

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_r). Accordingly, the end of the second section *End section 2* can be set within the range of 100 percent to 300 percent (or % I_r).

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.

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 CT errors.

In section 3, where I_b/I_n > *End section 2*, the slope of the characteristic can be set by *Slope section 3* that defines the increase in the differential current to the corresponding increase in the biasing 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 63)

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 64)

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 65)

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.

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 `INT_BLKD` output is 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.

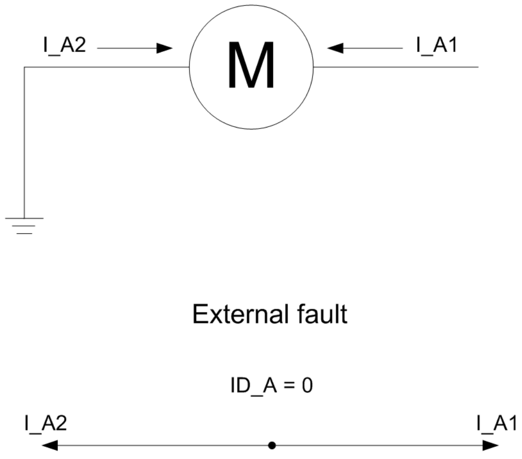


Figure 258: Positive direction of current

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.

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.

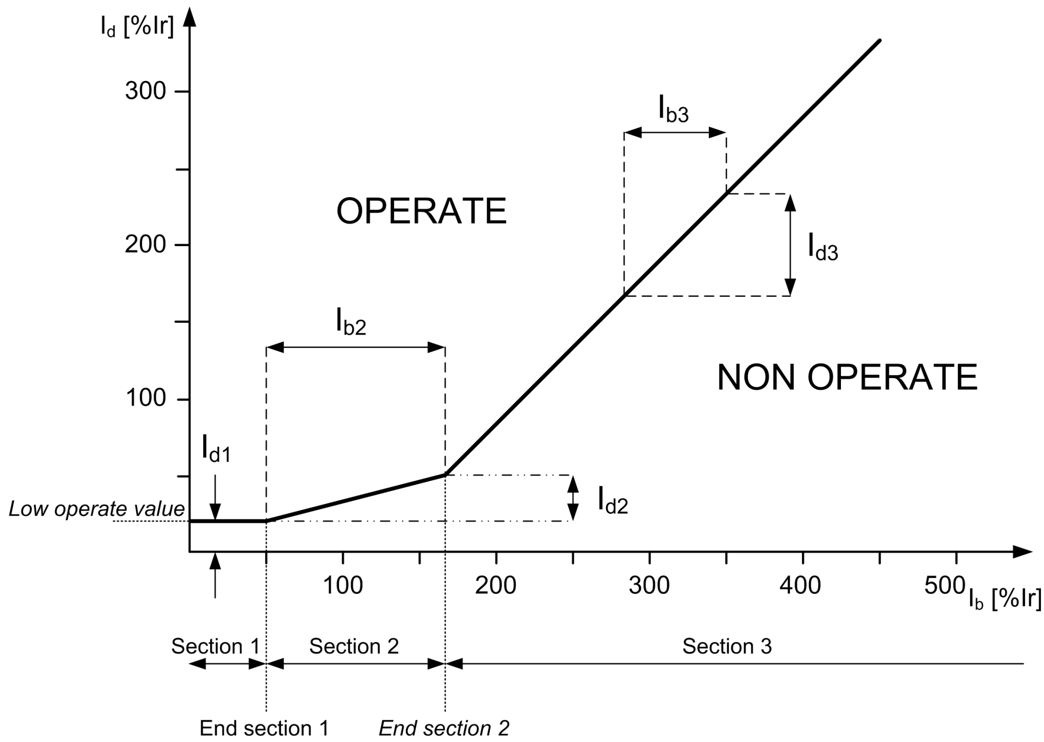


Figure 259: Operating characteristic for the stabilized stage of the generator differential protection function

4.3.1.5 Application

The differential protection works on the principle of calculating the differential current at the 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 is 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.

$$F_a = F_n \times \frac{S_{in} + S_n}{S_{in} + S_a}$$

(Equation 66)

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 Ω and the rated accuracy limit factor F_n corresponding to the rated burden is 20 (5P20). The internal burden of the current transformer is $S_{in} = (5A)^2 \times 0.07\ \Omega = 1.75$ VA. The input impedance of the protection relay 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 $S_a = (5A)^2 \times (0.113 + 0.020)\ \Omega = 3.33$ 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 the operating times of the protection relay 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 67)

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, $2 \times \pi \times f_n$
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 pu 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 67 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 67 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 68)

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 primary current transformers are designated as Type 1 and Type 2.

- If the positive directions of the winding 1 and winding 2 protection relay currents are opposite, the *CT connection type* is of "Type 1". The connection examples of "Type 1" are as shown in figures *Figure 260* and *Figure 261*.
- If the positive directions of the winding 1 and winding 2 protection relay currents equate, the *CT connection type* setting parameter is "Type 2". The connection examples of "Type 2" are as shown in figures *Figure 262* and *Figure 263*.
- The default value of the *CT connection type* setting is "Type 1".

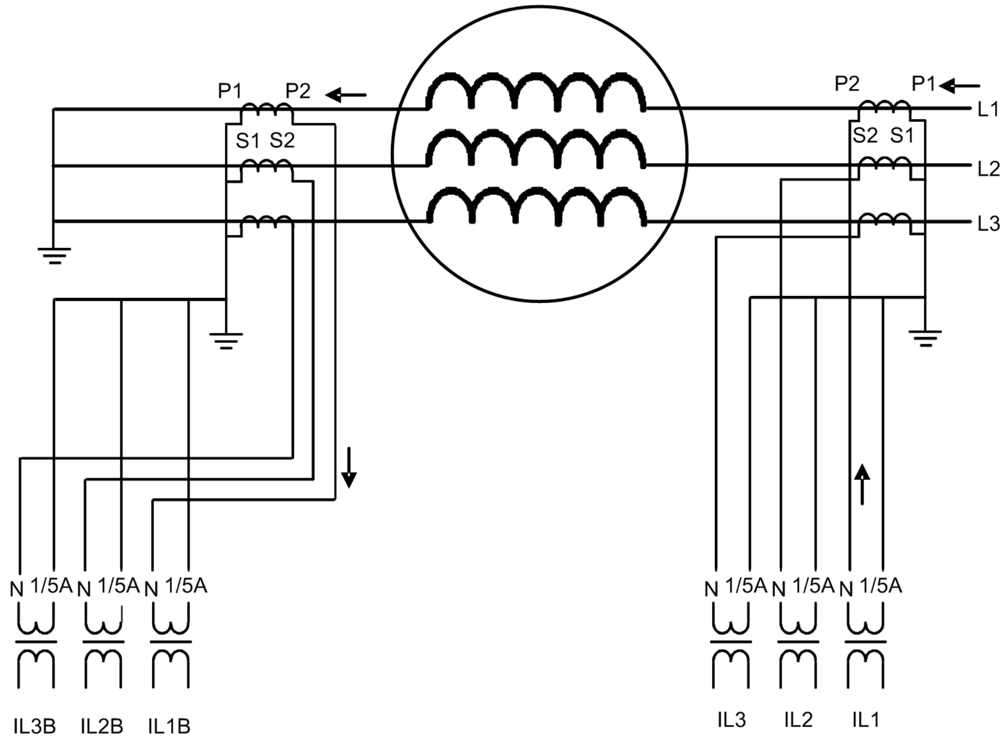


Figure 260: Connection of current transformer of Type 1, example 1

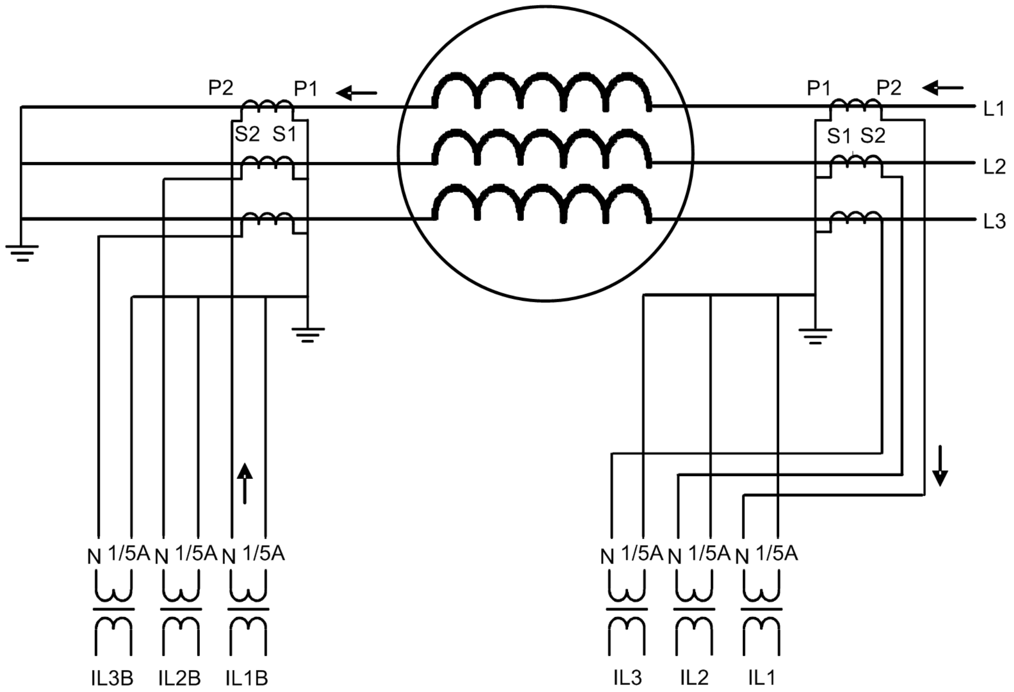


Figure 261: Connection of current transformer of Type 1, example 2

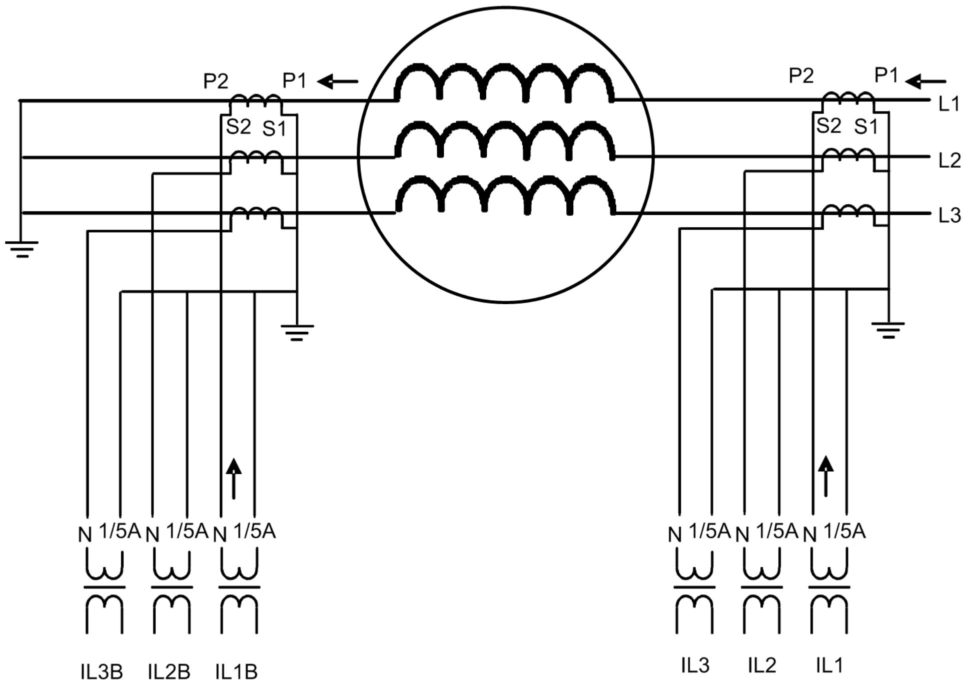


Figure 262: Connection of current transformer of Type 2, example 1

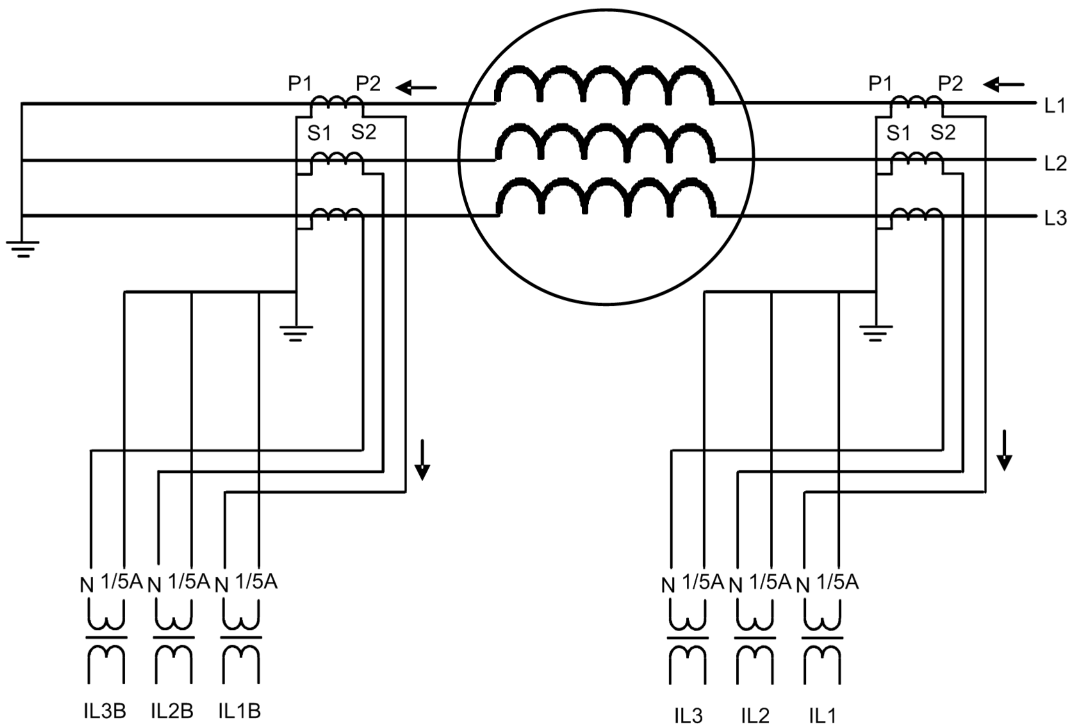


Figure 263: Connection of current transformer of Type 2, example 2

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 264*. A DC component in the current also causes the flux to increase until the CT saturates. This is known as DC saturation.

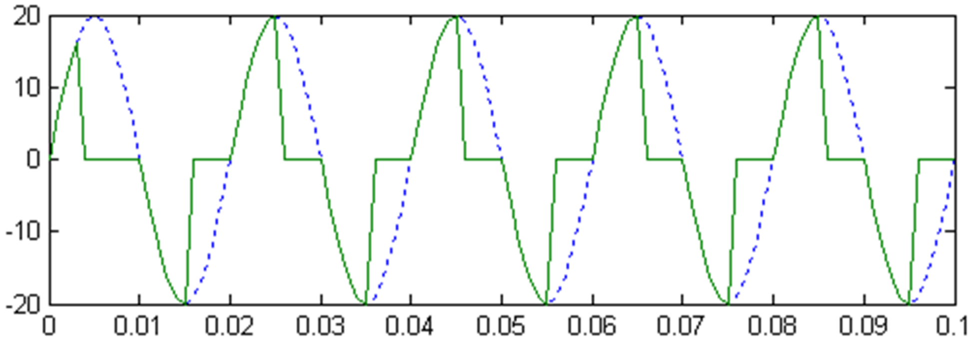


Figure 264: AC saturation

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 265* 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 seconds, causing saturation. As the DC component decays, the CT recovers gradually from the saturation.

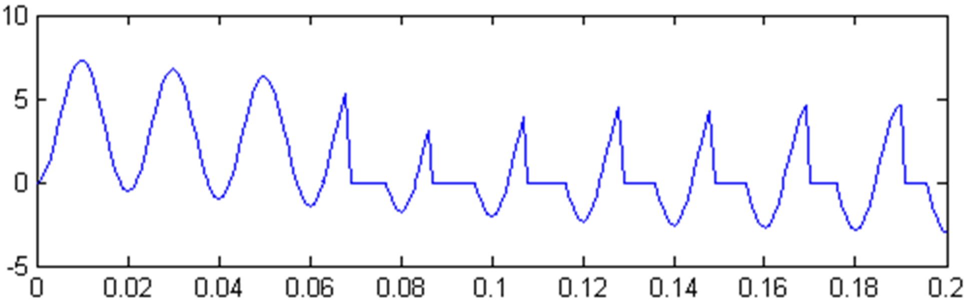


Figure 265: DC saturation

4.3.1.6 Signals

Table 476: MPDIF Input signals

Name	Type	Default	Description
I_A1	Signal	0	Phase A primary current
I_B1	Signal	0	Phase B primary current

Table continues on the next page

Name	Type	Default	Description
I_C1	Signal	0	Phase C primary current
I_A2	Signal	0	Phase A secondary current
I_B2	Signal	0	Phase B secondary current
I_C2	Signal	0	Phase C secondary current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_OPR_LS	BOOLEAN	0=False	Blocks operate outputs from biased stage
BLK_OPR_HS	BOOLEAN	0=False	Blocks operate outputs from instantaneous stage

Table 477: MPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_LS	BOOLEAN	Operate from low set
OPR_HS	BOOLEAN	Operate from high set
INT_BLKD	BOOLEAN	Internal block status

4.3.1.7 Settings

Table 478: MPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Low operate value	5...30	%Ir	1	5	Basic setting for the stabilized stage start
High operate value	100...1000	%Ir	10	500	Instantaneous stage operate value
Slope section 2	10...50	%	1	30	Slope of the second line of the operating characteristics
End section 1	0...100	%Ir	1	50	Turn-point between the first and the second line of the operating characteristics
End section 2	100...300	%Ir	1	150	Turn-point between the second and the third line of the operating characteristics

Table 479: MPDIF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Slope section 3	10...100	%	1	100	Slope of the third line of the operat-ing characteristics
DC restrain enable	0=False 1=True			0=False	Setting for ena-bling DC restrain feature

Table 480: MPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
CT connection type	1=Type 1 2=Type 2			1=Type 1	CT connection type. Determined by the directions of the connected cur-rent transformers
CT ratio Cor Line	0.40...4.00		0.01	1.00	CT ratio correction, line side
CT ratio Cor Neut	0.40...4.00		0.01	1.00	CT ratio correction, neutral side

4.3.1.8 Monitored data

Table 481: MPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=False 1=True		Operate phase A
OPR_B	BOOLEAN	0=False 1=True		Operate phase B
OPR_C	BOOLEAN	0=False 1=True		Operate phase C
INT_BLKD_A	BOOLEAN	0=False 1=True		Internal block status phase A
INT_BLKD_B	BOOLEAN	0=False 1=True		Internal block status phase B
INT_BLKD_C	BOOLEAN	0=False 1=True		Internal block status phase C
ID_A	FLOAT32	0.00...80.00	xIr	Differential cur-rent phase A
ID_B	FLOAT32	0.00...80.00	xIr	Differential cur-rent phase B

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
ID_C	FLOAT32	0.00...80.00	xIr	Differential current phase C
IB_A	FLOAT32	0.00...80.00	xIr	Biasing current phase A
IB_B	FLOAT32	0.00...80.00	xIr	Biasing current phase B
IB_C	FLOAT32	0.00...80.00	xIr	Biasing current phase C
I_ANGL_A1_B1	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, line side
I_ANGL_B1_C1	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, line side
I_ANGL_C1_A1	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, line side
I_ANGL_A2_B2	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, neutral side
I_ANGL_B2_C2	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, neutral side
I_ANGL_C2_A2	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, neutral side
I_ANGL_A1_A2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between line and neutral side, Phase A
I_ANGL_B1_B2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between line and neutral side, Phase B
I_ANGL_C1_C2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between line and neutral side, Phase C
MPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		5=off		
IL1-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL1
IL2-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL2
IL3-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL3
IL1-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL1
IL2-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL2
IL3-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL3

4.3.1.9 Technical data

Table 482: MPDIF Technical data

Characteristic		Value
Operation accuracy		At the frequency f_n
		±3% of the set value or ±0.002 x I_n
Operate time ,	Biased low stage	Typical 40 ms (±10 ms)
	Instantaneous high stage [3]	Typical 15 ms (±10 ms)
Reset time		<40 ms
Reset ratio		Typically 0.96
Retardation time		<20 ms

4.3.2 Stabilized and instantaneous differential protection for two-winding transformers TR2PTDF

[1] F_n = 50 Hz, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the power output contact
[3] Ifault = 2 x *High operate value*

4.3.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Stabilized and instantaneous differential protection for two-winding transformers	TR2PTDF	3dI>T	87T

4.3.2.2 Function block

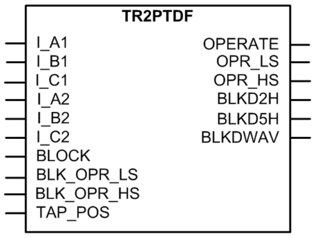


Figure 266: Function block

4.3.2.3 Functionality

The stabilized and instantaneous differential protection function 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 overexcitation.

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.

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 TR2PTDF can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

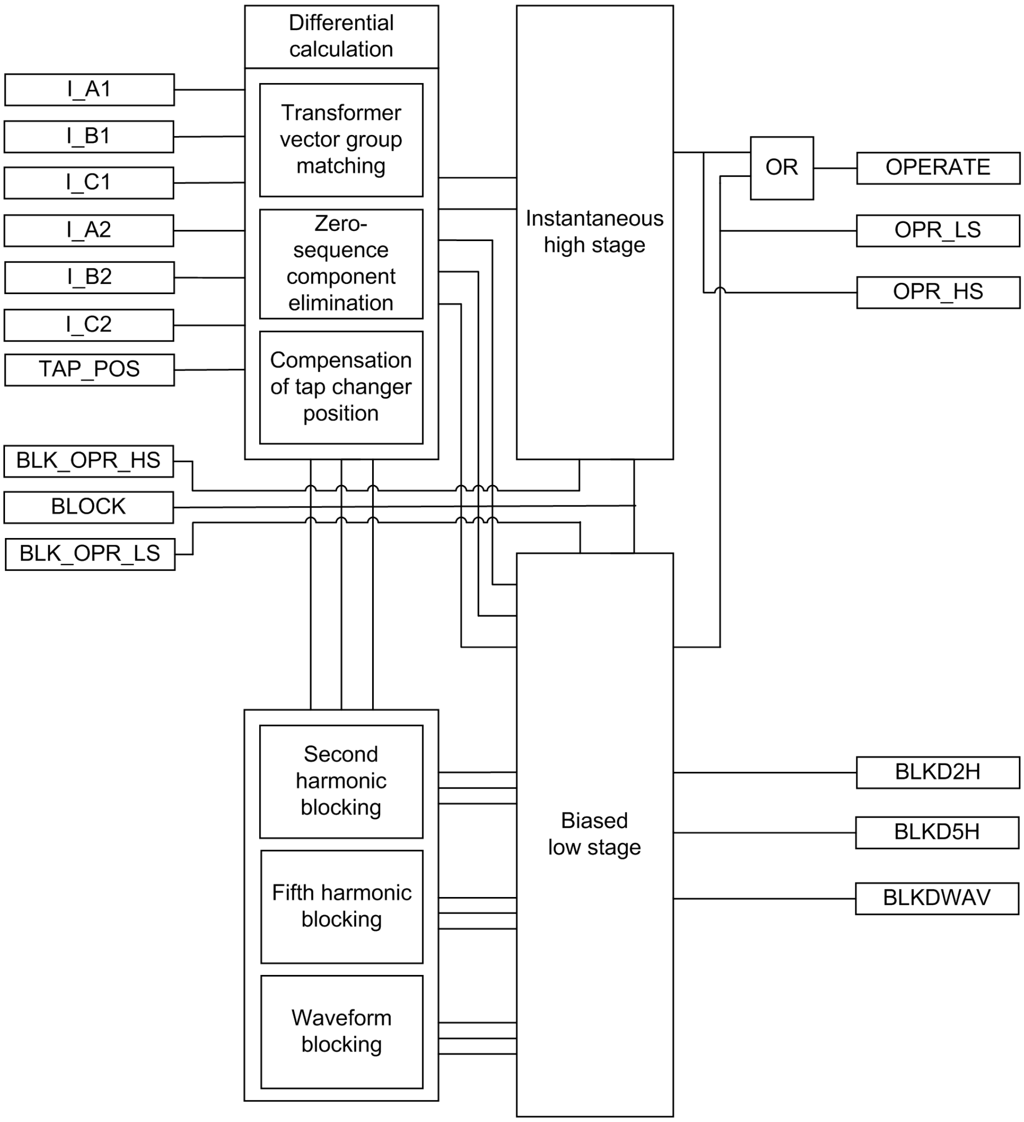


Figure 267: Functional module diagram

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.

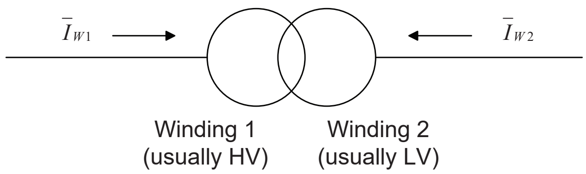


Figure 268: Positive direction of the currents

$$I_d = \left| \bar{I}_{W1} + \bar{I}_{W2} \right|$$

(Equation 69)

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 protection relay 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 70)

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 protection relay. Then the operation value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

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 protection relay. The *Winding 1 type* parameter determines the connection on winding 1 (”Y”, ”YN”, ”D”, ”Z”, ”ZN”). The *Winding 2 type* parameter determines the connections of the phase windings on the low voltage side (“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 protection relay does not change. When the vector group matching is Yy6, the phase currents are turned 180° in the protection relay.

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 71)

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 72)

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 73)

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 TPOSYLTC.

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" or "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.

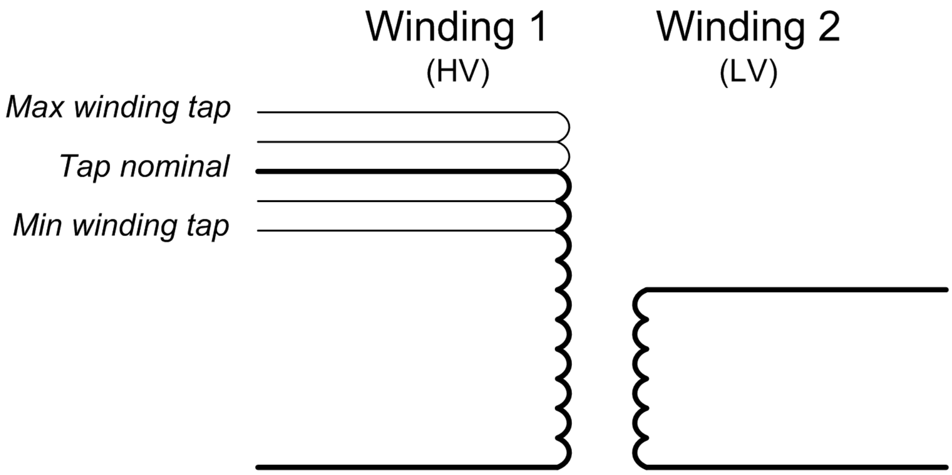


Figure 269: Simplified presentation of the high voltage and medium voltage windings with demonstration of the Max winding tap, Min winding tap and Tap nominal parameters

The position value is available through the Monitored data view on LHMI or through other communication tools in the tap position indication function. When the quality of the `TAP_POS` value is not good, the position information in `TAP_POS` is not used but the last value with the good quality information 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 74)

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 protection relay, 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, that is I_r>12×In, 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 . 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. The fifth harmonic ratios I_5H_RAT_x are given in Monitored data.

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.

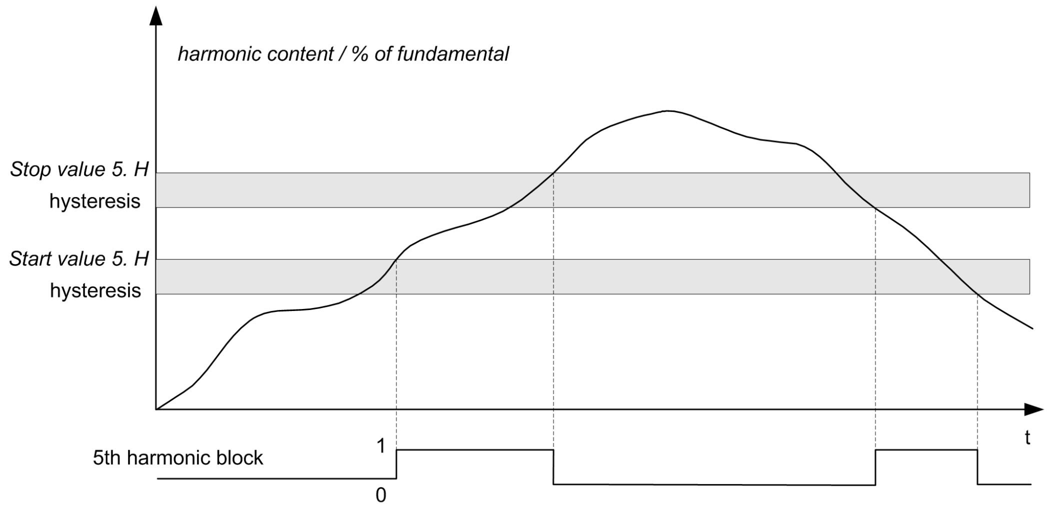


Figure 270: The limits and operation of the fifth harmonic blocking when both blocking and deblocking features are enabled using the Harmonic deblock 5.H control parameter.

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 various factors.

- CT errors
- CT saturation at high currents passing through the generator

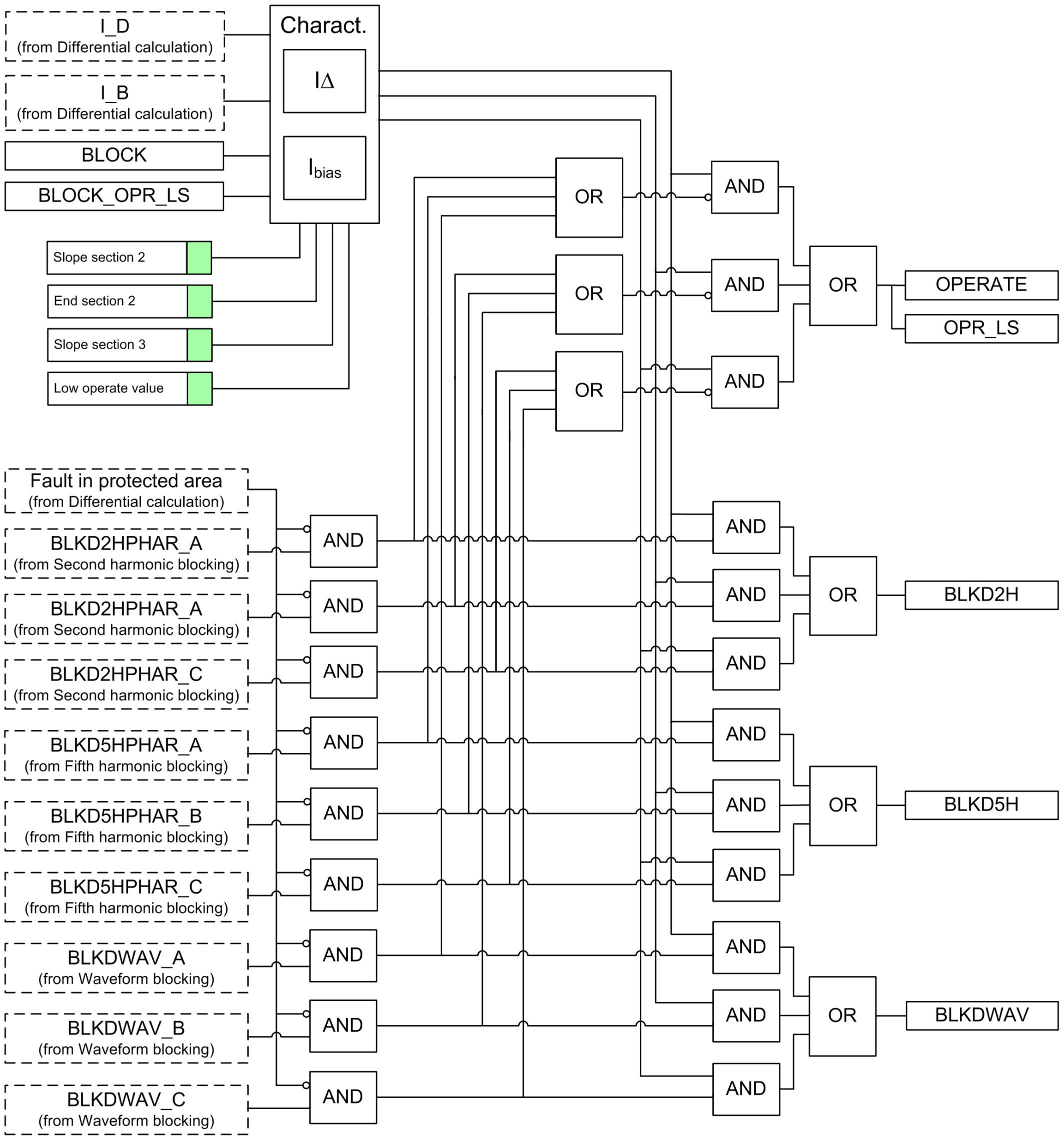


Figure 271: Operation logic of the biased low stage

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 start-up 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 is 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 suitable period, which is 1.1 times the fundamental cycle, the OPR_LS output is activated. The OPERATE output is always activated when the OPR_LS output is activated .

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 BLKD2H output is activated.

When operation of the biased low stage is blocked by the fifth harmonic blocking functionality, the BLKD5H output is activated. Correspondingly, when the operation of the biased low stage is blocked by the waveform blocking functionality, the BLKDWAV output is 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.

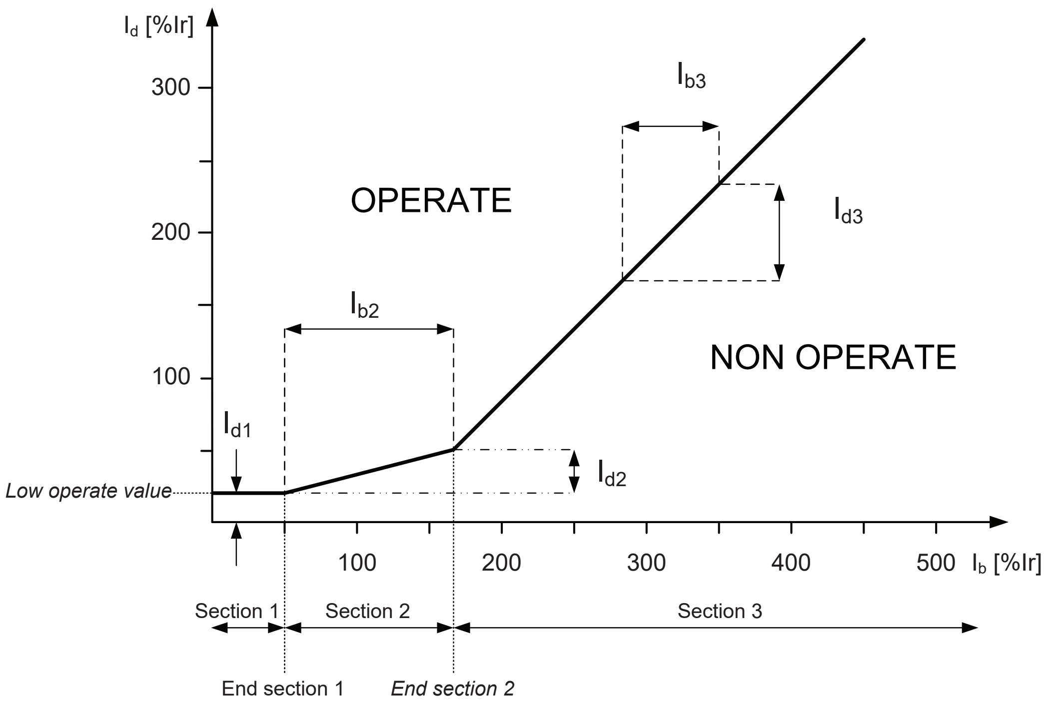


Figure 272: Operation characteristic for biased operation of TR2PTDF

The *Low operate value* of the biased stage of the differential function is determined according to the operation characteristic:

Low operate value = Id1

Slope section 2 and *Slope section 3* are determined correspondingly:

$$Slope\ \ section2 = \frac{I_{d2}}{I_{b2}} \cdot 100\%$$

(Equation 75)

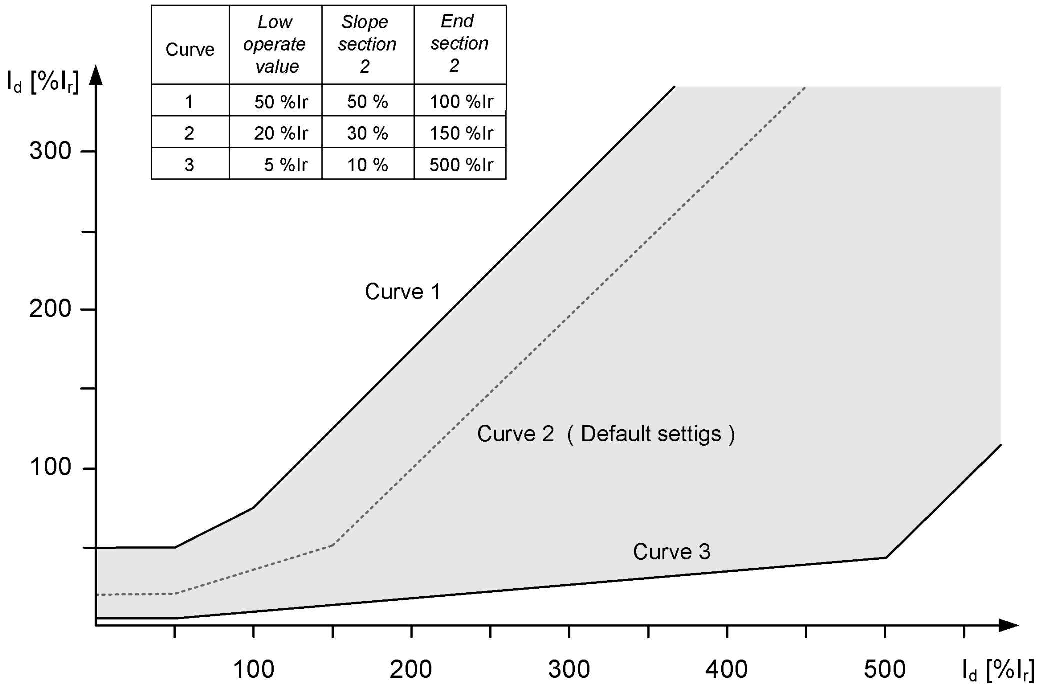
$$Slope\ \ section\,3 = \frac{I_{d3}}{I_{b3}} \cdot 100\%$$

(Equation 76)

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 percent Ir < Ib < 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 can be set by *Slope section 3* that defines the increase in the differential current 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 273: 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 × √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.

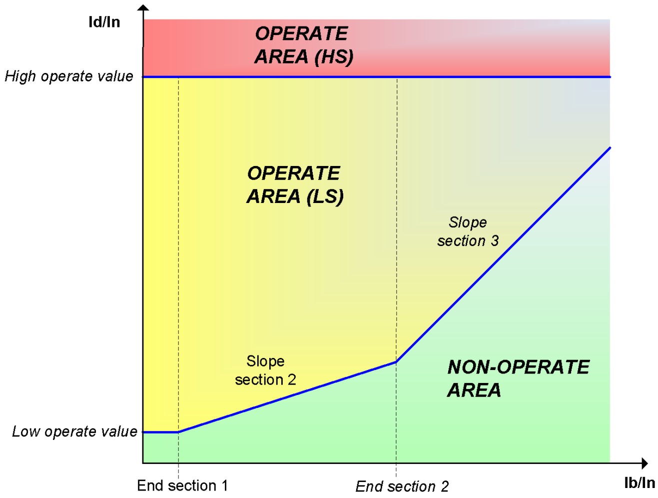


Figure 274: Operating characteristics of the protection. (LS) stands for the biased low stage and (HS) for the instantaneous high stage

The OPERATE output is activated always when the OPR_HS output activates .

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.

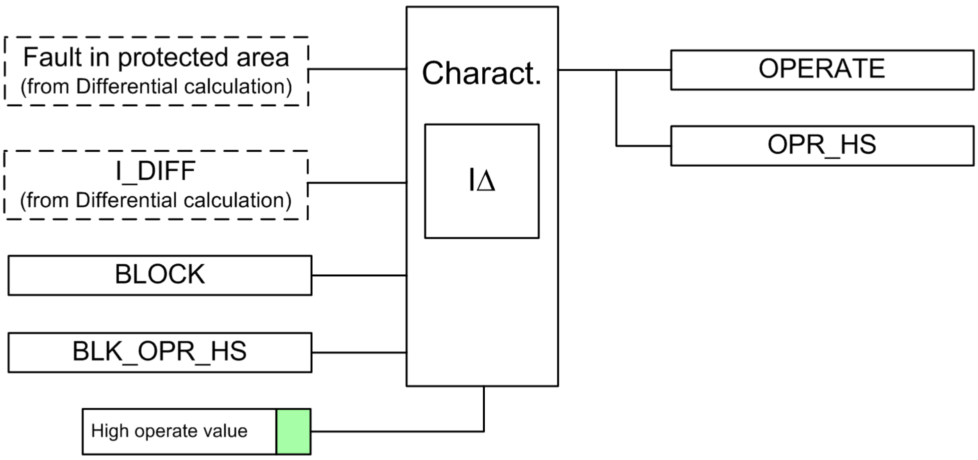


Figure 275: Operation logic of instantaneous high stage

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 OPERATE output 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 OPERATE output can be activated only by the biased low stage (if not blocked as well).

4.3.2.5 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 protection relay, 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. However, there are several different phenomena other than internal faults that 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.

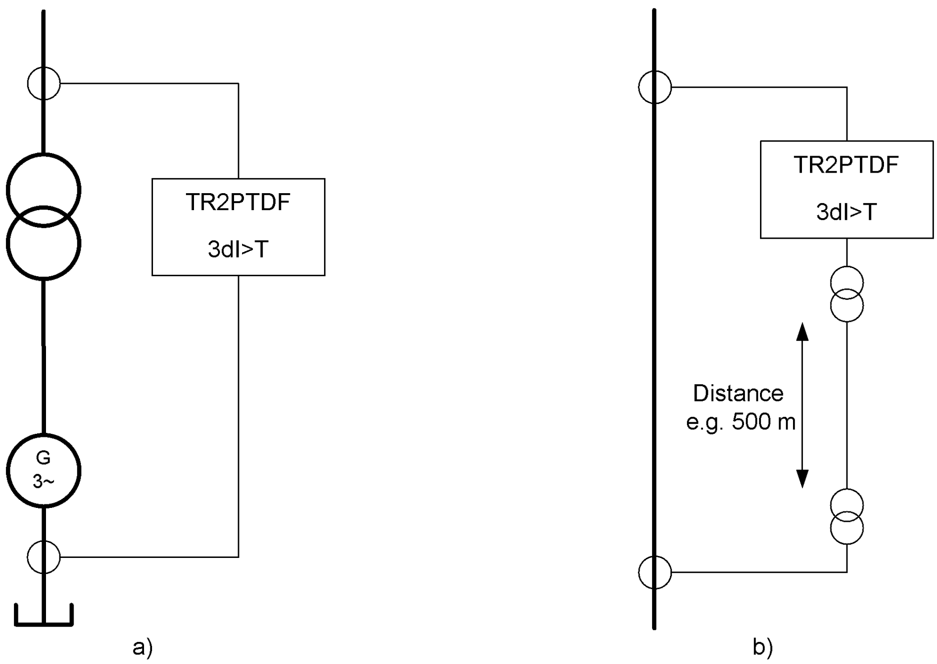


Figure 276: Differential protection of a generator-transformer block and short cable/line

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 protection relay.

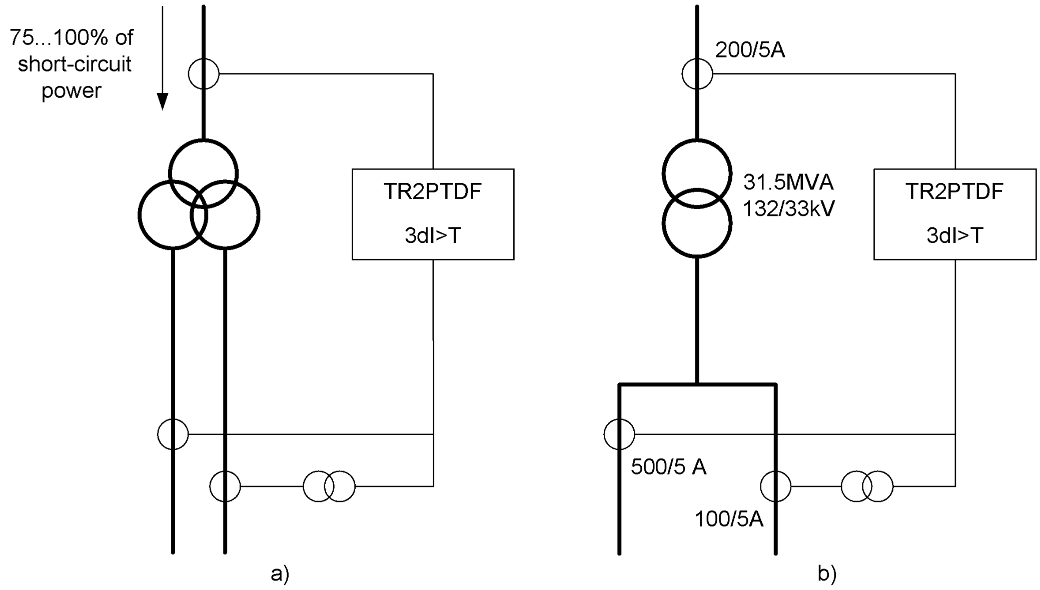


Figure 277: Differential protection of a three-winding transformer and a transformer with two output feeders

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 protection relay 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

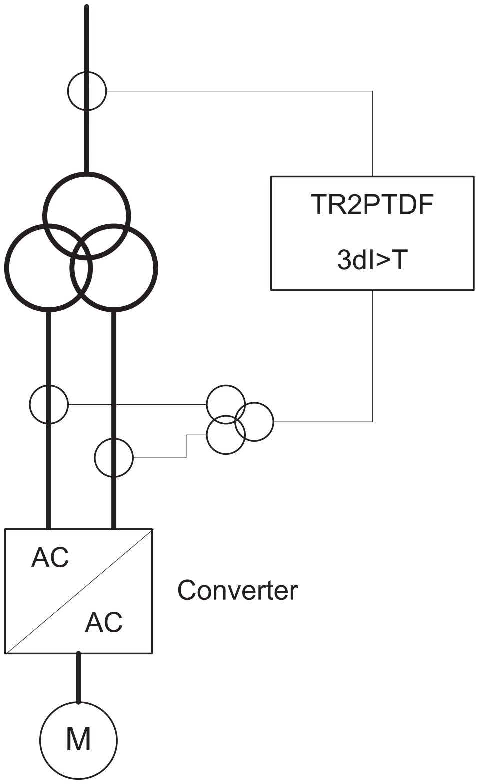


Figure 278: Protection of the power transformer feeding the frequency converter

Transforming ratio correction of CTs

The CT secondary currents often 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 *CT ratio Cor Wnd 1* and *CT ration Cor Wnd 2* settings.

First, the rated load of the power transformer must be calculated on both sides when the apparent power and phase-to-phase voltage are known.

$$I_{nT} = \frac{S_n}{\sqrt{3} \times U_n}$$

(Equation 77)

I_{nT}	rated load of the power transformer
S_n	rated power of the power transformer
U_n	rated phase-to-phase voltage

Next, the settings for the CT ratio correction can be calculated.

$$CT\ ratio\ correction = \frac{I_{1n}}{I_{nT}}$$

(Equation 78)

I_{1n}	nominal primary current of the CT

After the CT ratio correction, the measured currents and corresponding setting values of TR2PTDF are expressed in multiples of the rated power transformer current I_r (xI_r) or percentage value of I_r ($\%I_r$).

The rated input current (1A or 5A) of the relay does not have to be same for the HV and the LV side. For example, the rated secondary current of 5 A can be used on the HV side, while 1A is used on the LV side or vice versa.

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

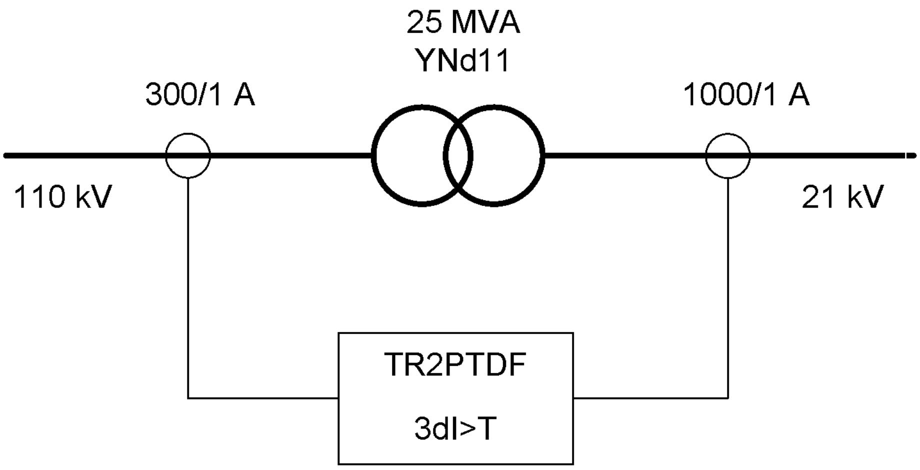


Figure 279: Example of two-winding power transformer differential protection

The rated load of the transformer is calculated:

HV side: I_{nT_Wnd1} = 25 MVA / (1.732 x 110 kV) = 131.2 A

LV side: I_{nT_Wnd2} = 25 MVA / (1.732 x 21 kV) = 687.3 A

Settings:

CT ratio Cor Wnd 1= 300 A / 131.2 A = “2.29”

CT ratio Cor Wnd 2= 1000 A / 687.3 A = “1.45”

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 protection relay. If the neutral of a star-connected power transformer is earthed, any earth fault in the network is perceived by the protection relay 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 483: 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

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
Dd6	D	d	Clk Num 6	Not needed
Dd8	D	d	Clk Num 8	Not needed
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

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
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
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

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
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
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
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

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
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
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

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
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
Yy0	Y	y	Clk Num 0	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 from 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 I_r.

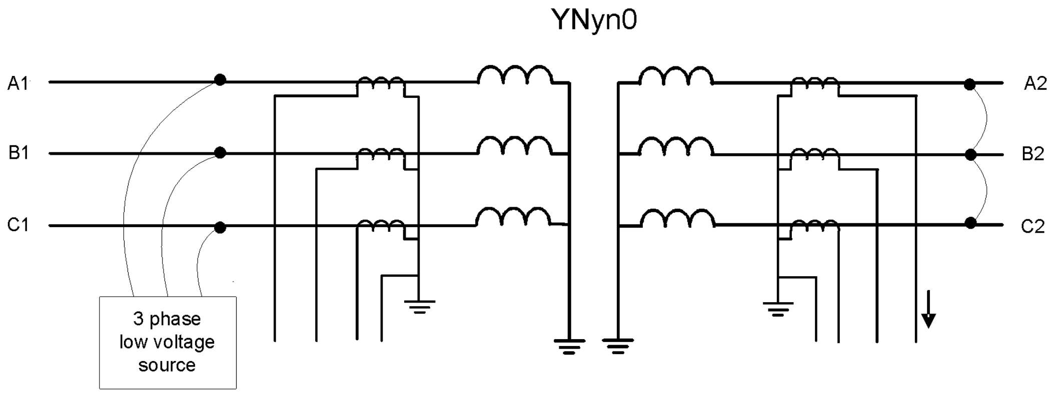


Figure 280: Low voltage test arrangement. The three-phase low voltage source can be the station service transformer.

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 5 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 79)

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 * 0.07 Ω = 1.75 VA. The input impedance of the protection relay 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 * (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 protection relay 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 80)

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*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 p.u. 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 = 50Hz).

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 I_r 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 I_r
T_{dc}	100 ms
ω	100π Hz
T_m	10 ms
K_r	1

   When the values are substituted in Equation 80, 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 (I_r)
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 79 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 81)

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.

4.3.2.6 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 protection relay currents are opposite, the *CT connection type* setting parameter is "Type 1". The connection examples of "Type 1" are as shown in *Figure 281* and *Figure 282*.
- If the positive directions of the winding 1 and winding 2 protection relay currents equate, the *CT connection type* setting parameter is "Type 2". The connection examples of "Type 2" are as shown in *Figure 283* and *Figure 284*.
- The default value of the *CT connection type* setting is "Type 1".

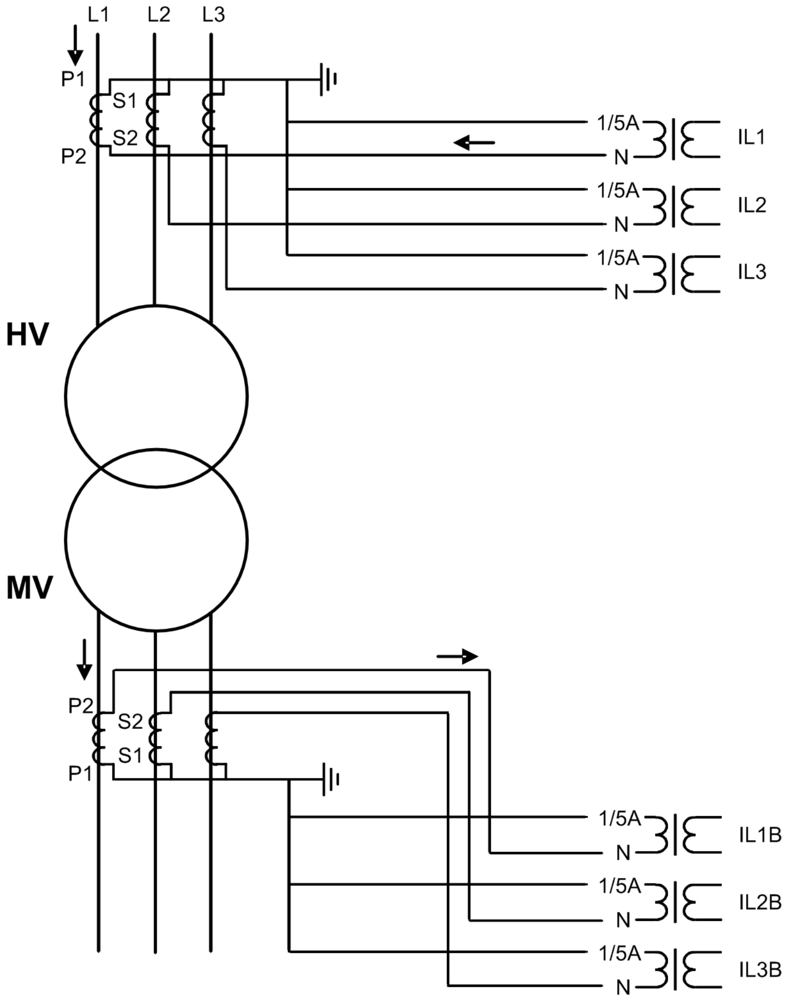


Figure 281: Connection example of current transformers of Type 1

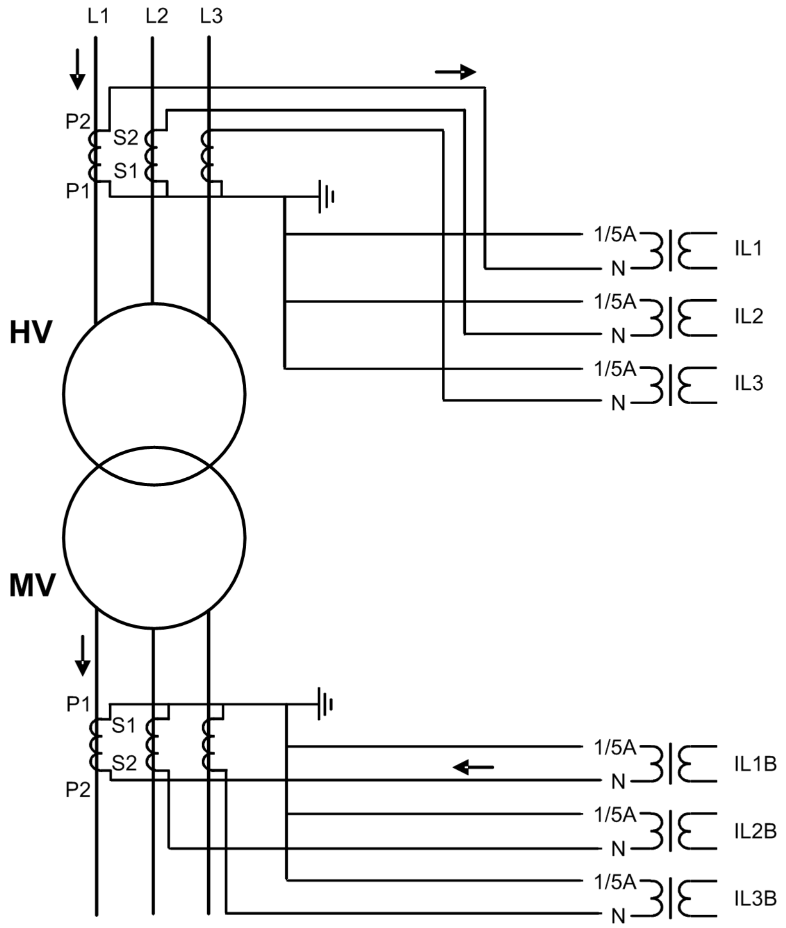


Figure 282: Alternative connection example of current transformers of Type 1

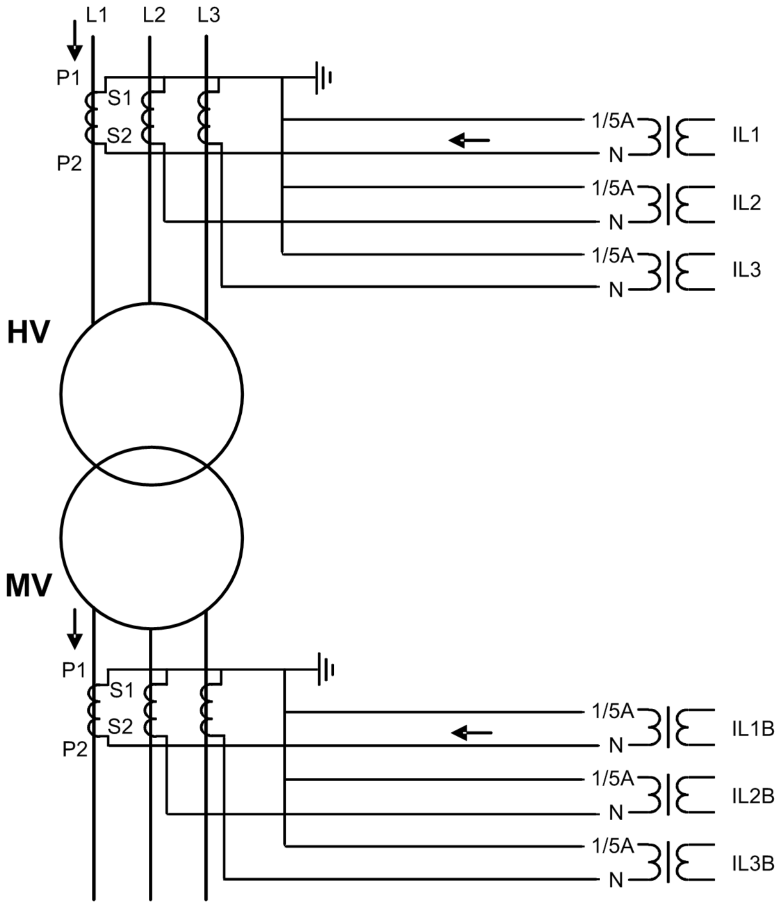


Figure 283: Connection of current transformers of Type 2 and example of the currents during an external fault

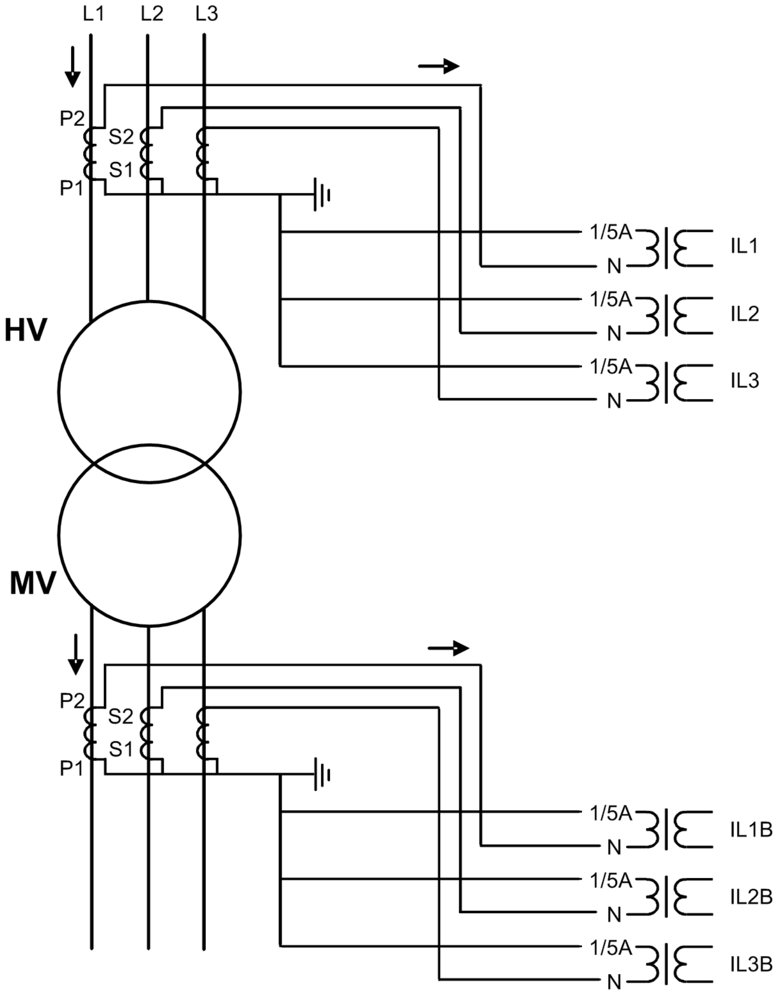


Figure 284: Alternative connection example of current transformers of Type 2

The CT secondary currents often 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 *CT ratio Cor Wnd 1* and *CT ratio Cor Wnd 2* settings.

4.3.2.7 Signals

Table 484: TR2PTDF Input signals

Name	Type	Default	Description
I_A1	SIGNAL	0	Phase A primary current
I_B1	SIGNAL	0	Phase B primary current
I_C1	SIGNAL	0	Phase C primary current

Table continues on the next page

Name	Type	Default	Description
I_A2	SIGNAL	0	Phase A secondary current
I_B2	SIGNAL	0	Phase B secondary current
I_C2	SIGNAL	0	Phase C secondary current
BLOCK	BOOLEAN	0=False	Block
BLK_OPR_LS	BOOLEAN	0=False	Blocks operate outputs from biased stage
BLK_OPR_HS	BOOLEAN	0=False	Blocks operate outputs from instantaneous stage
TAP_POS	INT8	0	Tap position indication

Table 485: TR2PTDF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate combined
OPR_LS	BOOLEAN	Operate from low set
OPR_HS	BOOLEAN	Operate from high set
BLKD2H	BOOLEAN	2nd harmonic restraint block status
BLKD5H	BOOLEAN	5th harmonic restraint block status
BLKDWAV	BOOLEAN	Waveform blocking status

4.3.2.8 Settings

Table 486: TR2PTDF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
High operate value	500...3000	%Ir	10	1000	Instantaneous stage setting
Low operate value	5...50	%Ir	1	20	Basic setting for biased operation
Slope section 2	10...50	%	1	30	Slope of the second line of the operating characteristics
End section 2	100...500	%Ir	1	150	Turn-point between the second and the third line of the operating characteristics
Restraint mode	5=Waveform 6=2.h + waveform 8=5.h + waveform 9=2.h + 5.h + wav			9=2.h + 5.h + wav	Restraint mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
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 487: TR2PTDF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Enable high set	0=False 1=True			1=True	Enable high set stage
Slope section 3	10...100	%	1	100	Slope of the third line of the operating characteristics
Harmonic deblock 2.	0=False 1=True			1=True	2. harmonic deblocking in case of switch on to fault
Stop value 5.H	10...50	%	1	35	5. harmonic deblocking ratio
Harmonic deblock 5.	0=False 1=True			0=False	5. harmonic deblocking in case of severe overvoltage

Table 488: TR2PTDF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off/On
CT connection type	1=Type 1 2=Type 2			1=Type 1	CT connection type. Determined by the directions of the connected current transformers
Winding 1 type	1=Y 2=YN 3=D 4=Z 5=ZN			1=Y	Connection of the HV side windings
Winding 2 type	1=y 2=yn 3=d 4=z 5=zn			1=y	Connection of the LV side windings
Clock number	0=Clk Num 0 1=Clk Num 1 2=Clk Num 2 4=Clk Num 4 5=Clk Num 5 6=Clk Num 6 7=Clk Num 7 8=Clk Num 8 10=Clk Num 10 11=Clk Num 11			0=Clk Num 0	Setting the phase shift between HV and LV with clock number for connection group compensation (e.g. Dyn11 -> 11)

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Zro A elimination	1=Not eliminated 2=Winding 1 3=Winding 2 4=Winding 1 and 2			1=Not eliminated	Elimination of the zero-sequence current
CT ratio Cor Wnd 1	0.40...4.00		0.01	1.00	CT ratio correction, winding 1
CT ratio Cor Wnd 2	0.40...4.00		0.01	1.00	CT ratio correction, winding 2

Table 489: TR2PTDF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Min winding tap	-36...36		1	36	The tap position number resulting the minimum number of effective winding turns on the side of the transformer where the tap changer is.
Max winding tap	-36...36		1	0	The tap position number resulting the maximum number of effective winding turns on the side of the transformer where the tap changer is.
Tap nominal	-36...36		1	18	The nominal position of the tap changer resulting the default transformation ratio of the transformer (as if there was no tap changer)
Tapped winding	1=Not in use 2=Winding 1 3=Winding 2			1=Not in use	The winding where the tap changer is connected to
Step of tap	0.60...9.00	%	0.01	1.50	The percentage change in voltage corresponding one step of the tap changer

4.3.2.9 Monitored data

Table 490: TR2PTDF Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=False 1=True		Operate phase A
OPR_B	BOOLEAN	0=False 1=True		Operate phase B
OPR_C	BOOLEAN	0=False		Operate phase C

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		1=True		
BLKD2H_A	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase A status
BLKD2H_B	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase B status
BLKD2H_C	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase C status
BLKD5H_A	BOOLEAN	0=False 1=True		5th harmonic restraint block phase A status
BLKD5H_B	BOOLEAN	0=False 1=True		5th harmonic restraint block phase B status
BLKD5H_C	BOOLEAN	0=False 1=True		5th harmonic restraint block phase C status
BLKDWAV_A	BOOLEAN	0=False 1=True		Waveform blocking phase A status
BLKDWAV_B	BOOLEAN	0=False 1=True		Waveform blocking phase B status
BLKDWAV_C	BOOLEAN	0=False 1=True		Waveform blocking phase C status
BLKD2HPHAR	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, combined
BLKD2HPHAR_A	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase A
BLKD2HPHAR_B	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase B
BLKD2HPHAR_C	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase C
BLKD5HPHAR	BOOLEAN	0=False		5th harmonic restraint blocking

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		1=True		for PHAR LN, combined
BLKD5HPHAR_A	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase A
BLKD5HPHAR_B	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase B
BLKD5HPHAR_C	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase C
I_AMPL_A1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase A
I_AMPL_B1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase B
I_AMPL_C1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase C
I_AMPL_A2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase A
I_AMPL_B2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase B
I_AMPL_C2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase C
ID_A	FLOAT32	0.00...80.00	xIr	Differential Current phase A
ID_B	FLOAT32	0.00...80.00	xIr	Differential Current phase B
ID_C	FLOAT32	0.00...80.00	xIr	Differential Current phase C
IB_A	FLOAT32	0.00...80.00	xIr	Biasing current phase A

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
IB_B	FLOAT32	0.00...80.00	xIr	Biasing current phase B
IB_C	FLOAT32	0.00...80.00	xIr	Biasing current phase C
I_2H_RAT_A	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase A
I_2H_RAT_B	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase B
I_2H_RAT_C	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase C
I_ANGL_A1_B1	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 1
I_ANGL_B1_C1	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 1
I_ANGL_C1_A1	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 1
I_ANGL_A2_B2	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 2
I_ANGL_B2_C2	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 2
I_ANGL_C2_A2	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 2
I_ANGL_A1_A2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase A
I_ANGL_B1_B2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase B
I_ANGL_C1_C2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase C

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
I_5H_RAT_A	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase A
I_5H_RAT_B	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase B
I_5H_RAT_C	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase C
TR2PTDF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
IL1-diff	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL1
IL2-diff	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL2
IL3-diff	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL3
IL1-bias	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL1
IL2-bias	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL2
IL3-bias	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL3

4.3.2.10 Technical data

Table 491: TR2PTDF Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±3.0% of the set value or ±0.002 × I_n

Table continues on the next page

Characteristic		Value		
Start time ,	Low stage High stage	Minimum	Typical	Maximum
		36 ms 21 ms	41 ms 22 ms	46 ms 24 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5, …		

4.3.2.11 Technical revision history

Table 492: TR2PTDF Technical revision history

Technical revision	Change
B	5th harmonic and waveform blockings taken to event data set
C	Added setting *Slope section 3*. Added input `TAP_POS`"

4.3.3 Numerical stabilized low-impedance restricted earth-fault protection LREFPNDF

4.3.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Numerical stabilized low-impedance restricted earth-fault protection	LREFPNDF	dIoLo>	87NL

4.3.3.2 Function block

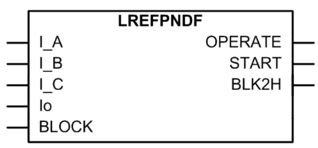


Figure 285: Function block

[1] Current before fault = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements

[2] Includes the delay of the output contact. When differential current = 2 × set operate value and f_n = 50 Hz.

4.3.3.3 Functionality

The numerical stabilized low-impedance restricted earth-fault protection function 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.

The function contains a blocking functionality. The neutral current second harmonic is used for blocking during the transformer inrush situation. It is also 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 LREFPNDF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

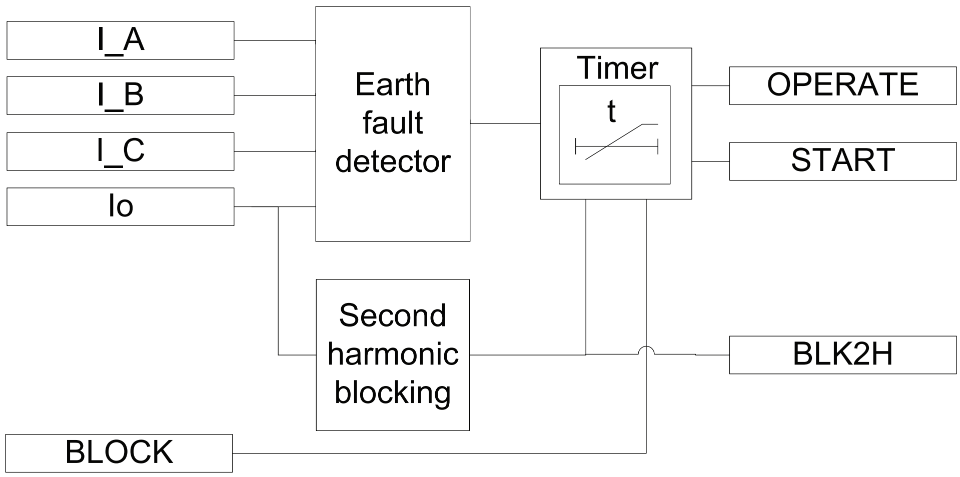


Figure 286: Functional module diagram

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.

$$ID\_COSPHI = (\left|\overline{\Sigma I} - \bar{I}o\right|) \times \cos\varphi$$

(Equation 82)

$\overline{\Sigma I}$	Residual current
φ	Phase difference between the residual and neutral currents
$\bar{I}o$	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.

$$IB = \frac{\left|\overline{I\_A}\right| + \left|\overline{I\_B}\right| + \left|\overline{I\_C}\right|}{3}$$

(Equation 83)

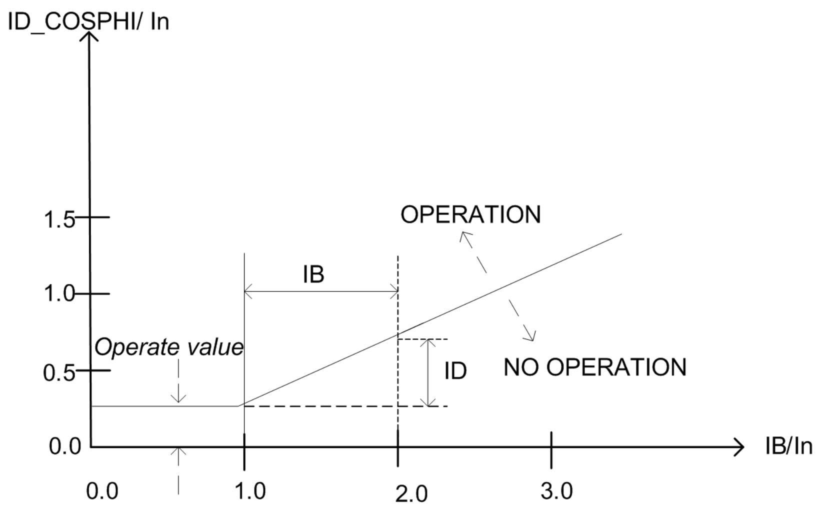


Figure 287: Operating characteristics of the stabilized earth-fault protection function

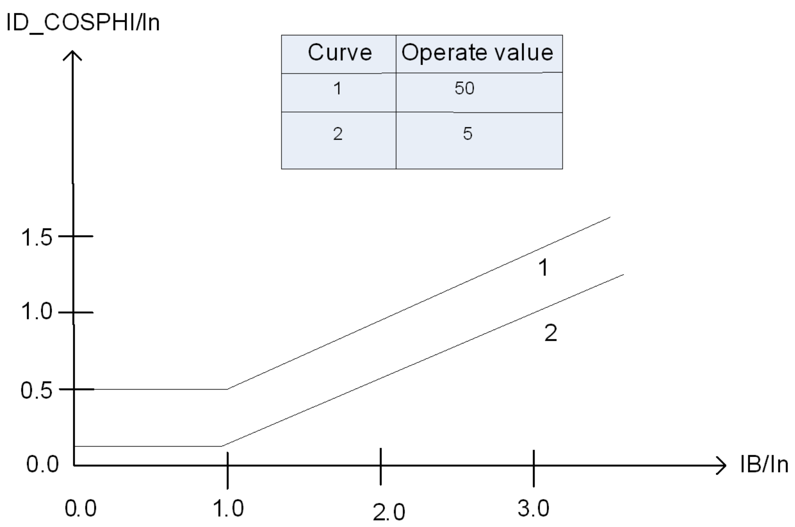


Figure 288: Setting range of the operating characteristics for the stabilized differential current principle of the earth-fault protection function

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 the In in this context refers to the nominal of the phase current inputs. When the stabilizing current is higher than 1.0, the slope of the operation characteristic (ID/IB) is constant at 50 percent. Different operating characteristics are possible based on the *Operate value* setting.

For the protection of the trip, the measured neutral current has to be above 4 percent. When the condition has been fulfilled, the measured neutral current must stay above 2 percent, otherwise reset time is started.

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 operate time. The value is available through the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated. The activation of the output of the second harmonic blocking signal BLK2H deactivates the OPERATE output.

4.3.3.5 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 primary current transformers are designated as "Type 1" and "Type 2".

- If the positive directions of the winding 1 and winding 2 protection relay currents are opposite, the *CT connection type* setting parameter is "Type 1". The connection examples of "Type 1" are as shown in figures *Figure 289* and *Figure 290*.
- If the positive directions of the winding 1 and winding 2 protection relay currents equate, the *CT connection type* setting parameter is "Type 2". The connection examples of "Type 2" are as shown in figures *Figure 291* and *Figure 292*.
- The default value of the *CT connection type* setting is "Type 1".

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".

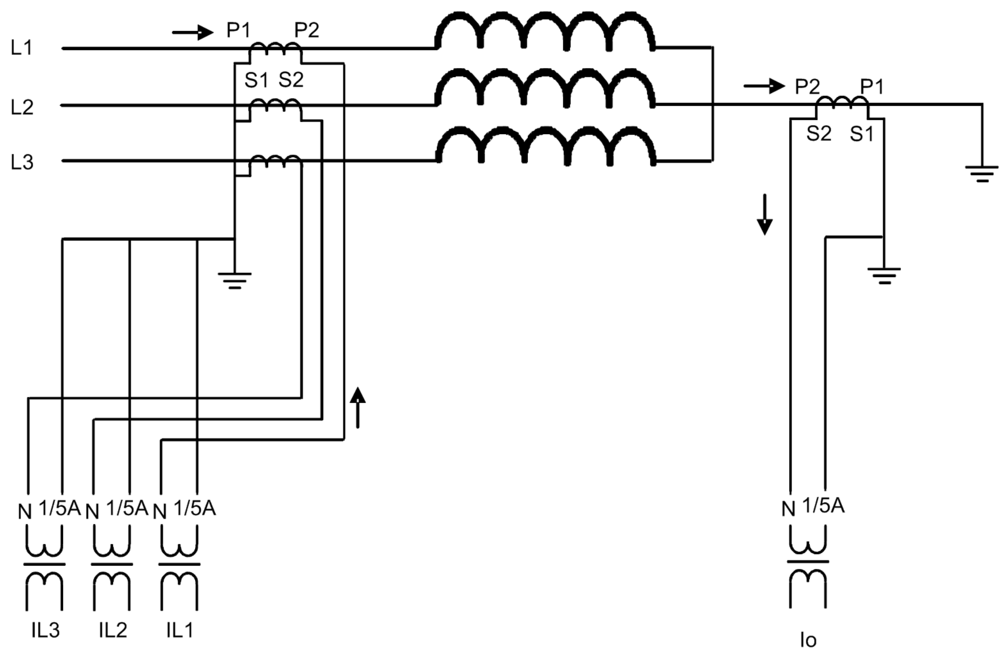


Figure 289: Connection of the current transformers of Type 1. The connected phase currents and the neutral current have opposite directions at an external earth-fault situation. Both earthings are inside the area to be protected.

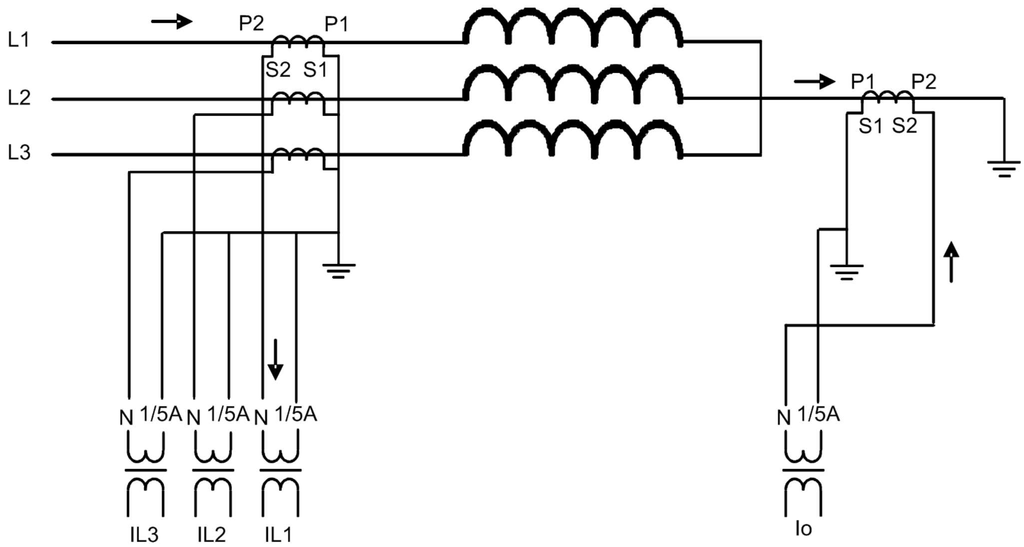


Figure 290: Connection of the current transformers of Type 1. The connected phase currents and the neutral current have opposite directions at an external earth-fault situation. Both earthings are outside the area to be protected.

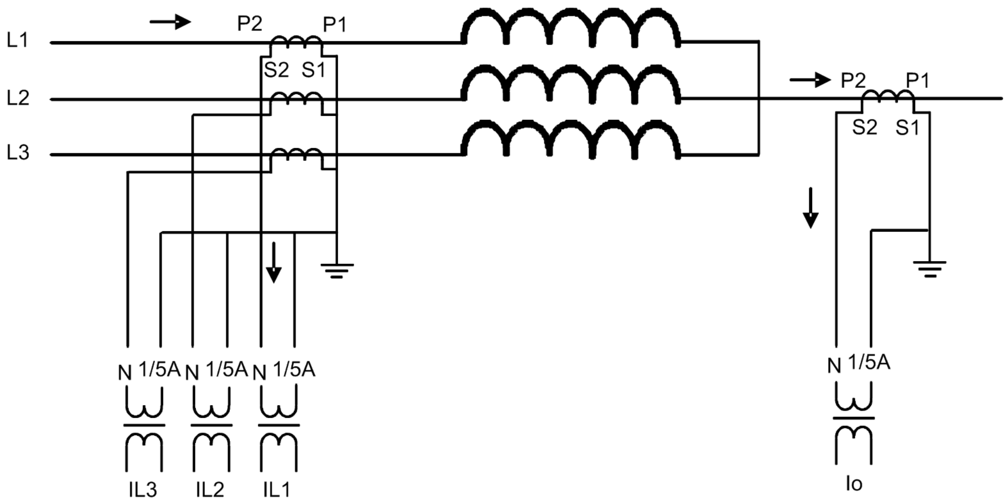


Figure 291: Connection of the current transformers of Type 2. The phase currents and the neutral current have equal directions at an external earth-fault situation. Phase earthing is inside and neutral earthing is outside the area to be protected.

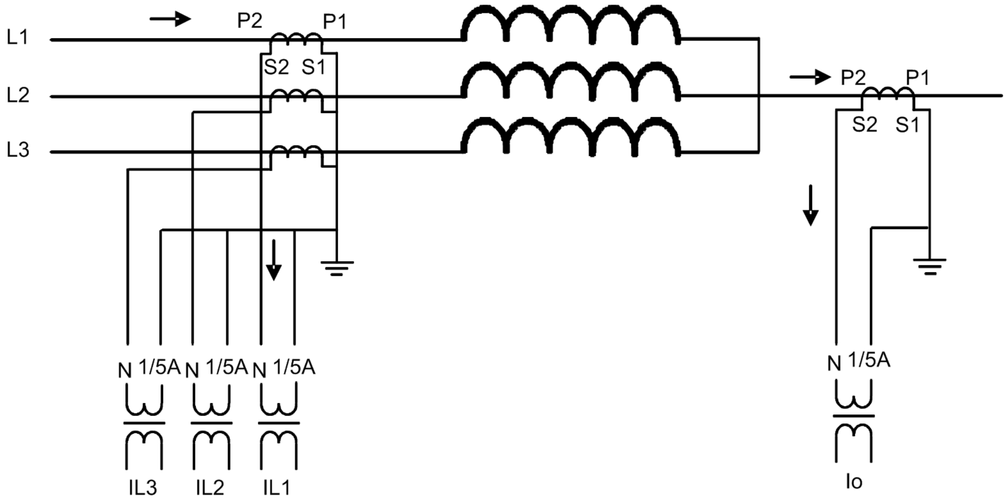


Figure 292: Connection of the current transformers of Type 2. The phase currents and the neutral current have equal directions at an external earth-fault situation. Phase earthing is outside and neutral earthing is inside the area to be protected.

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.

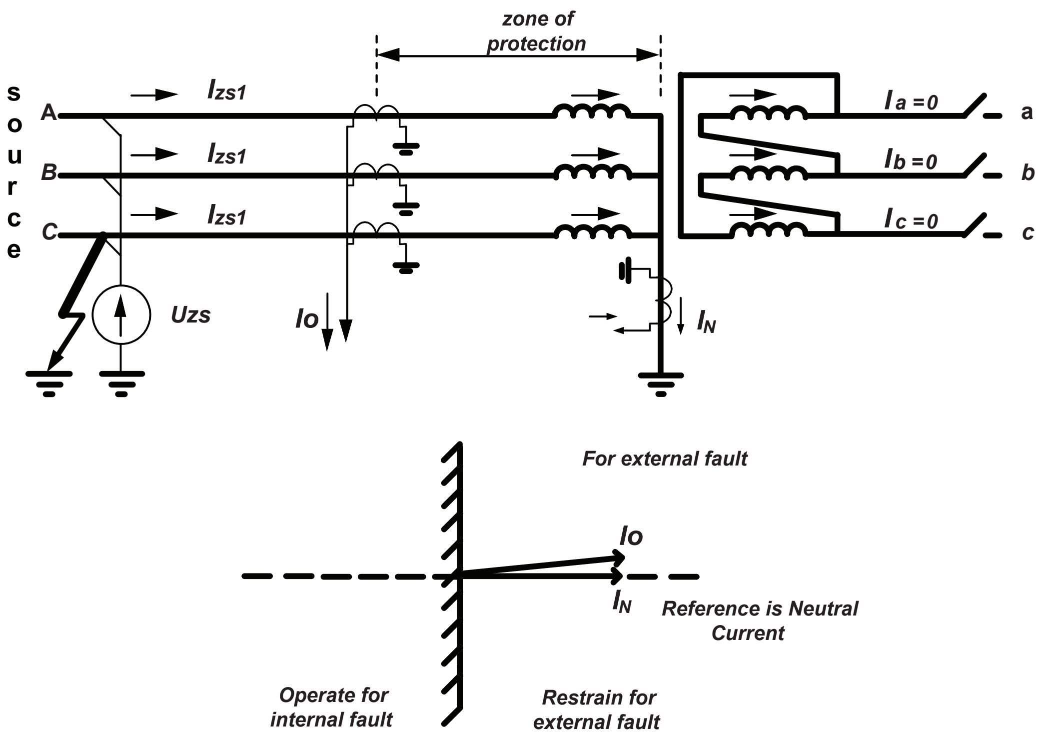


Figure 293: Current flow in all the CTs for an external fault

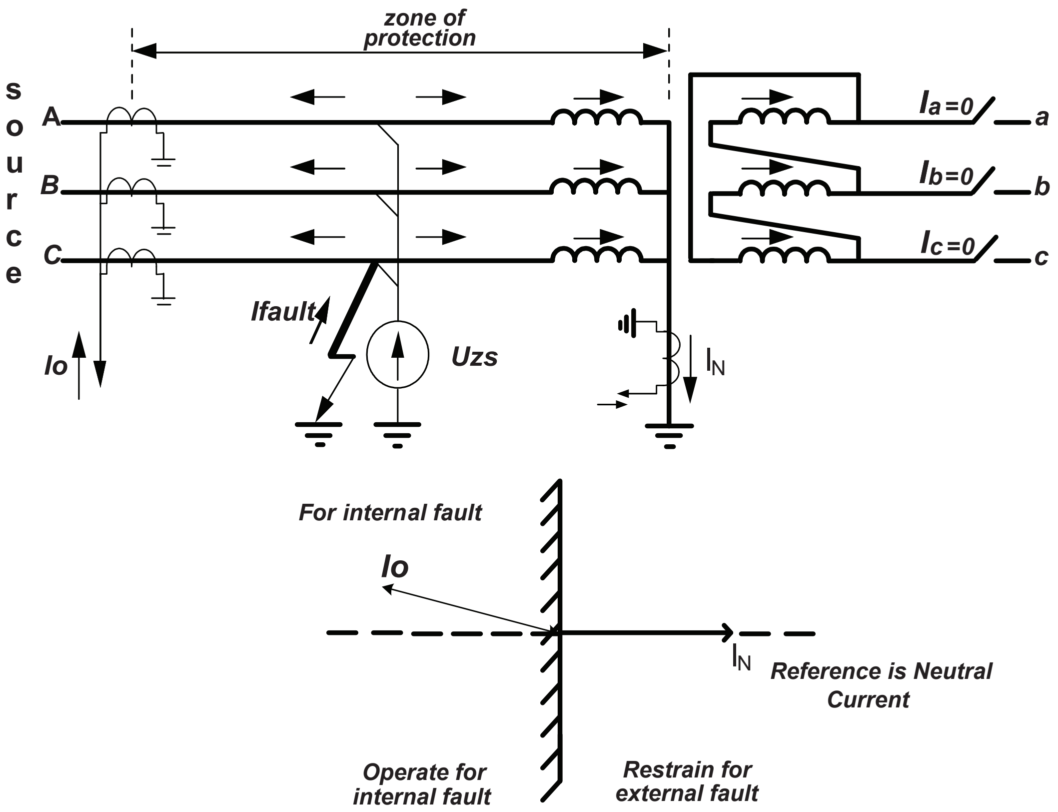


Figure 294: Current flow in all the CTs for an internal fault

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 protection relay, the inrush current represents the differential current, which causes the protection relay 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.

4.3.3.6 Signals

Table 493: LREFPNDF Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 494: LREFPNDF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
BLK2H	BOOLEAN	2nd harmonic block

4.3.3.7 Settings

Table 495: LREFPNDF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	5.0...50.0	%In	1.0	5.0	Operate value

Table 496: LREFPNDF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	40...300000	ms	1	40	Minimum operate time
Restraint mode	1=None 2=Harmonic2			1=None	Restraint mode
Start value 2.H	10...50	%	1	50	The ratio of the 2. harmonic to fundamental component required for blocking

Table 497: LREFPNDF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
CT connection type	1=Type 1 2=Type 2			2=Type 2	CT connection type

Table 498: LREFPNDF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.3.3.8 Monitored data

Table 499: LREFPNDF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
RES2H	BOOLEAN	0=False 1=True		2nd harmonic restraint
ID_COSPHI	FLOAT32	0.00...80.00	xIn	Directional differential current Id cosphi
IB	FLOAT32	0.00...80.00	xIn	Bias current
LREFPNDF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.3.3.9 Technical data

Table 500: LREFPNDF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±2.5% of the set value or ±0.002 x I_n		
Start time [1, 2]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Operate value*	37 ms	41 ms	45 ms
Reset time		Typically 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 Current before fault = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements

2 Includes the delay of the signal output contact

4.3.3.10 Technical revision history

Table 501: LREFPNDF Technical revision history

Technical revision	Change
B	Unit for setting *Start value 2.H* changed from %In to %.
C	Internal Improvement.

4.3.4 High-impedance based restricted earth-fault protection HREFPDIF

4.3.4.1 Identification

Function description	**IEC 61850 identification**	**IEC 60617 identification**	**ANSI/IEEE C37.2 device number**
High-impedance based restricted earth-fault protection	HREFPDIF	dIoHi>	87NH

4.3.4.2 Function block

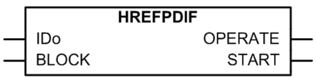


Figure 295: Function block

4.3.4.3 Functionality

The high-impedance based restricted earth-fault protection function HREFPDIF is used for the restricted earth-fault protection of generators and power transformers.

The function starts when the differential neutral current exceeds the set limit. HREFPDIF operates with the DT characteristic.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

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 HREFPDIF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

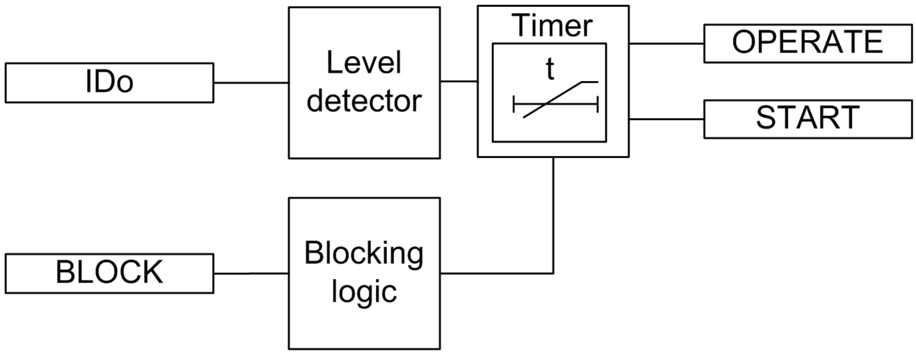


Figure 296: Functional module diagram

Level detector

The level detector compares the differential neutral current IDo to the set value of the *Operate value* setting. If the differential neutral current exceeds the *Operate value* setting, 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 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 operation timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration/System/ Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

4.3.4.5 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.

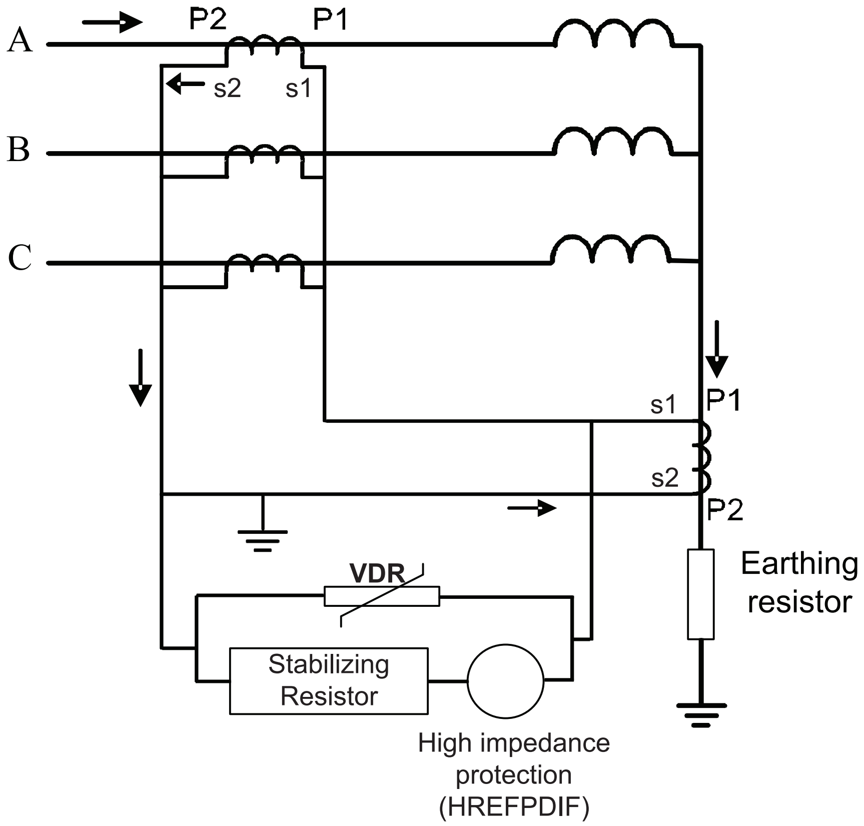


Figure 297: Connection scheme for the restricted earth-fault protection according to the high-impedance principle

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 298*. The measuring branch is a series connection of stabilizing resistor and IED.

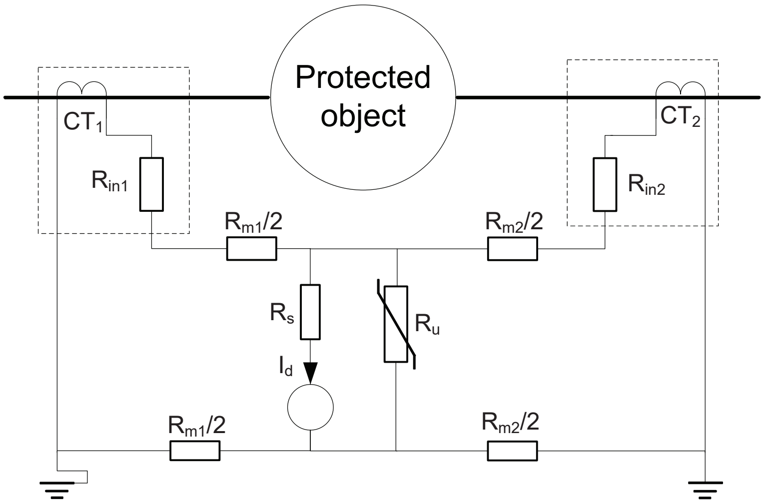


Figure 298: High-impedance principle

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 299*.

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.

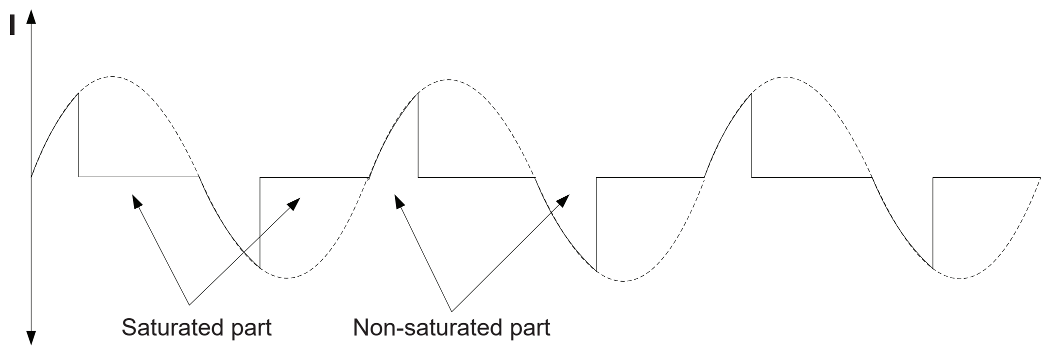


Figure 299: Secondary waveform of a saturated CT

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 298*.

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.

4.3.4.6 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 84)

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 85)

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.

4.3.4.7 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 86)

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 87)

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 88)

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 89)

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 90)

I_{prim}	the primary current at which the protection is to start
n	the turn ratio of the current transforme
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 $U_{kn} \approx 2 \times U_s$, the value of $I_m \approx \frac{I_e}{2}$ gives an approximate value for *Equation 90*.

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: $I_{kmax} = 16 \times I_n$ (corresponds to z_k = 6% and infinite grid)
   - Large power transformers: $I_{kmax} = 12 \times I_n$ (corresponds to z_k = 8% and infinite grid)
   - Generators and motors: $I_{kmax} = 6 \times I_n$

   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 87*. 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 91*.
4. The sensitivity I_{prim} is calculated with *Equation 90*. 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 91)

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 87*, 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 $U_k \geq 2 \times U_s$, fast IED operation is secure.
2. If $U_k \geq 1.5 \times U_s$ and $< 2 \times U_s$, IED operation can be slightly prolonged and 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 the VDR depends on certain conditions.

First, voltage U_{max}, ignoring the CT saturation during the fault, is calculated with the equation

$$U_{max} = \frac{I_{k\,max\,in}}{n} \times (R_{in} + R_m + R_s) \approx \frac{I_{k\,max\,in}}{n} \times R_s$$

(Equation 92)

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 93)

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.

4.3.4.8 Setting examples

Example 1

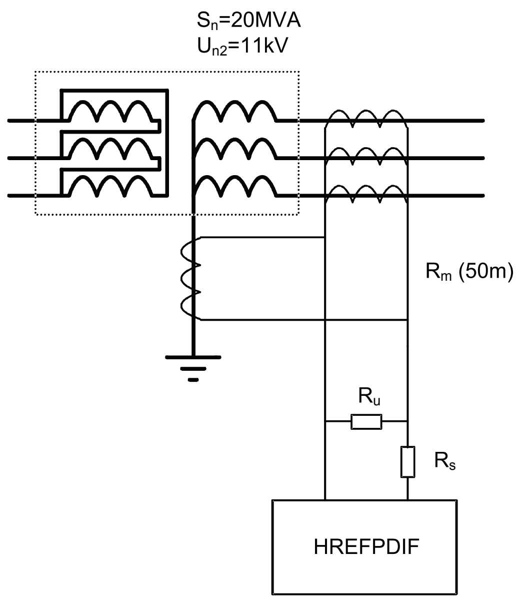


Figure 300: Restricted earth-fault protection of a transformer

The data for the protected power transformer are:

S_n = 20 MVA

U_{2n} = 11 kV

The longest distance of the secondary circuit is 50 m (the whole loop is 100 m) and the area of the cross section is 10 mm ^{2}.

$I_n = S_n / (\sqrt{3} \cdot U_n)$ = 1050 A

$I_{kmax} = 12 \cdot I_n$= 12600 A

In this example, the CT type is IHBF 12, the core size is 35 percent, the primary current is 1200 A and the secondary current is 5 A.

R_{in} = 0.26 Ω (value given by the manufacturer).

U_k = 40 V (value given by the manufacturer).

I_e = 0.055 A (value given by the manufacturer).

R_m = 1.81 Ω/km · 2 · 0.05 km = 0.181 Ω ≈ 0.18 Ω

$$U_s = \frac{12600 \times (0.26 + 0.18)}{240} V \approx 23V$$

According to the criterion, the value of U_k should be $2 \cdot U_s$ = 2 · 23 V = 46 V. It depends on if the stability of the scheme is achieved with U_k = 40 V. Otherwise, it is possible to choose a bigger core of 65 percent with:

R_{in} = 0.47 Ω (value given by the manufacturer).

U_k = 81 V (value given by the manufacturer).

R_m = 0.18 Ω

$$U_s = \frac{12600 \times (0.47 + 0.18)}{240} V \approx 34V$$

$U_k = 2 \cdot U_s = 68$ V (required value).

As mentioned earlier, $I_m = 0.5 \cdot I_e$ gives a realistic value for I_{prim} in *Equation 90*. If $I_u = 0$ and $I_{rs} = m \cdot 0.5 \cdot I_o$, the value for the sensitivity is:

$I_{prim} = n \cdot m \cdot I_e = 240 \cdot 4 \cdot 0.055$ A ≈ 53 A

$I_{rs} = 4 \cdot 0.5 \cdot 0.055$ A = 0.11 A

The setting value can be calculated with:

$$Operate\ value = \left(\frac{I_{rs}}{I_{CT\_n2}}\right) = \left(\frac{0.11A}{5A}\right) \approx 2.2\%$$

The resistance of the stabilizing resistor can be calculated:

$R_s = U_s / I_{rs} = 34$ V / 0.11 A ≈ 309 Ω

However, the sensitivity can be calculated more accurately when the actual values of I_u and I_{rs} are known. The stabilizing resistor of the relay is chosen freely in the above example and it is assumed that the resistor value is not fixed.

Example 2a

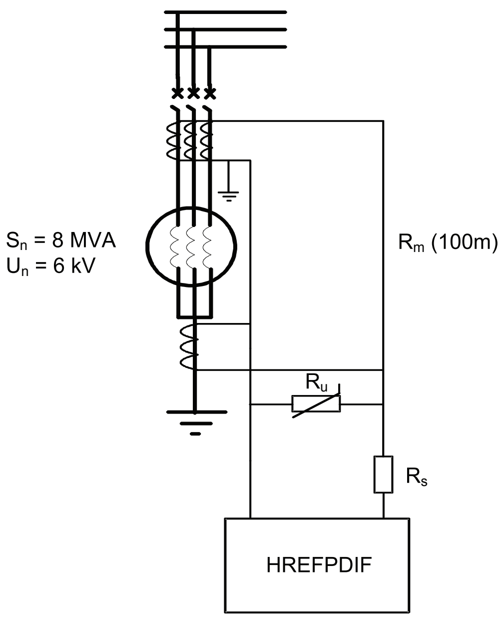


Figure 301: Restricted earth-fault protection of a generator

In the protected generator:

$S_n = 8$ MVA

$U_n = 6$ kV.

I_n = 770 A

I_{kmax} = 6 · I_n = 6 · 770 A = 4620 A

In this example, the CT type is KOFD 12 A 21 with:

I_{CT_1n} = 1000 A (value given by the manufacturer).

I_{CT_2n} = 1 A (value given by the manufacturer).

U_k = 323 V (value given by the manufacturer).

R_{in} = 15.3 Ω (value given by the manufacturer).

I_e = 0.012 A (value given by the manufacturer).

If the length of the secondary circuit is 100 m (the whole loop is 200 m) and the area of the cross section is 2.5 mm^2:

R_m = 7.28 Ω/km · 2 · 0.1 km ≈ 1.46 Ω

The required knee-point voltage can be calculated using equation

U_k = 2 · (4620 A / 1000) · (15.3 + 1.46) ≈ 155 V.

The value 155 V is lower than the value 323 V, which means that the value of U_k is high enough.

As mentioned earlier, I_m = 0.5 · I_e gives a realistic value for I_{prim} in *Equation 90*. If I_u = 0 and I_{rs} = m · 0.5 · I_e, the value for the sensitivity is:

I_{prim} = n · m · I_e = 1000 · 4 · 0.012 A = 48 A (≈ 6 % x I_n).

I_{rs} = 4 · 0.5 · 0.012 A = 0.024 A.

The setting value can be calculated with:

$$Operate\,value = \left(\frac{I_{rs}}{I_{CT\_2n}}\right) = \left(\frac{0.024\,A}{1A}\right) \approx 2.4\%$$

The resistance of the stabilizing resistor can now be calculated:

R_s = U_s / I_{rs} = 78 V / (2 · I_e) = 78 V / (2 · 0.012 A) = 3250 Ω.

Example 2b

In this example, I_{rs} = 4 x 12 mA = 48 mA and I_u = 30 mA. This results in the sensitivity:

I_{prim} = n · (I_{rs} + I_u + m · I_m) = 1000 · (48 + 30 + 24) mA = 102 A

The setting value can be calculated with:

$$Operate\,value = \left(\frac{I_{rs}}{I_{CT\_2n}}\right) = \left(\frac{0.048\,A}{1A}\right) \approx 4.8\%$$

The resistance of the stabilizing resistor is now:

R_s = U_s / I_{rs}= 78 V / 48 mA ≈ 1630 Ω

In this example, the relay is of such a type that the stabilizing resistor can be chosen freely.

4.3.4.9 Signals

Table 502: HREFPDIF Input signals

Name	Type	Default	Description
IDo	SIGNAL	0	Differential current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 503: HREFPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.3.4.10 Settings

Table 504: HREFPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	1.0...50.0	%In	0.1	1.0	Low operate value, percentage of the nominal current
Minimum operate time	40...300000	ms	1	40	Minimum operate time

Table 505: HREFPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 506: HREFPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.3.4.11 Monitored data

Table 507: HREFPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
HREFPDIF	Enum	1=on 2=blocked 3=test		Status

Name	Type	Values (Range)	Unit	Description
		4=test/blocked		
		5=off		

4.3.4.12 Technical data

Table 508: HREFPDIF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1, 2]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Operate value*	16 ms	21 ms	23 ms
	I_{Fault} = 10.0 × set *Operate value*	11 ms	13 ms	14 ms
Reset time		Typically 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		

4.3.4.13 Technical revision history

Table 509: HREFPDIF Technical revision history

Technical revision	Change
B	Internal improvement.
C	Internal improvement.

4.3.5 High-impedance differential protection HIxPDIF

[1] Current before fault = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.
[2] Includes the delay of the signal output contact.

4.3.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance differential protection for phase A	HIAPDIF	dHi_A>	87A
High-impedance differential protection for phase B	HIBPDIF	dHi_B>	87B
High-impedance differential protection for phase C	HICPDIF	dHi_C>	87C

4.3.5.2 Function block

Figure 302: Function block

4.3.5.3 Functionality

The high-impedance differential protection function HIxPDIF is a general differential protection. It provides a phase-segregated short circuit protection for the busbar. However, the function can also be used for providing generator, motor, transformer and reactor protection.

The function starts and operates when the differential current exceeds the set limit. The operate time characteristics are according to definite time (DT).

The function contains a blocking functionality. It is possible to block the function outputs, timer or the whole function.

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 HIxPDIF can be described with a module diagram. All the modules in the diagram are explained in the next sections.

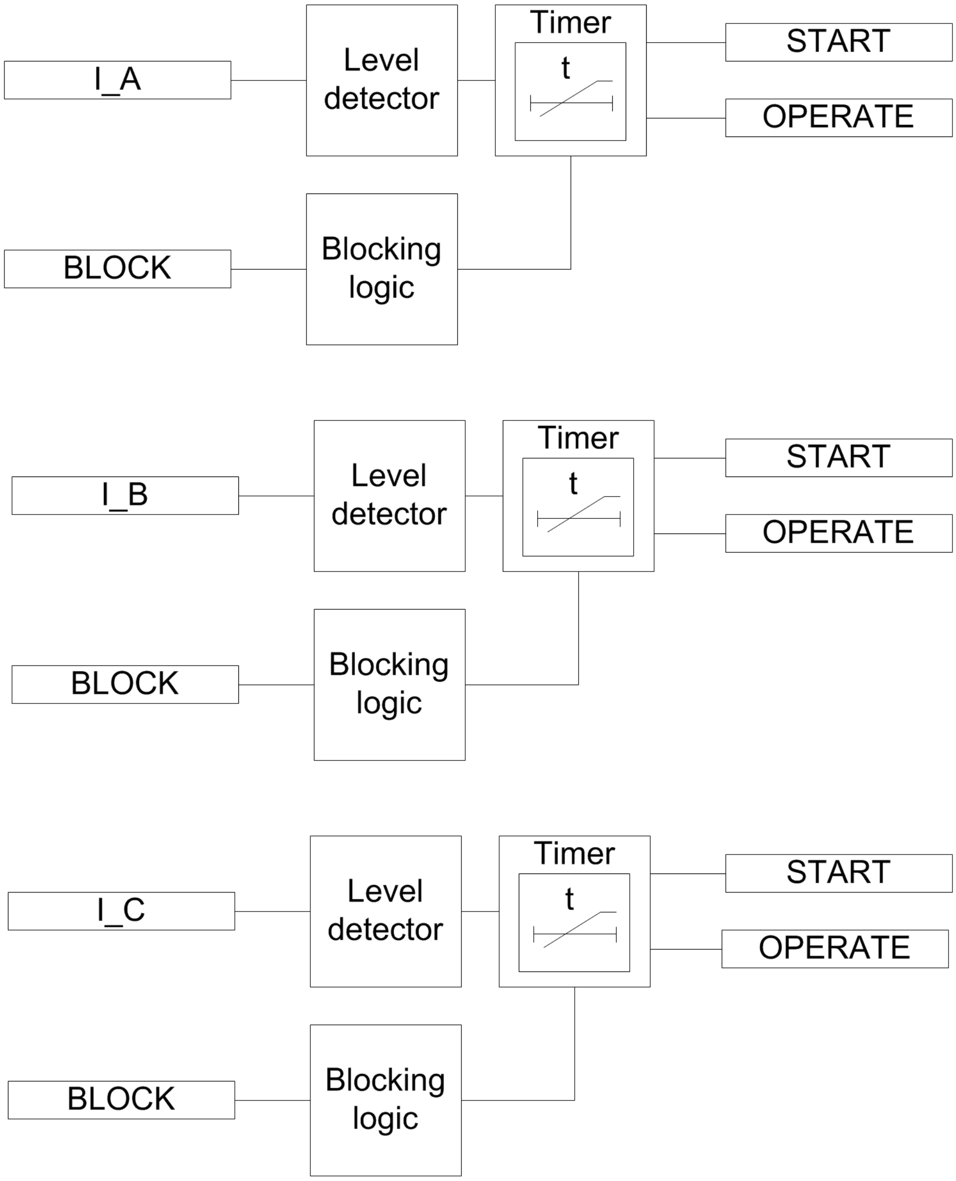


Figure 303: Functional module diagram

The module diagram illustrates all the phases of the function. Functionality for phases A, B and C is identical.

All three phases have independent settings.

Level detector

The module compares differential currents `I_A` calculated by the peak-to-peak measurement mode to the set *Operate value*. The Timer module is activated if the differential current exceeds the value of the *Operate value* setting.

Timer

Once activated, Timer activates the START output. The time characteristic is according to DT. When the operation timer reaches 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.

Timer calculates the start duration START_DUR value, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the Monitored data view.

The activation of the BLOCK input resets Timer and deactivates the START and OPERATE outputs.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.3.5.5 Application

HIxPDIF provides a secure and dependable protection scheme against all types of faults. The high-impedance principle is used for differential protection due to its capability to manage the through-faults also with the heavy current transformer (CT) saturation.

For current transformer recommendations, see the Requirements for measurement transformers section in this manual.

High-impedance principle

The phase currents are measured from both the incoming and the outgoing feeder sides of the busbar. The secondary of the current transformer in each phase is connected in parallel with a protection relay measuring branch. Hence, the relay measures only the difference of the currents. In an ideal situation, there is a differential current to operate the relay only if there is a fault between the CTs, that is, inside the protected zone.

If there is a fault outside the zone, a high current, known as the through-fault current, can go through the protected object. This can cause partial saturation in the CTs. The relay operation is avoided with a stabilizing resistor (R_S) in the protection relay measuring branch. R_S increases the impedance of the protection relay; hence the name high-impedance differential scheme.

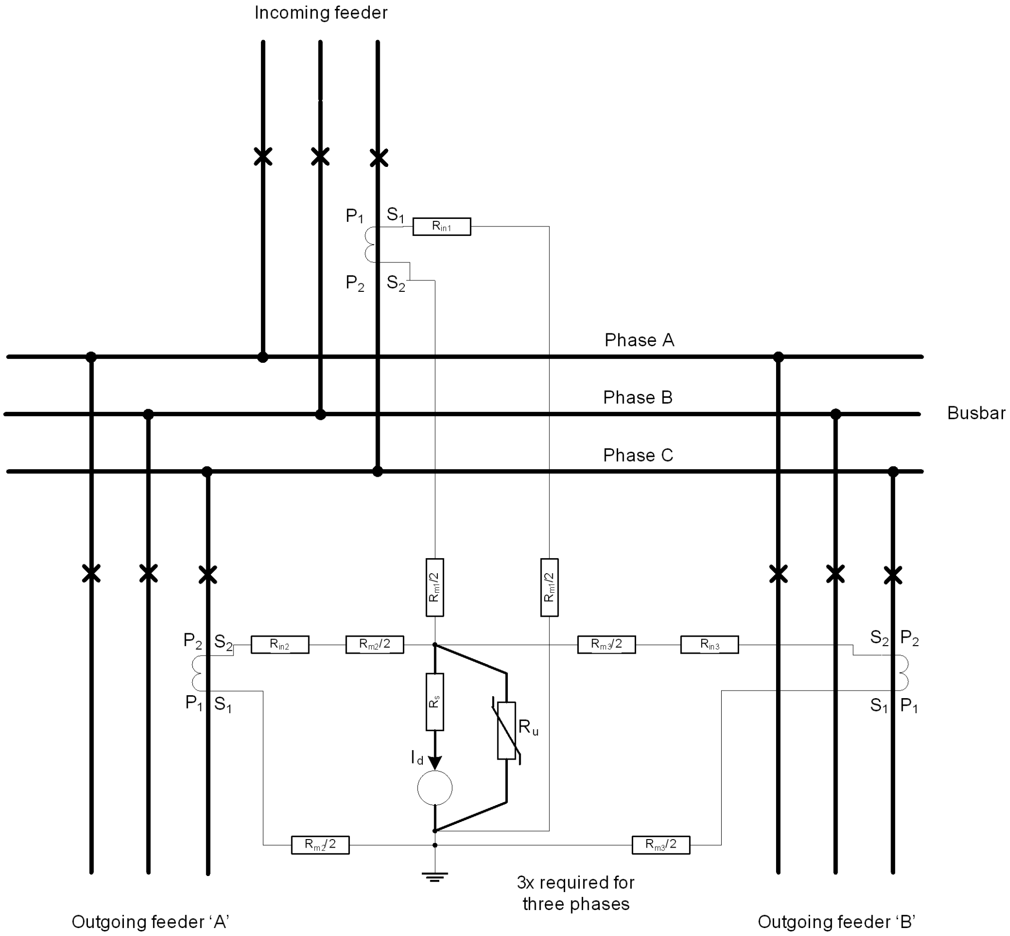


Figure 304: Phase-segregated bus differential protection based on high-impedance principle

CT secondary winding resistances (R_{in}) and connection wire resistances ($R_m/2$) are also shown in *Figure 305*.

Figure 305 demonstrates a simplified circuit consisting only of one incoming and outgoing feeder. To keep it simple, the voltage-dependent resistor (R_u) is not included. The wiring resistances are presented as total wiring resistances R_{m1} and R_{m2}.

R_{m1} is the maximum wiring resistance concerning all incoming feeder sets, whereas R_{m2} is the maximum wiring resistance concerning all outgoing feeder sets.

The lower part of *Figure 305* shows the voltage balance when there is no fault in the system and no CT saturation.

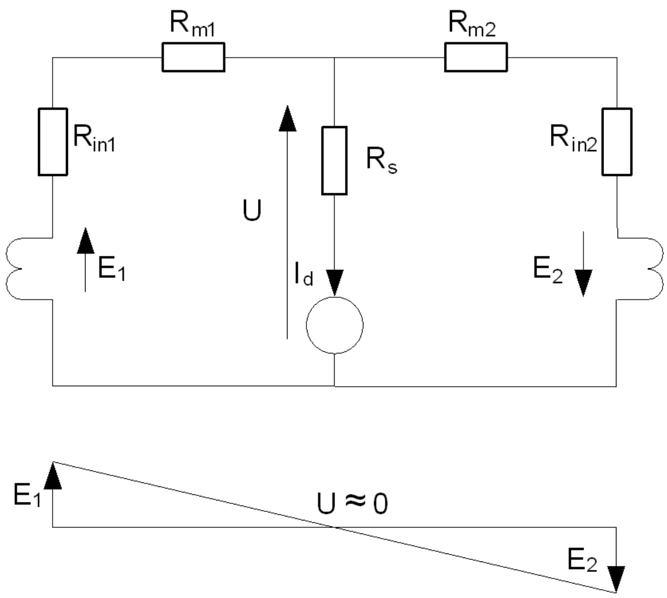


Figure 305: Equivalent circuit when there is no fault or CT saturation

When there is no fault, the CT secondary currents and their emf voltages, E_1 and E_2, are opposite and the protection relay measuring branch has no voltage or current. If an in-zone fault occurs, the secondary currents have the same direction. The relay measures the sum of the currents as a differential and trips the circuit breaker. If the fault current goes through only one CT, its secondary emf magnetizes the opposite CT, that is, $E_1 \approx E_2$.

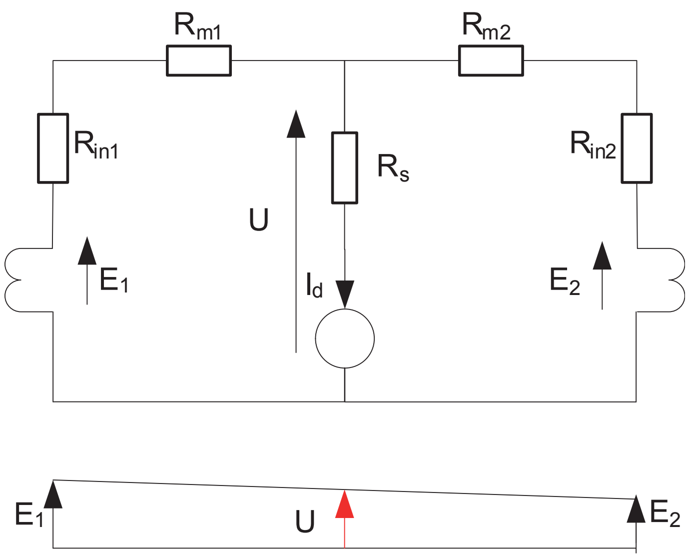


Figure 306: Equivalent circuit in case of in-zone fault

Figure 307 shows CT saturation at a through-fault, that is, out-of-zone, situation. The magnetization impedance of a saturated CT is almost zero. The saturated CT winding can be presented as a short circuit. When one CT is saturated, the current of the non-saturated CT follows two paths, one through the protection relay measuring branch (R_s + relay) and the other through the saturated CT ($R_m + R_{in2}$).

The protection relay must not operate during the saturation. This is achieved by increasing the relay impedance by using the stabilizing resistor (R_s) which forces the majority of the differential current to flow through the saturated CT. As a result, the relay operation is avoided, that is, the relay operation is stabilized against the CT saturation at through-fault current. The stabilizing voltage U_s is the basis of all calculations.

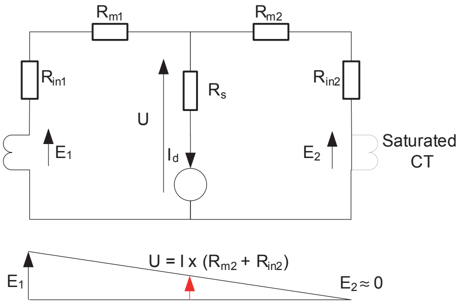


Figure 307: Equivalent circuit in case of the CT saturation at through-fault

The CT saturation happens most likely in the case of an in-zone fault. This is not a problem, because although the operation remains stable (non-operative) during the saturated parts of the CT secondary current waveform, the non-saturated part of the current waveform causes the protection to operate.

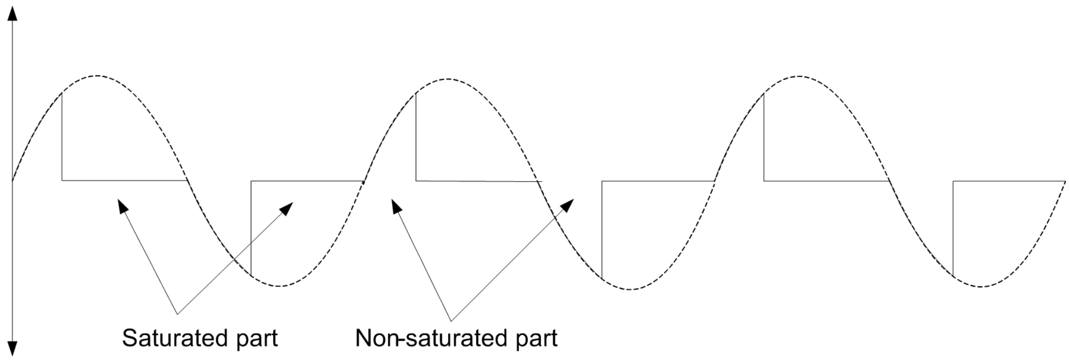


Figure 308: Secondary waveform of a saturated CT

The secondary circuit voltage can easily exceed the isolation voltage of the CTs, connection wires and the protection relay because of the stabilizing resistance and CT saturation. A voltage dependent resistor (VDR, R_u) is used to limit the voltage as shown in *Figure 304*.

Busbar protection scheme

The basic concept for any bus differential protection relay is a direct use of Kirchoff's first law that the sum of all currents connected to one differential protection zone is zero. If the sum is not zero, an internal fault has occurred. In other words, as seen by the busbar differential protection, the sum of all currents that flow into the protection zone, that is, currents with positive value, must be equal to currents that flow out of the protection zone, that is, currents with negative value, at any instant of time.

Figure 309 shows an example of a phase segregated single busbar protection employing high-impedance differential protection. The example system consists of a single incoming busbar feeder and two outgoing busbar feeders. The CTs from both the outgoing busbar feeders and the incoming busbar feeders are connected in parallel with the polarity. During normal load conditions, the total instantaneous incoming current is equal to the total instantaneous outgoing current and the difference current is negligible. A fault in the busbar results in an imbalance between the incoming and the outgoing current. The difference current flows through the protection relay, which generates a trip signal.

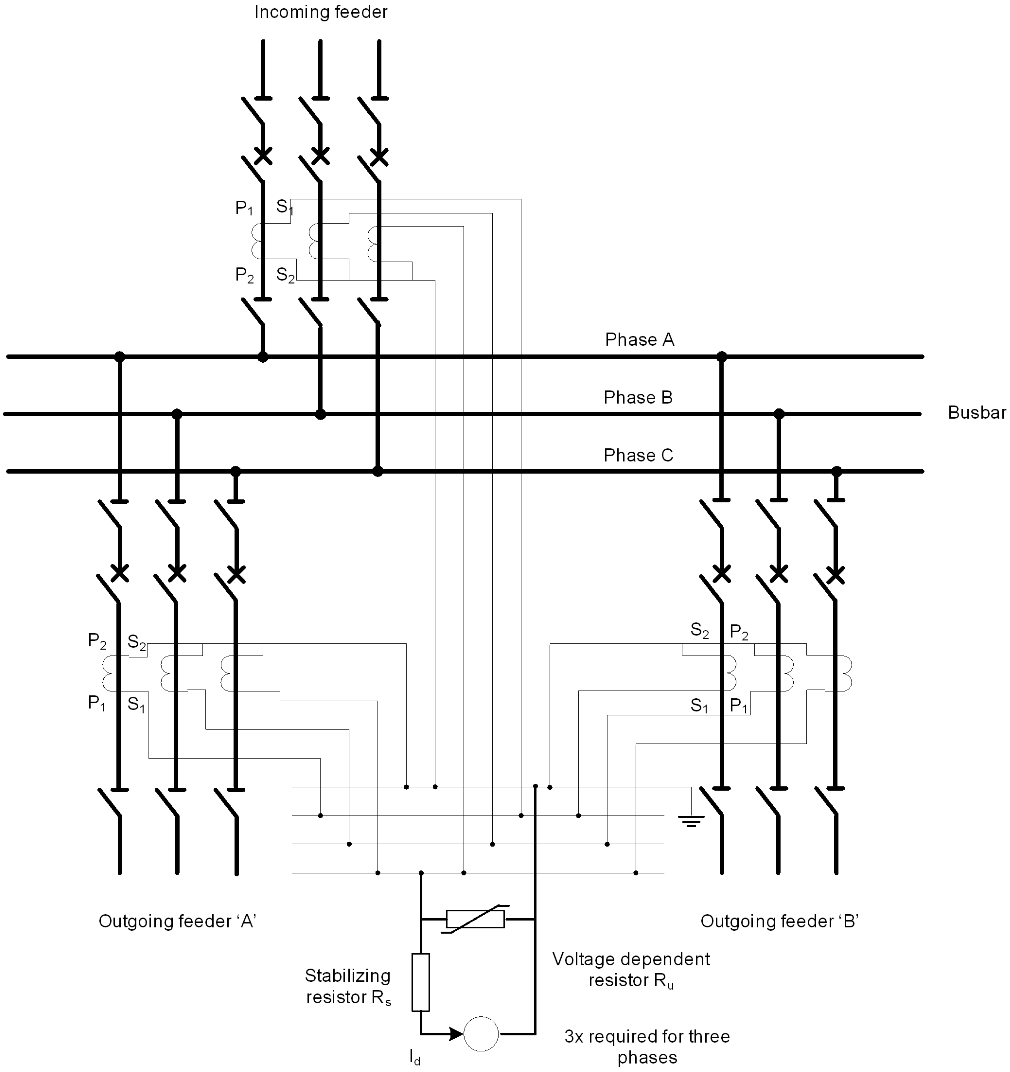


Figure 309: Phase-segregated single busbar protection employing high-impedance differential protection

Figure 310 shows an example for a system consisting of two busbar section coupled with a bus coupler. Each busbar section consists of two feeders and both sections are provided with a separate differential protection to form different zones. The formed zones overlap at the bus coupler.

When the bus coupler is in the open position, each section of the busbar handles the current flow independently, that is, the instantaneous incoming current is equal to the total instantaneous outgoing current and the difference current is negligible. The difference current is no longer zero with a fault in the busbar and the protection operates.

With the bus coupler in the closed position, the current also flows from one busbar section to another busbar section. Thus, the current flowing through the bus coupler needs to be considered in calculating differential current. During normal condition, the summation of the current on each bus section is zero. However, if there is a fault in any busbar section, the difference current is no longer zero and the protection operates.

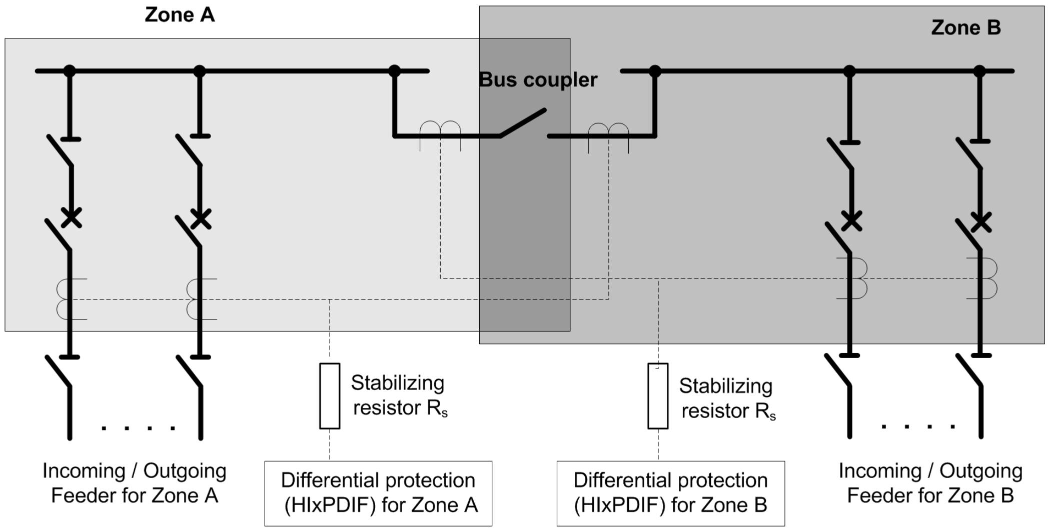


Figure 310: Differential protection on busbar with bus coupler (Single-phase representation)

4.3.5.6 Example calculations for busbar high-impedance differential protection

The protected object in the example for busbar differential protection is a single-bus system with two zones of protection.

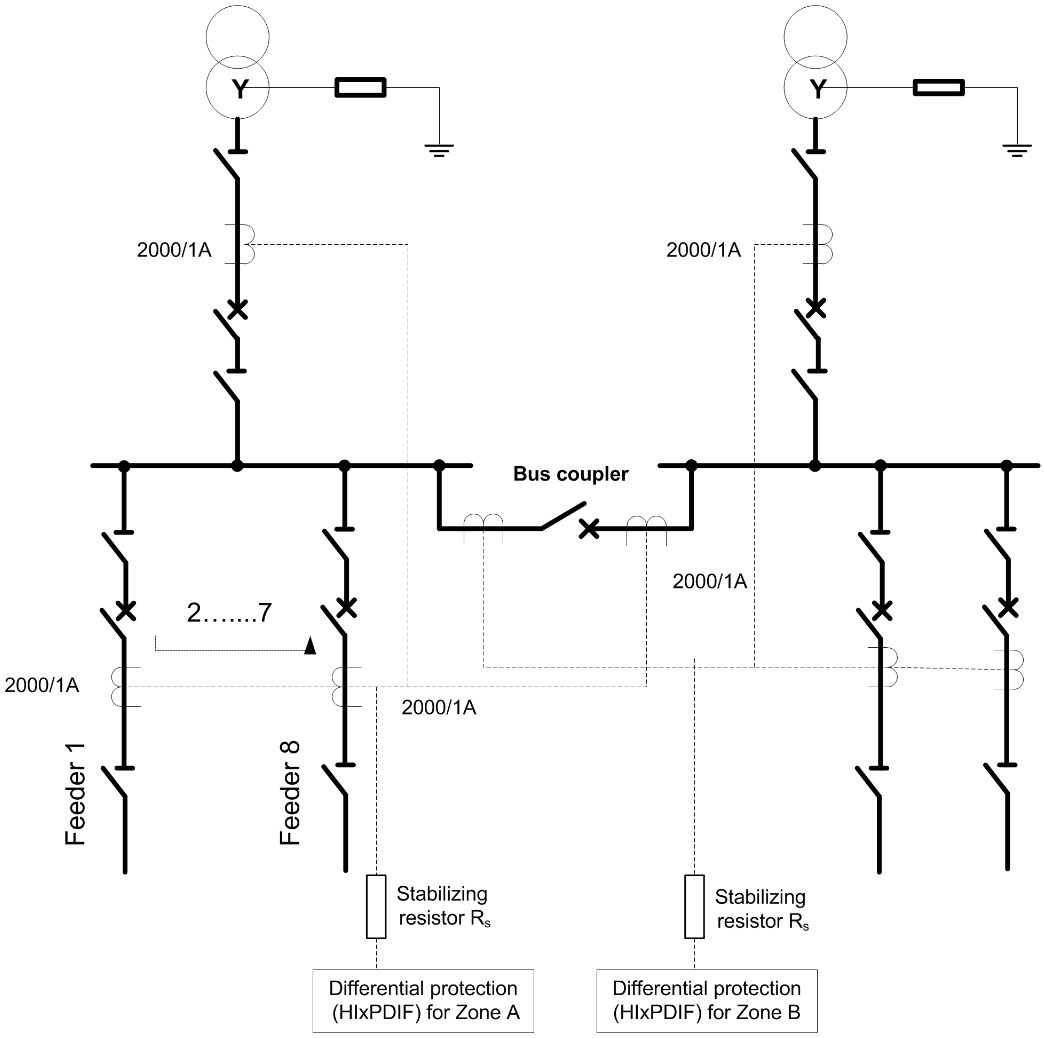


Figure 311: Example for busbar differential protection

Bus data:

U_n	20 kV
I_n	2000 A
I_{kmax}	25 kA

10 feeders per protected zone including bus coupler and incomer.

CT data is assumed to be:

CT	2000/1 A
R_{in}	15.75 Ω
U_{kn}	436 V
I_e	<7 mA (at U_{kn})
R_m	1Ω

The stabilizing voltage is calculated using the formula:

$$U_s = \frac{25000A}{2000}(15.75\Omega + 1.\Omega) \approx 209.37\ V$$

(Equation 94)

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 as:

$$I_m = \frac{U_s}{U_{kn}} \cdot I_e$$

(Equation 95)

$$I_m = \frac{209.37V}{436V} \cdot 7mA \approx 3.4mA$$

(Equation 96)

To obtain adequate protection stability, the setting current I_{rs} must be at the minimum of the sum of magnetizing currents of all connected CTs.

$$I_{rs} = 10 \cdot 3.4mA \approx 34\,mA$$

(Equation 97)

The resistance of the stabilizing resistor is calculated based on *Equation 98*.

$$R_S = \frac{209.37\ V}{0.034A} \approx 6160\,\Omega$$

(Equation 98)

The calculated value is the maximum value for the stabilizing resistor. If the value is not available, the next available value below should be selected and the protection relay setting current is tuned according to the selected resistor. For example, in this case, the resistance value 5900 Ω is used.

$$I_{rs} = \frac{209.37V}{5900\,\Omega} \approx 35\,mA$$

(Equation 99)

The sensitivity of the protection is obtained as per *Equation 100*, assuming $I_u = 0$.

$$I_{prim} = 2000 \cdot (0.035\,A + 10 \cdot 0.0034\,A + 0\,A) \approx 140A$$

(Equation 100)

The power of the stabilizing resistor is calculated:

$$P \geq \frac{(436V)^2}{5900\Omega} \approx 32W$$

(Equation 101)

Based on *Equation 102* and *Equation 103*, the need for voltage-dependent resistor is checked.

$$U_{max} = \frac{25000A}{2000}(5900\,\Omega + 15.75\Omega + 1.00\,\Omega) \approx 74.0\,kV$$

(Equation 102)

$$\breve{u} = 2 \cdot \sqrt{2 \cdot 436V \cdot (74000V - 436V)} \approx 16.0\,kV$$

(Equation 103)

The voltage-dependent resistor (one for each phase) is needed in this case as the voltage during the fault is higher than 2 kV.

The leakage current through the VDR at the stabilizing voltage can be available from the VDR manual, assuming that to be approximately 2 mA at stabilizing voltage

$$Iu \approx 0.002\,A$$

(Equation 104)

The sensitivity of the protection can be recalculated taking into account the leakage current through the VDR as per *Equation 105*.

$$I_{prim} = 2000 \cdot (0.035\,A + 10 \cdot 0.0034\,A + 0.002\,A) \approx 142\,A$$

(Equation 105)

4.3.5.7 Signals

Table 510: HIAPDIF Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 511: HIBPDIF Input signals

Name	Type	Default	Description
I_B	SIGNAL	0	Phase B current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 512: HICPDIF Input signals

Name	Type	Default	Description
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 513: HIAPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 514: HIBPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 515: HICPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.3.5.8 Settings

Table 516: HIAPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	1.0...200.0	%In	1.0	5.0	Operate value, percentage of the nominal current
Minimum operate time	20...300000	ms	10	20	Minimum operate time

Table 517: HIAPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 518: HIAPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

Table 519: HIBPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	1.0...200.0	%In	1.0	5.0	Operate value, percentage of the nominal current
Minimum operate time	20...300000	ms	10	20	Minimum operate time

Table 520: HIBPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 521: HIBPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

Table 522: HICPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	1.0...200.0	%In	1.0	5.0	Operate value, percentage of the nominal current
Minimum operate time	20...300000	ms	10	20	Minimum operate time

Table 523: HICPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 524: HICPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

4.3.5.9 Monitored data

Table 525: HIAPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
HIAPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Name	Type	Values (Range)	Unit	Description
		5=off		

Table 526: HIBPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
HIBPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 527: HICPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
HICPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.3.5.10 Technical data

Table 528: HIxPDIF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the current measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1], [2]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Start value*	12 ms	16 ms	24 ms
	I_{Fault} = 10 × set *Start value*	10 ms	12 ms	14 ms

Table continues on the next page

[1] *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 50 Hz, 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

Characteristic	Value
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

4.3.5.11 Technical revision history

Table 529: HIxPDIF Technical revision history

Technical revision	Change
B	Function name changed from HIPDIF to HIA-PDIF, HIBPDIF, HICPDIF

4.3.6 High-impedance/flux-balance based differential protection for motors MHZPDIF

4.3.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance/flux-balance based differential protection for motors	MHZPDIF	3dIHi>M	87MH

4.3.6.2 Function block

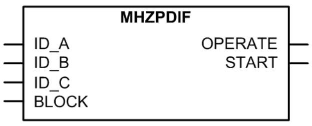


Figure 312: Function block

4.3.6.3 Functionality

The high-impedance/flux-balance based differential protection for motors function MHZPDIF provides winding short circuit protection for motors.

MHZPDIF starts and operates when any of the three-phase differential currents, ID_A, ID_B or ID_C, exceeds the set limit. The operation timer characteristic is according to the definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, timers or the function itself.

4.3.6.4 Operation principle

The function can be enabled and disabled with the *Operation setting*. The corresponding parameter values are "On" and "Off".

The operation of MHZPDIF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

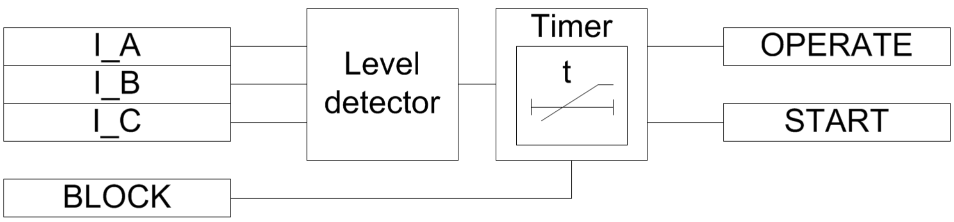


Figure 313: Functional module diagram

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 or 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.

4.3.6.5 Application

MHZPDIF provides the winding short circuit and earth-fault protection for 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 protection relay.

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 protection relay's 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.

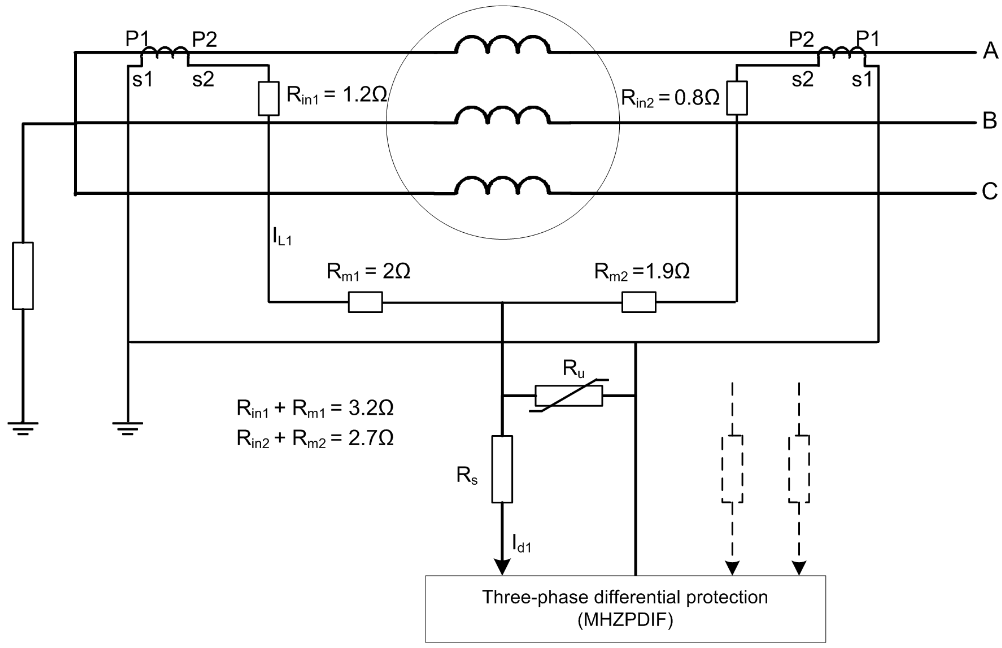


Figure 314: Three-phase differential protection for motors based on highimpedance principle

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.

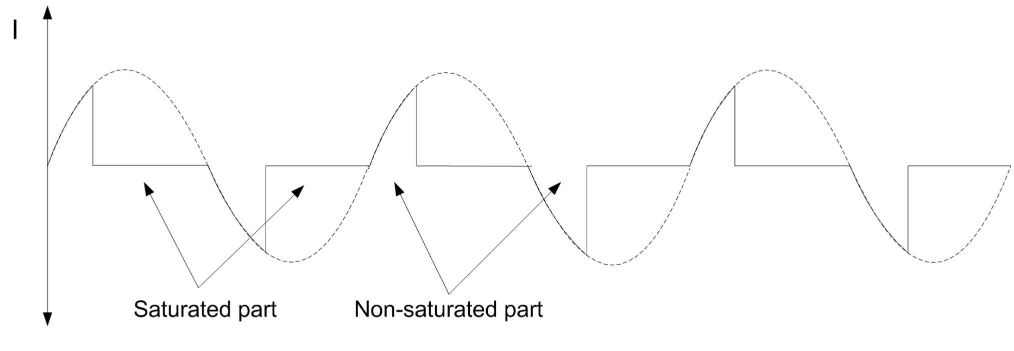


Figure 315: Secondary waveform of a saturated CT

At an internal fault, the secondary circuit voltage can easily exceed the isolation voltage of the CTs, connection wires and the protection relay. 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.

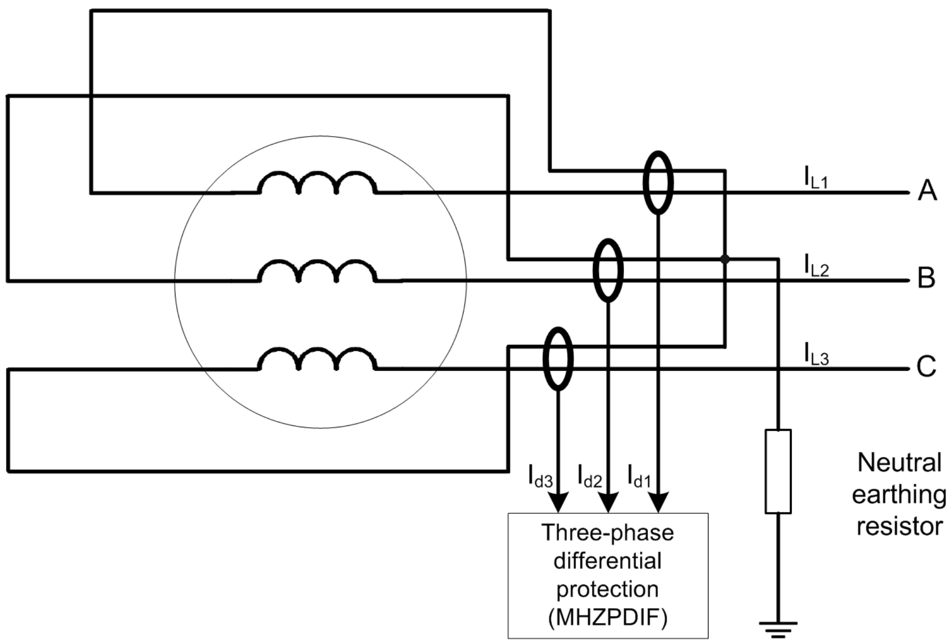


Figure 316: Three-phase differential protection for motors based on fluxbalancing principle

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 highimpedance principle or stabilized three-phase differential protection must be used.

4.3.6.6 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. This means that they should be preferably from the same manufacturing batch, that is, an identical construction is 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. If 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.

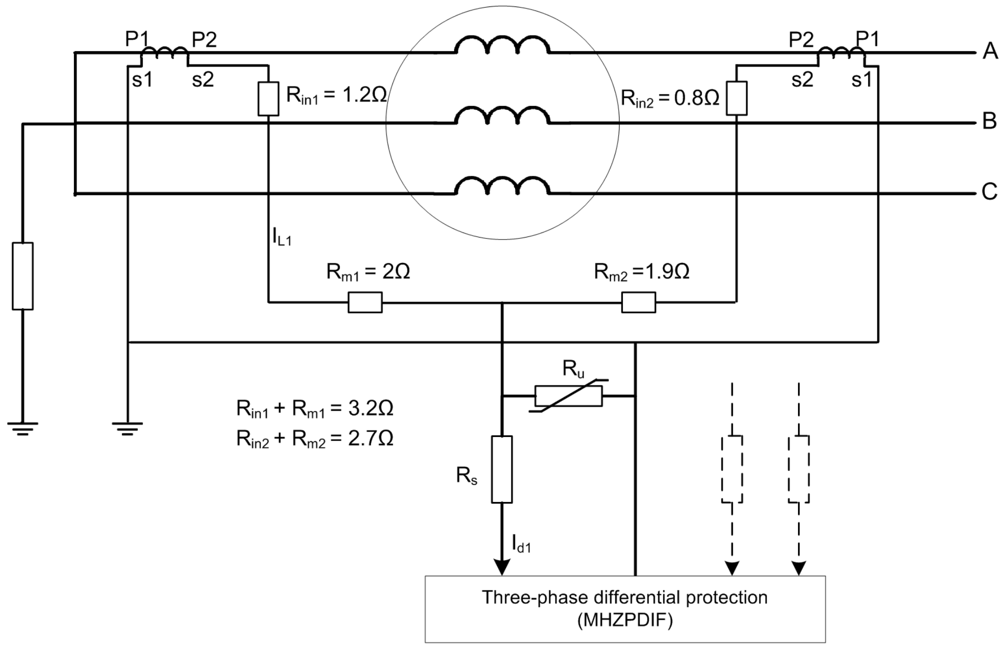


Figure 317: High-impedance differential protection with different CT burden value on each branch

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

$$U_s = \frac{I_{k\max}}{n}(R_{in} + R_m)$$

(Equation 106)

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 relay 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 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 107)

U_{kn}	Knee point voltage
U_s	Stabilizing voltage

The factor two is used when delay in the operating time of the protection is not acceptable in any situation. It is advisable to use 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 protection relay 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 108)

R_s	The resistance of the stabilizing resistor
U_s	The stabilizing voltage of the protection relay
I_{rs}	The 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 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 109)

The actual sensitivity of the protection is affected by the protection relay 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 protection relay operates at a certain setting can be calculated with the formula

$$I_{prim} = n \cdot \left(I_{rs} + I_u + m \cdot I_m \right)$$

(Equation 110)

I_m	The magnetizing current per current transformer at the U_s voltage
I_{prim}	The primary current at which the protection is to start
I_{rs}	The value of the *Operate value* setting
I_u	The leakage current flowing through the VDR at the U_s voltage
n	The turn ratio of the current transformer
m	The number of current transformers included in the protection per phase (=2)

The I_e value given in many catalogs is the excitation current at knee point voltage.

Assuming $U_{kn} \approx 2 \times U_s$, the value of $I_m \approx \frac{I_e}{2}$ gives an approximate value for *Equation 110*.

The selection of current transformers can be divided into the following steps.

1. The rated current In of the protected machine should be known. The value of In also affects the magnitude of I_{kmax}. Normally the I_{kmax} value for motors is $6 \cdot I_n$.
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 with *Equation 107*. 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 a Class X current transformer or it can be estimated with *Equation 111*.
4. The sensitivity I_{prim} is calculated with *Equation 110*. 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 a Class X CT is not 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 111)

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 107*, 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. However, the network conditions have to be known well enough to ensure the stability.

- If $U_k \geq 2 \times U_s$, fast relay operation is secure.
- If $U_k \geq 1.5 \times U_s$ and $< 2 \times U_s$, relay operation can be slightly prolonged and should be studied case by case.
- If $U_k < 1.5 \times U_s$, the relay operation is jeopardized. Another CT has to be chosen.

The need for voltage dependent resistor (VDR) depends on the insulation level for which the protection relays are tested.

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 112)

I_{kmaxin}	The maximum fault current inside the zone, in primary amperes
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

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 113)

U_{kn}	The knee point voltage of the CT

The VDR is recommended when the peak voltage û ≥ 2kV. This the insulation level for which protection relays are tested.

For example, the maximum fault current in case of a 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. The stabilizing resistor is 330 Ohms.

$$U_{\max} = \frac{12600\,A}{240} \cdot 330\,\Omega = 17325\,V$$

(Equation 114)

$$\breve{u} = 2\sqrt{2 \cdot 81 \cdot (17325 - 81)} \approx 3.34\,kV$$

(Equation 115)

As the peak voltage û = 3.2 kV, VDR must be used. In some cases, VDR can be avoided if R_s is smaller. The value of R_s depends on the protection relay operation current and stabilizing voltage. Thus, a higher setting in the protection relay 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. The core-balance transformers used in an ordinary overcurrent protection are adequate here as well.

4.3.6.7 Example calculations for high-impedance differential protection

The example shows the calculations for the *Operate value* setting, stabilizing resistor value (R_s) and required knee point voltage (U_{kn}) of the CTs.

Table 530: Protected generator values

Quantity	Value
S_n	8 MVA
U_n	6 kV
I_n	770 A
I_{kmax}	4620 A (6 × I_n) out-of-zone fault
I_{kmaxin}	9.24 kA (12 × I_n) in-zone fault

Table 531: Assumed CT data

Quantity	Value
CT	1000/1 A
R_{in}	15.3 Ω
U_{kn}	323 V
I_e	35 mA (at U_{kn})

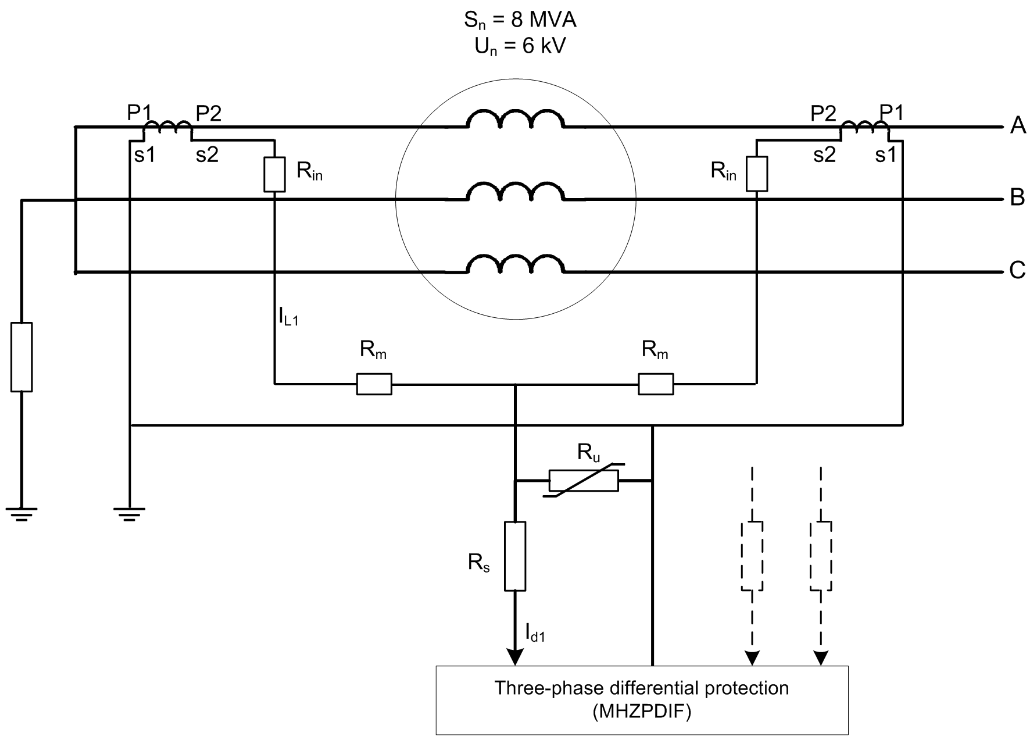


Figure 318: Example calculation for high-impedance differential protection (only one phase is presented in detail)

The length of the secondary circuit loop is 200 m and the area of the cross-section is 2.5 mm^2. Resistance at 75°C is 0.00865 Ω/m.

$$R_m = 0.00865 \frac{\Omega}{m} \cdot 200m \approx 1.73\Omega$$

(Equation 116)

First the stabilizing voltage is calculated based on *Equation 106*.

$$U_s = \frac{6 \cdot 770\,A}{1000} \cdot (15.3\,\Omega + 1.73\,\Omega) \approx 78.7\,V$$

(Equation 117)

In this case the requirement for the current transformer knee point voltage is fulfilled because $U_{kn} > 2U_s$.

The magnetising curve of the CT is assumed to be linear. The magnetizing current at the stabilizing voltage can be estimated.

$$I_m = \frac{U_s}{U_{kn}} \cdot I_e$$

(Equation 118)

$$I_m = \frac{78.7\,V}{323\,V} \cdot 35mA \approx 8.5mA$$

(Equation 119)

The setting current I_{rs} should be at the minimum of the sum of the magnetizing currents of all connected CTs to obtain adequate protection stability.

$$I_{rs} = 2 \cdot 8.5\,mA \approx 17\,mA$$

(Equation 120)

The resistance of the stabilizing resistor is calculated based on *Equation 108*.

$$R_s = \frac{78.7\,V}{0.017\,A} \approx 4629\,\Omega$$

(Equation 121)

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 protection relay setting current is to be tuned according to the selected resistor. For example in this case the resistance value 3900 Ω is used.

$$I_{rs} = \frac{78.7\,V}{3900\,V} \approx 20\,mA$$

(Equation 122)

The sensitivity of the protection is obtained as per *Equation 110*, (assuming I_u to be zero)

$$I_{prim} = 1000 \cdot (0.020\,A + 2 \cdot 0.0085\,A + 0\,A) \approx 37\,A$$

(Equation 123)

The power of the stabilizing resistor is calculated as follows.

$$P \geq \frac{(323\,V)^2}{3900\,\Omega} \approx 27\,W$$

(Equation 124)

Based on *Equation 112* and *Equation 113*, the need for voltage dependent resistor is checked.

$$U_{max} = \frac{12 \cdot 770\,A}{1000} \cdot (3900\,\Omega + 15.3\,\Omega + 1.73\,\Omega + 0.10\,\Omega) \approx 36.2\,kV$$

(Equation 125)

$$\breve{u} = 2\sqrt{2 \cdot 323\,V \cdot (36200\,V - 323\,V)} \approx 9.6\,kV$$

(Equation 126)

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 stabilizing voltage.

$$Iu \approx 0.002\,A$$

(Equation 127)

The sensitivity of the protection can be re-calculated taking into account the leakage current through the varistor as per *Equation 110*.

$$I_{prim} = 1000 \cdot (0.020\,A + 2 \cdot 0.0085\,A + 0.002\,A) \approx 39\,A$$

(Equation 128)

4.3.6.8 Signals

Table 532: MHZPDIF Input signals

Name	Type	Default	Description
ID_A	REAl	0.0	Differential current amplitude (DFT) phase A
ID_B	REAL	0.0	Differential current amplitude (DFT) phase B

Table continues on the next page

Name	Type	Default	Description
ID_C	REAL	0. 0	Differential current amplitude (DFT) phase C
BLOCK	BOOLEAN	0=False	Block signal for acti-vating the blocking mode

Table 533: MHZPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.3.6.9 Settings

Table 534: MHZPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	0.5...50.0	%In	0.1	0.5	Operate value, per-centage of the nominal current
Minimum operate time	20...300000	ms	10	20	Minimum operate time

Table 535: MHZPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 536: MHZPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	0	Reset delay time

4.3.6.10 Monitored data

Table 537: MHZPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
ID_A	FLOAT32	0.00...80.00	xIn	Differential cur-rent phase A
ID_B	FLOAT32	0.00...80.00	xIn	Differential cur-rent phase B

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
ID_C	FLOAT32	0.00...80.00	xIn	Differential current phase C
MHZPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.3.6.11 Technical data

Table 538: MHZPDIF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the current measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 x I_n		
Operate time ,		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Start Value* (one phase fault)	13 ms	17 ms	21 ms
	I_{Fault} = 2.0 × set *Start Value* (three phases fault)	11 ms	14 ms	17 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 of ±20 ms		

4.4 Unbalance protection

4.4.1 Negative-sequence overcurrent protection NSPTOC

4.4.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overcurrent protection	NSPTOC	I2>	46

1 *Measurement mode* = “Peak-to-Peak”, current before fault = 0.0 × I_n, f_n = 50 Hz, 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.

4.4.1.2 Function block

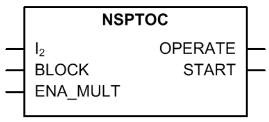


Figure 319: Function block

4.4.1.3 Functionality

The negative-sequence overcurrent protection function 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.

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 NSPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

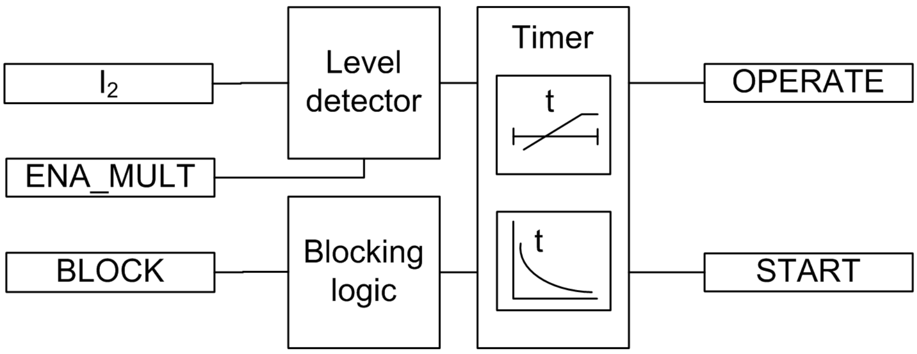


Figure 320: Functional module diagram

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 protection relay does not accept the *Start value* or *Start value Mult* setting if the product of the settings exceeds the *Start value* setting range.

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 *Chapter 11.2.1 IDMT curves for overcurrent protection* 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.4.1.5 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.

The most common application for the negative sequence overcurrent protection is probably rotating machines, where negative sequence current quantities indicate unbalanced loading conditions (unsymmetrical voltages). Unbalanced loading normally causes extensive heating of the machine and can result in severe damages even over a relatively short time period.

Multiple time curves and time multiplier settings are also available for coordinating with other devices in the system.

4.4.1.6 Signals

Table 539: NSPTOC Input signals

Name	Type	Default	Description
I_2	SIGNAL	0	Negative phase sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 540: NSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.1.7 Settings

Table 541: NSPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...5.00	xIn	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 in IEC/ANSI IDMT curves
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type

Table 542: NSPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 543: NSPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		1	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		1	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter D	0.46...30.00		1	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 544: NSPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time

4.4.1.8 Monitored data

Table 545: NSPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
NSPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.4.1.9 Technical data

Table 546: NSPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Start time ,		Minimum	Typical	Maximum
	I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	23 ms 15 ms	26 ms 18 ms	28 ms 20 ms
Reset time		Typically 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		

Table continues on the next page

[1] Negative sequence current before fault = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.

[2] Includes the delay of the signal output contact.

Characteristic	Value
Operate time accuracy in inverse time mode	±5.0% of the theoretical value or ±20 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

4.4.1.10 Technical revision history

Table 547: NSPTOC Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting
C	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting
D	Internal improvement
E	Internal Improvements

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

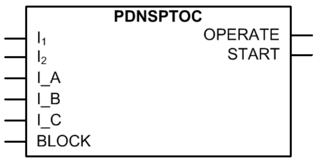


Figure 321: Function block

4.4.2.3 Functionality

The phase discontinuity protection function 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.

[3] Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20.

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 PDNSPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

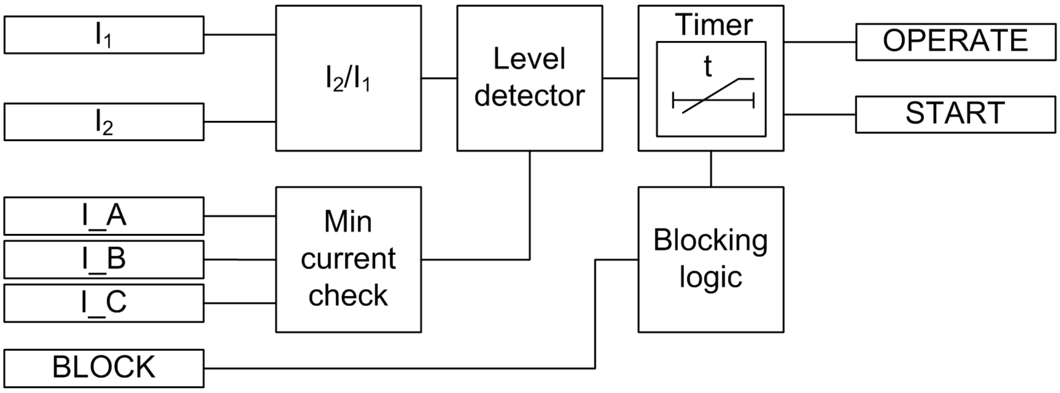


Figure 322: Functional module diagram

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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.4.2.5 Application

In three-phase distribution and subtransmission network applications the phase discontinuity in one phase can cause an 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 the positive-sequence and negative-sequence currents. This gives a better sensitivity and stability compared to plain negative-sequence current protection since the calculated ratio of positive-sequence and negative-sequence currents is relatively constant during load variations.

The unbalance of the network is detected by monitoring the negative-sequence 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 with the equation.

$$Iratio = \frac{I_2}{I_1}$$

(Equation 129)

Broken conductor fault situation can occur in phase A in a feeder.

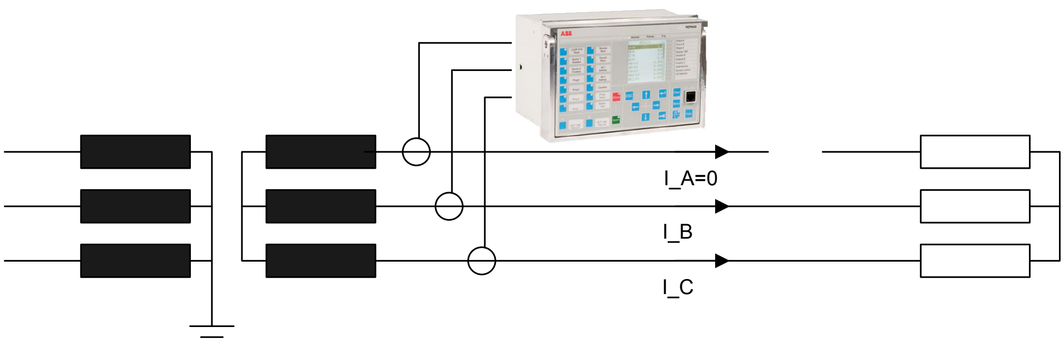


Figure 323: Broken conductor fault situation in phase A in a distribution or subtransmission feeder

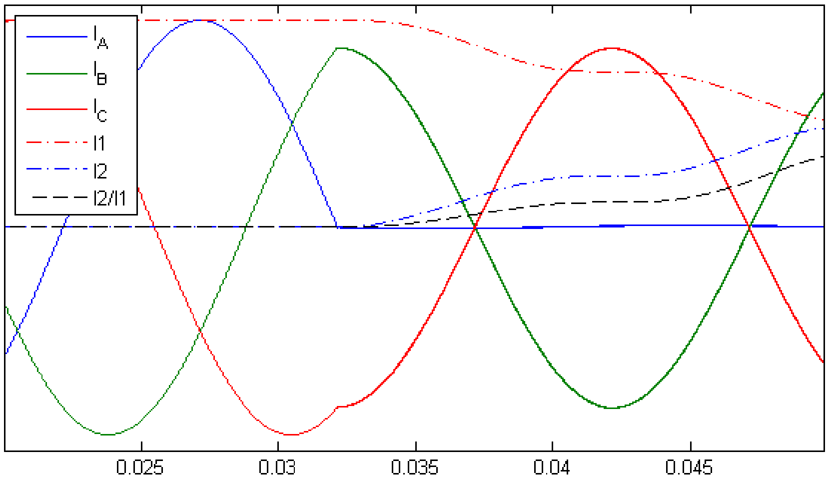


Figure 324: Three-phase current quantities during the broken conductor fault in phase A with the ratio of negative-sequence and positive-sequence currents

4.4.2.6 Signals

Table 548: PDNSPTOC Input signals

Name	Type	Default	Description
I_1	SIGNAL	0	Positive sequence current
I_2	SIGNAL	0	Negative sequence current
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 549: PDNSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.2.7 Settings

Table 550: PDNSPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	10...100	%	1	10	Start value
Operate delay time	100...30000	ms	1	100	Operate delay time

Table 551: PDNSPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 552: PDNSPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Min phase current	0.05...0.30	xIn	0.01	0.10	Minimum phase current

4.4.2.8 Monitored data

Table 553: PDNSPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
RATIO_I2_I1	FLOAT32	0.00...999.99	%	Measured current ratio I2 / I1
PDNSPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.4.2.9 Technical data

Table 554: PDNSPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±2% of the set value
Start time	<70 ms

Table continues on the next page

Characteristic	Value
Reset time	Typically 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,…

4.4.2.10 Technical revision history

Table 555: PDNSPTOC Technical revision history

Technical revision	Change
B	Internal improvement
C	Internal improvement
D	Internal improvement

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

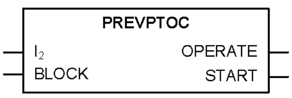


Figure 325: Function block

4.4.3.3 Functionality

The phase reversal protection function 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 start-up. 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.

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 PREVPTOC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

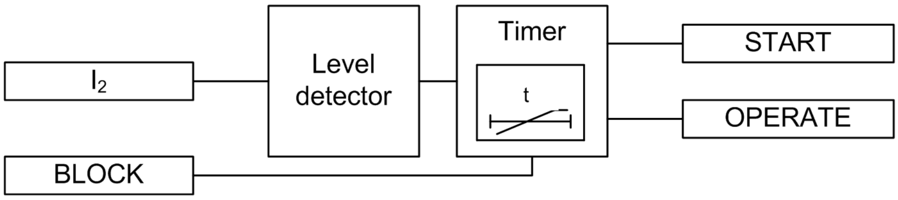


Figure 326: Functional module diagram

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.

4.4.3.5 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 operating signal that disconnects the motor from the supply.

4.4.3.6 Signals

Table 556: PREVPTOC Input signals

Name	Type	Default	Description
I_2	SIGNAL	0	Negative sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 557: PREVPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.3.7 Settings

Table 558: PREVPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.00	xIn	0.01	0.75	Start value
Operate delay time	100...60000	ms	10	100	Operate delay time

Table 559: PREVPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

4.4.3.8 Monitored data

Table 560: PREVPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PREVPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.4.3.9 Technical data

Table 561: PREVPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1, 2]	I_{Fault} = 2.0 × set *Start value*	Minimum	Typical	Maximum
		23 ms	25 ms	28 ms
Reset time		Typically 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,…		

4.4.3.10 Technical revision history

Table 562: PREVPTOC Technical revision history 46R Technical revision history

Technical revision	Change
B	Internal improvement

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>M	46M

4.4.4.2 Function block

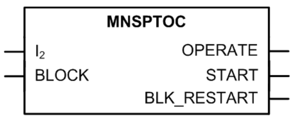


Figure 327: Function block

[1] Negative-sequence current before = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.
[2] Includes the delay of the signal output contact.

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.

The function contains a blocking functionality. It is possible to block the function outputs, timers or the function itself.

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 MNSPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

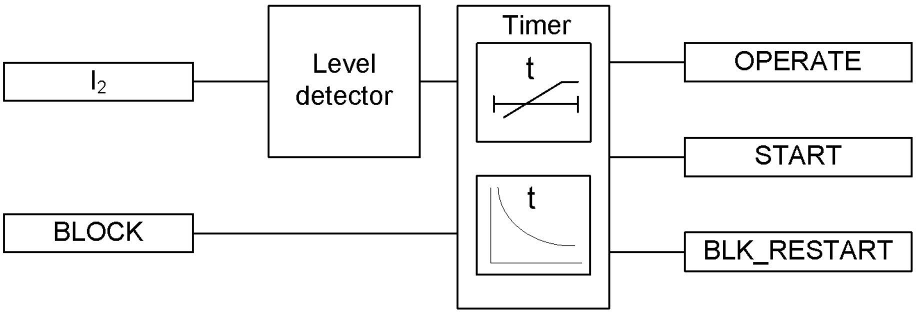


Figure 328: Functional module diagram

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. In case there is a mismatch between the used CT and the protected motor's nominal current values, it is possible to fit the IDMT curves for the protected motor using the *Current reference* setting.

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 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.

4.4.4.5 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 protection relay 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 130)

t[s]	Operate time in seconds
k	Set *Machine time Mult*
I_2	Negative-sequence current
I_r	Set *Rated current*

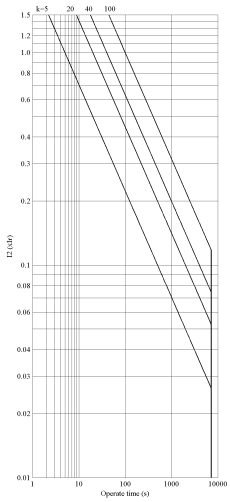


Figure 329: MNSPTOC Inverse Curve A

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 131)

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. 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. 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 132)

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*

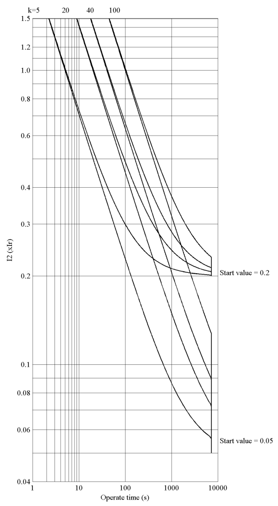


Figure 330: MNSPTOC Inverse Curve B

If the fault disappears, the negative-sequence current drops below the *Start value* setting and the START output is deactivated. The function does not reset instantaneously. Resetting depends on the equation or the *Cooling time* setting.

The timer is reset in two ways:

- When the negative sequence current drops 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.

4.4.4.6 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.

4.4.4.7 Signals

Table 563: MNSPTOC Input signals

Name	Type	Default	Description
I_2	SIGNAL	0	Negative sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 564: MNSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
BLK_RESTART	BOOLEAN	Overheated machine reconnection blocking

4.4.4.8 Settings

Table 565: MNSPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...0.50	xIn	0.01	0.20	Start value
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 17=Inv. Curve A 18=Inv. Curve B			15=IEC Def. Time	Selection of time delay curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Machine time Mult	5.0...100.0		0.1	5.0	Machine related time constant
Operate delay time	100...120000	ms	10	1000	Operate delay time

Table 566: MNSPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Maximum operate time	500000...7200000	ms	1000	1000000	Max operate time regardless of the inverse characteris-tic
Minimum operate time	100...120000	ms	1	100	Minimum operate time for IDMT curves
Cooling time	5...7200	s	1	50	Time required to cool the machine

Table 567: MNSPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Current reference	0.30...2.00	xIn	0.01	1.00	Rated current (Ir) of the machine (used only in the IDMT)
Reset delay time	0...60000	ms	1	20	Reset delay time

4.4.4.9 Monitored data

Table 568: MNSPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / op-erate time
T_ENARESTART	INT32	0...10000	s	Estimated time to reset of block restart
MNSPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.4.4.10 Technical data

Table 569: MNSPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1, 2]	I_{Fault} = 2.0 × set *Start value*	Minimum	Typical	Maximum

Table continues on the next page

[1] Negative-sequence current before = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.

Characteristic		Value		
		23	25 ms	28 ms
Reset time		Typically 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 ms [3]		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.4.4.11 Technical revision history

Table 570: MNSPTOC Technical revision history

Technical revision	Change
B	Internal improvement
C	Internal improvement

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

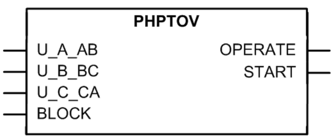


Figure 331: Function block

4.5.1.3 Functionality

The three-phase overvoltage protection function 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

2 Includes the delay of the signal output contact.
3 *Start value* multiples in range of 1.10...5.00.

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.

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.

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 PHPTOV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

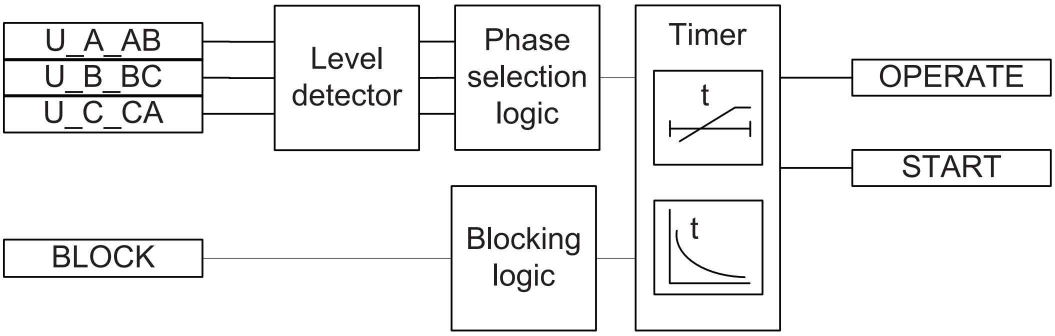


Figure 332: Functional module diagram

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 differs 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 *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. The *Curve Sat relative* setting is used for preventing undesired operation.

For a more detailed description of the IDMT curves and the use of the *Curve Sat Relative* setting, see *Chapter 11.3.1.3 IDMT curve saturation of overvoltage protection* in this manual.

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 match with the set *Num of start phases*, the phase selection logic activates 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 selected according to DT or IDMT.

For a detailed description of the voltage IDMT curves, see *Chapter 11.3.1 IDMT curves for overvoltage protection* in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value defined by the IDMT, the OPERATE output is activated.

When the user-programmable IDMT 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 operate delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected operate 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 operate 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 571: Reset time functionality when IDMT operation time curve selected

Reset functionality		Setting Type of reset curve	Setting Type of time reset	Setting 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”	Operate timer is reset after the set *Reset delay time* has elapsed
Linear decrease	Operation timer value linearly decreases during the drop-off situation	“Def time reset”	“Decrease Op timer”	Operate timer is reset after the set *Reset delay time* has elapsed

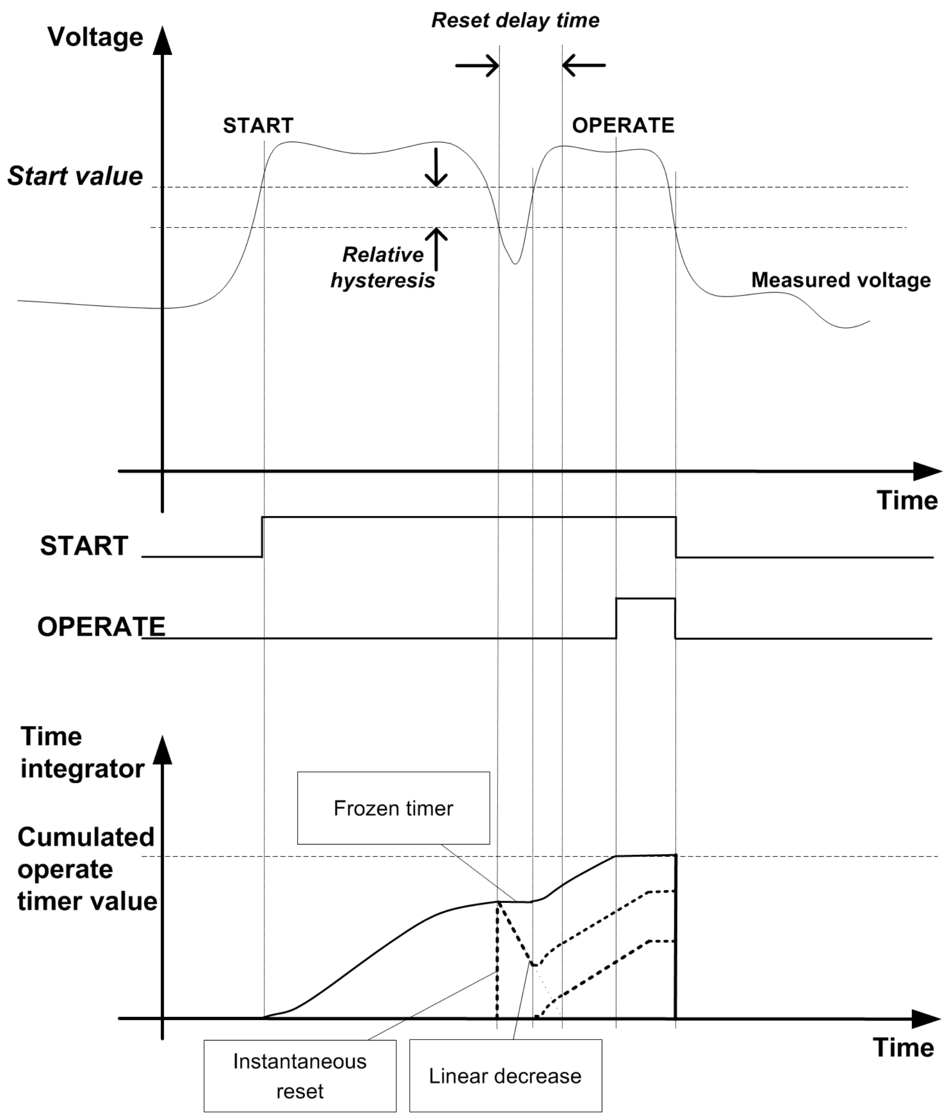


Figure 333: Behavior of different IDMT reset modes. Operate signal is based on settings Type of reset curve = "Def time reset" and Type of time reset= "Freeze Op timer". The effect of other reset modes is also presented

The *Time multiplier* setting is used for scaling the IDMT operate times.

The *Minimum operate time* setting parameter 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 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 *Chapter 11.3.1 IDMT curves for overvoltage protection* 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` input signal activation is preselected with the global *Blocking mode* setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the Timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

The “Freeze timers” mode of blocking has no effect during the inverse reset mode.

4.5.1.5 Timer characteristics

The operating curve types supported by PHPTOV are:

Table 572: Timer characteristics supported by IDMT operate curve types

Operating curve type
(5) ANSI Def. Time
(15) IEC Def. Time
(17) Inv. Curve A
(18) Inv. Curve B
(19) Inv. Curve C
(20) Programmable

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 relay's protection function is used to protect against power frequency overvoltages.

The power frequency overvoltage may occur in the network due to contingencies such as:

- The 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 inherent large voltage regulation of a typical alternator.
- Sudden loss of load due to the tripping of outgoing feeders, leaving the generator isolated or feeding a very small load. This causes a sudden rise in the terminal voltage due to the trapped field flux and overspeed.

If a load sensitive to overvoltage remains connected, it leads to equipment damage.

It is essential to provide power frequency overvoltage protection, in the form of time delayed element, either IDMT or DT to prevent equipment damage.

4.5.1.7 Signals

Table 573: PHPTOV Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 574: PHPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.1.8 Settings

Table 575: PHPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.60	xUn	0.01	1.10	Start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...300000	ms	10	40	Operate delay time
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 17=Inv. Curve A 18=Inv. Curve B 19=Inv. Curve C 20=Programmable			15=IEC Def. Time	Selection of time delay curve type

Table 576: PHPTOV Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate			1=Immediate	Selection of reset curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Def time reset				
Type of time reset	1=Freeze Op timer 2=Decrease Op timer			1=Freeze Op timer	Selection of time reset

Table 577: PHPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.005...200.000		1	1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00		1	1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0		1	0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000		1	0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000		1	1.000	Parameter E for customer programmable curve
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages

Table 578: PHPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	40...60000	ms	1	40	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve Sat Relative	0.0...10.0		0.1	0.0	Tuning parameter to avoid curve discontinuities
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.1.9 Monitored data

Table 579: PHPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHPTOV	Enum	1=on		Status

Name	Type	Values (Range)	Unit	Description
		2=blocked 3=test 4=test/blocked 5=off		

4.5.1.10 Technical data

Table 580: PHPTOV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time[1, 2]	U_{Fault} = 1.1 × set *Start value*	Minimum	Typical	Maximum
		23 ms	27 ms	31 ms
Reset time		Typically 40 ms		
Reset ratio		Depends on 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,…		

4.5.1.11 Technical revision history

Table 581: PHPTOV Technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.
C	Curve Sat relative max range widened from 3.0 to 10.0 % and default value changed from 2.0 to 0.0 %.
D	Added setting *Type of time reset*.

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, results based on statistical distribution of 1000 measurements

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

4.5.2 Single-phase overvoltage protection PHAPTOV

4.5.2.1 Identification

Function description	**IEC 61850 identification**	**IEC 60617 identification**	**ANSI/IEEE C37.2 device number**
Single-phase overvoltage protection, secondary side	PHAPTOV	U_A>	59_A

4.5.2.2 Function block

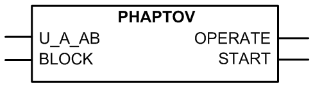


Figure 334: Function block

4.5.2.3 Functionality

The single-phase overvoltage protection function PHAPTOV 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.

PHAPTOV 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 PHAPTOV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

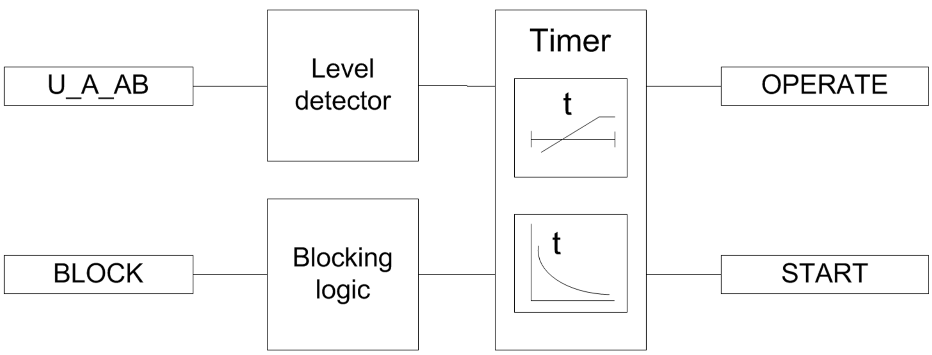


Figure 335: Functional module diagram

Level detector

The fundamental frequency component of the measured voltage is 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 activates the Timer. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly differs 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 *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. The *Curve Sat relative* setting is used for preventing undesired operation.

For a more detailed description of the IDMT curves and the use of the *Curve Sat Relative* setting, see the IDMT curve saturation of the overvoltage protection section in this manual.

Timer

Once activated, the Timer activates the START output. Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT.

For a detailed description of the voltage IDMT curves, see the IDMT curves for overvoltage protection 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 defined by the IDMT, the OPERATE output is activated.

When the user-programmable IDMT 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 operate 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 operate 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 582: Reset time functionality when IDMT operation time curve selected

Reset functionality		Setting Type of reset curve	Setting Type of time reset	Setting Reset delay time
Instantaneous reset	Operation timer is “Reset instan-	“Immediate”	Setting has no effect	Setting has no effect

Table continues on the next page

Reset functionality		Setting Type of reset curve	Setting Type of time reset	Setting Reset delay time
	taneously" when drop-off occurs			
Frozen timer	Operation timer is frozen during drop-off	"Def time reset"	"Freeze Op timer"	Operate timer is reset after the set *Reset delay time* has elapsed
Linear decrease	Operation timer value linearly decreases during the drop-off situation	"Def time reset"		

Example

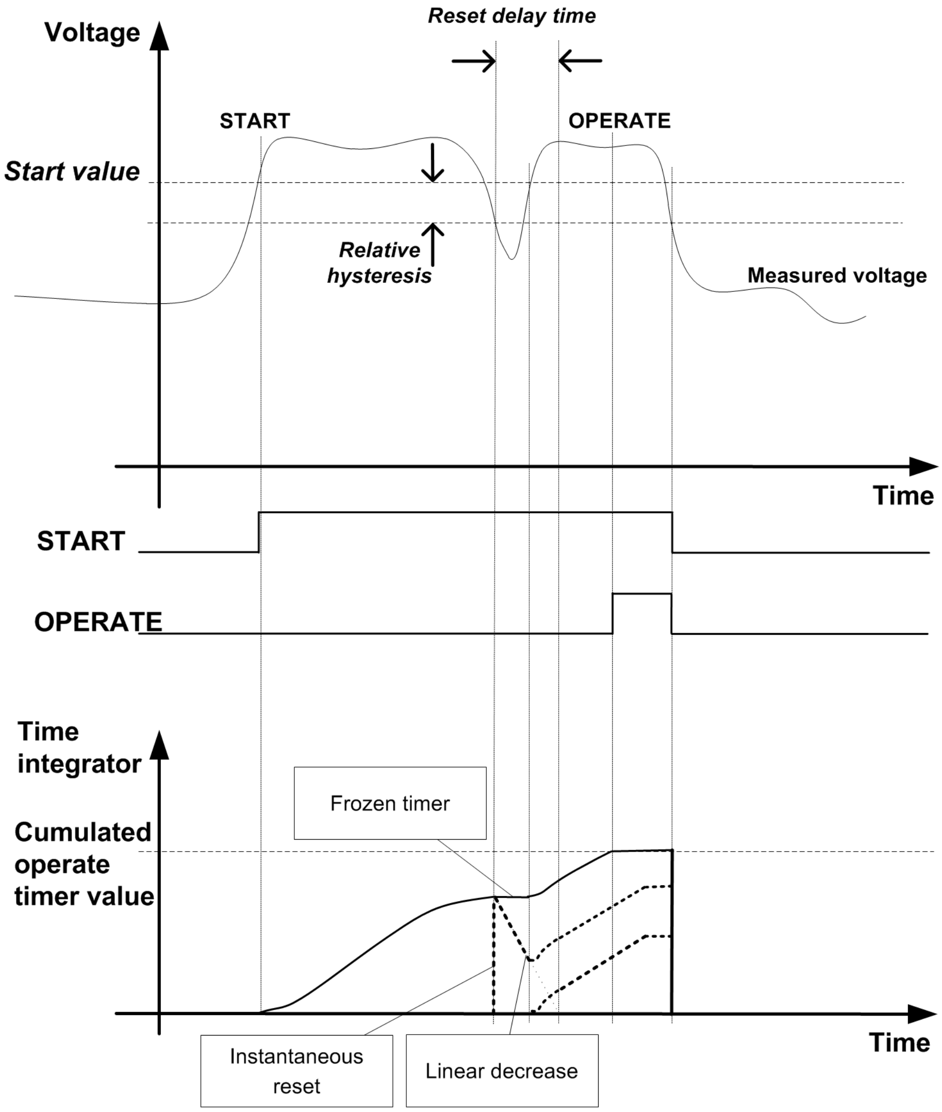


Figure 336: Behavior of different IDMT reset modes

Figure 336 shows the operate signal based on settings *Type of reset curve* = “Def time reset” and *Type of time reset* = “Freeze Op timer”. The effect of other reset modes is also presented.

The *Time multiplier* setting is used for scaling the IDMT operate times.

The *Minimum operate time* setting parameter 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 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCKinput can be controlled by a binary input, a horizontal communication input or an internal signal of the relay program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

The “Freeze timers” mode of blocking has no effect during the inverse reset mode.

4.5.2.5 Timer characteristics

PHAPTOV supports several operating curve types.

Table 583: Timer characteristics supported by IDMT operate curve types

Operating curve type
(5) ANSI Def. Time
(15) IEC Def. Time
(17) Inv. Curve A
(18) Inv. Curve B
(19) Inv. Curve C
(20) Programmable

4.5.2.6 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 relay protection function is used to protect against power frequency overvoltages.

The power frequency overvoltage may occur in the network due to contingencies such as:

- The 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.

If a load sensitive to overvoltage remains connected, it leads to equipment damage.

It is essential to provide power frequency overvoltage protection, in the form of time delayed element, either IDMT or DT to prevent equipment damage.

4.5.2.7 Signals

Table 584: PHAPTOV Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 585: PHAPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.2.8 Settings

Table 586: PHAPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.60	xUn	0.01	1.10	Start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operate delay time	40...300000	ms	10	40	Operate delay time
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 17=Inv. Curve A 18=Inv. Curve B 19=Inv. Curve C 20=Programmable			15=IEC Def. Time	Selection of time delay curve type

Table 587: PHAPTOV Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset			1=Immediate	Selection of reset curve type
Type of time reset	1=Freeze Op timer 2=Decrease Op timer			1=Freeze Op timer	Selection of time reset

Table 588: PHAPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.005...200.000		1	1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00		1	1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0		1	0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000		1	0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000		1	1.000	Parameter E for customer programmable curve
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages

Table 589: PHAPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	40...60000	ms	1	40	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve Sat Relative	0.0...3.0		0.1	2.0	Tuning parameter to avoid curve discontinuities
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.2.9 Monitored data

Table 590: PHAPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHAPTOV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.2.10 Technical data

Table 591: PHAPTOV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time ,	U_{Fault} = 1.1 × set *Start value*	Minimum	Typical	Maximum
		25 ms	28 ms	32 ms
Reset time		Typically 40 ms		
Reset ratio		Depends on 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		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.5.3 Three-phase undervoltage protection PHPTUV

4.5.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase undervoltage protection	PHPTUV	3U<	27

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, results based on statistical distribution of 1000 measurements

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

4.5.3.2 Function block

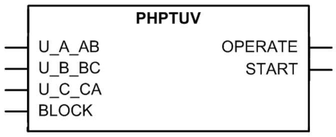


Figure 337: Function block

4.5.3.3 Functionality

The three-phase undervoltage protection function 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.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

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 PHPTUV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

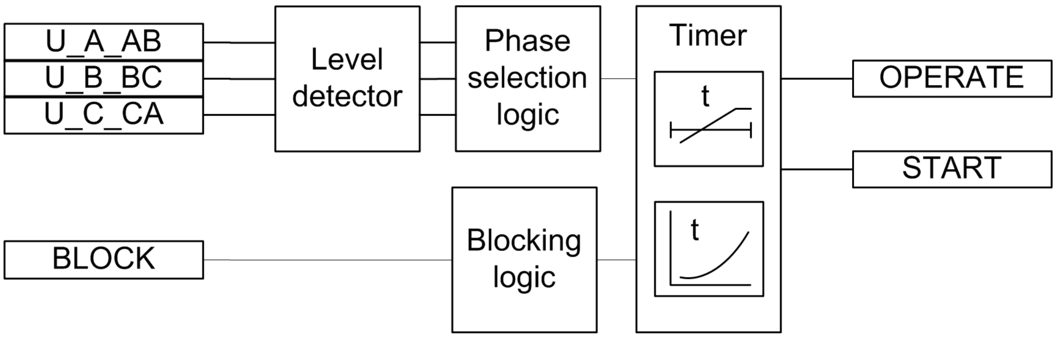


Figure 338: Functional module diagram

Level detector

The fundamental frequency component of the measured three phase voltages are compared phase-wise to the set *Start value*. 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 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 back to the hysteresis area.

The *Voltage selection* setting is used for selecting the phase-to-earth or phase-to-phase voltages for protection.

For the voltage IDMT mode of operation, the used IDMT curve equations contain discontinuity characteristics. The *Curve Sat relative* setting is used for preventing unwanted operation.

For more detailed description on IDMT curves and usage of *Curve Sat Relative* setting, see *Chapter 11.3.2 IDMT curves for undervoltage protection* in this manual.

The level detector contains a low-level blocking functionality for cases where one of the measured voltages 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 "True") and the blocking level can be set with the *Voltage block value* setting.

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 match with the set *Num of start phases*, the phase selection logic activates 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 selected according to DT or IDMT.

For a detailed description of the voltage IDMT curves, see *Chapter 11.3.2 IDMT curves for undervoltage protection* in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value defined by the IDMT, the OPERATE output is activated.

When the user-programmable IDMT 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 operate delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected operate 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 operate 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 592: Reset time functionality when IDMT operation time curve selected

Reset functionality		Setting Type of reset curve	Setting Type of time reset	Setting Reset delay time
Instantaneous reset	Operation timer is “Reset instan-	“Immediate”	Setting has no effect	Setting has no effect

Table continues on the next page

Reset functionality		Setting Type of reset curve	Setting Type of time reset	Setting Reset delay time
	taneously" when drop-off occurs			
Frozen timer	Operation timer is frozen during drop-off	"Def time reset"	"Freeze Op tim-er"	Operate timer is reset after the set *Reset delay time* has elapsed
Linear decrease	Operation timer value linearly de-creases during the drop-off sit-uation	"Def time reset"	"Decrease Op timer"	Operate timer is reset after the set *Reset delay time* has elapsed

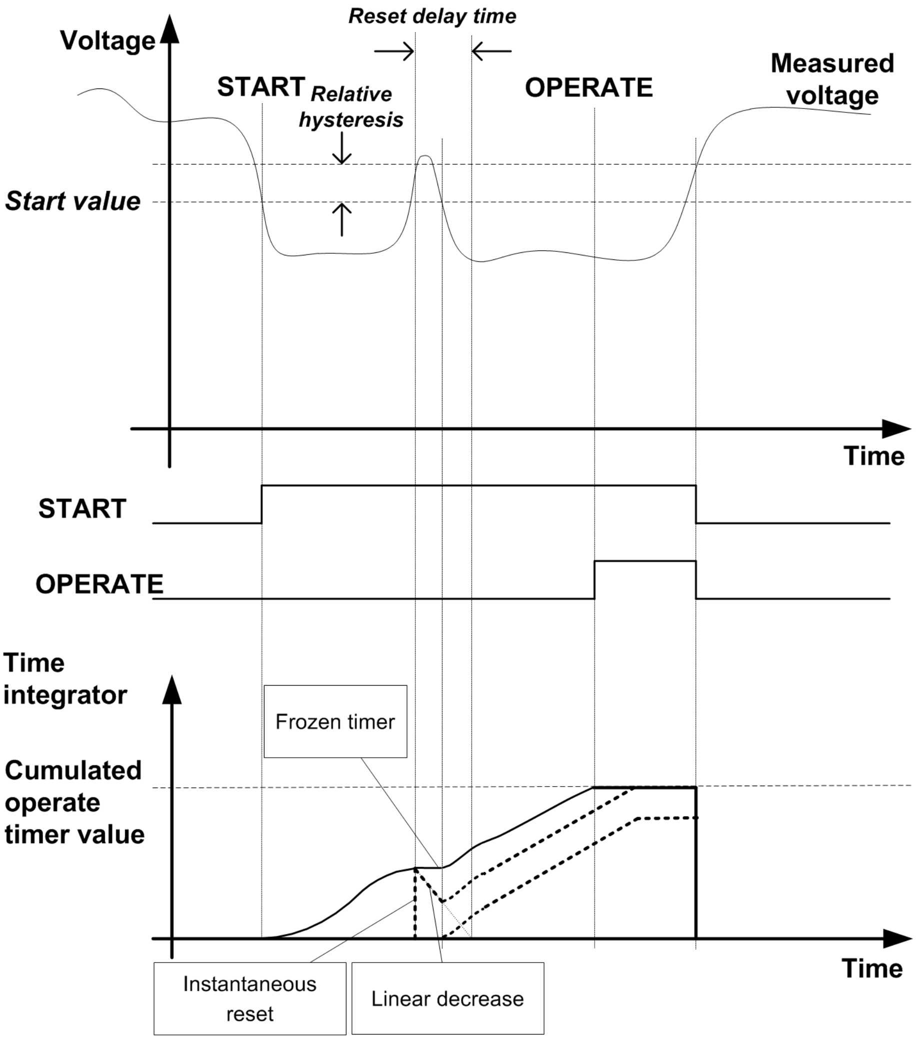


Figure 339: Behavior of different IDMT reset modes. Operate signal is based on settings Type of reset curve = "Def time reset" and Type of time reset= "Freeze Op timer". The effect of other reset modes is also presented

The *Time multiplier* setting is used for scaling the IDMT operate times.

The *Minimum operate time* setting parameter 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 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 *Chapter 11.3.2 IDMT curves for undervoltage protection* 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK input signal activation is preselected with the global *Blocking mode* setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the Timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

The “Freeze timers” mode of blocking has no effect during the “Inverse reset” mode.

4.5.3.5 Timer characteristics

The operating curve types supported by PHPTUV are:

Table 593: Supported IDMT operate curve types

Operating curve type
(5) ANSI Def. Time
(15) IEC Def. Time
(21) Inv. Curve A
(22) Inv. Curve B
(23) Programmable

4.5.3.6 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:

- Malfunctioning of a voltage regulator or incorrect settings under manual control (symmetrical voltage decrease)
- Overload (symmetrical voltage decrease)
- Short circuits, often as phase-to-earth faults (unsymmetrical voltage increase).

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.

4.5.3.7 Signals

Table 594: PHPTUV Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 595: PHPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.3.8 Settings

Table 596: PHPTUV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.20	xUn	0.01	0.90	Start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	60...300000	ms	10	60	Operate delay time
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 21=Inv. Curve A			15=IEC Def. Time	Selection of time delay curve type

Parameter	Values (Range)	Unit	Step	Default	Description
	22=Inv. Curve B 23=Programmable				

Table 597: PHPTUV Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset			1=Immediate	Selection of reset curve type
Type of time reset	1=Freeze Op timer 2=Decrease Op timer			1=Freeze Op timer	Selection of time reset

Table 598: PHPTUV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.005...200.000		1	1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00		1	1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0		1	0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000		1	0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000		1	1.000	Parameter E for customer programmable curve
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages

Table 599: PHPTUV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	60...60000	ms	1	60	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve Sat Relative	0.0...10.0		0.1	0.0	Tuning parameter to avoid curve discontinuities
Voltage block value	0.05...1.00	xUn	0.01	0.20	Low level blocking for undervoltage mode
Enable block value	0=False 1=True			1=True	Enable internal blocking
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.3.9 Monitored data

Table 600: PHPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHPTUV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.3.10 Technical data

Table 601: PHPTUV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the voltage measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time [1],[2]	U_{Fault} = 0.9 × set *Start value*	Minimum	Typical	Maximum
		62 ms	66 ms	70 ms
Reset time		Typically 40 ms		
Reset ratio		Depends on 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,…		

4.5.3.11 Technical revision history

Table 602: PHPTUV Technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.
C	Curve Sat relative max range widened from 3.0 to 10.0 % and default value changed from 2.0 to 0.0 %.
D	Added setting *Type of time reset*.

[1] *Start value* = 1.0 × U_n, Voltage before fault = 1.1 × U_n, f_n = 50 Hz, undervoltage in one phase-to-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] Minimum *Start value* = 0.50, *Start value* multiples in range of 0.90...0.20

4.5.4 Single-phase undervoltage protection PHAPTUV

4.5.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Single-phase undervoltage protection, secondary side	PHAPTUV	U_A<	27_A

4.5.4.2 Function block

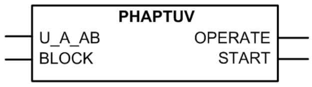


Figure 340: Function block

4.5.4.3 Functionality

The single-phase undervoltage protection function PHAPTUV is used to disconnect damaged devices from the network. These can be, for example, electric motors which are damaged when subjected to service under low voltage conditions.

The function contains a blocking functionality. It is possible to block function outputs, timers 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 PHAPTUV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

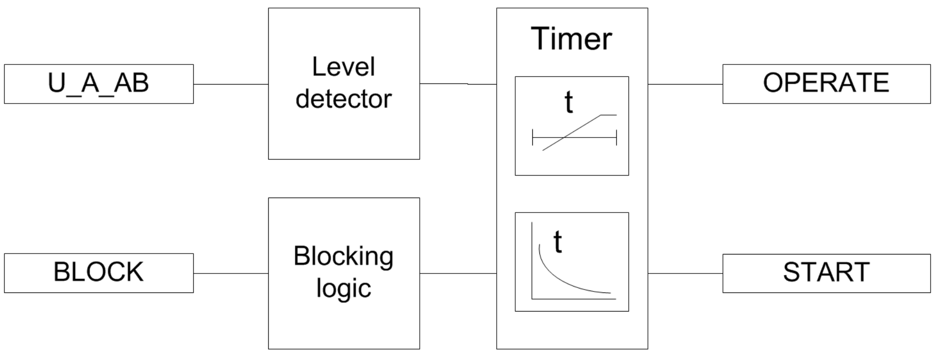


Figure 341: Functional module diagram

Level detector

The fundamental frequency component of the measured single-phase voltage is 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 Llevel detector activates the Timer module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies 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.

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. The *Curve Sat relative* setting is used for preventing unwanted operation.

For more detailed description on IDMT curves and usage of *Curve Sat Relative* setting, see the IDMT curves for undervoltage protection section in this manual.

The Level detector contains a low-level blocking functionality for cases where one of the measured voltages is below the desired level. This feature can be used when wanting to avoid unnecessary starts and operates during, for example, an autoreclose sequence. The low-level blocking is activated by default (Enable block value is set to "True") and the blocking level can be set with the *Voltage block value* setting.

Timer

Once activated, the Timer activates the `START` output. Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT.

For a detailed description of the voltage IDMT curves, see the IDMT curves for undervoltage protection 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 defined by the IDMT, the `OPERATE` output is activated.

When the user-programmable IDMT 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 operate 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 603: Reset time functionality when IDMT operation time curve selected

Reset functionality		Setting Type of reset curve	Setting Type of time reset	Setting 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”	Operate timer is reset after the set *Reset delay time* has elapsed
Linear decrease	Operation timer value linearly decreases during the drop-off situation	“Def time reset”	“Decrease Op timer”	Operate timer is reset after the set *Reset delay time* has elapsed

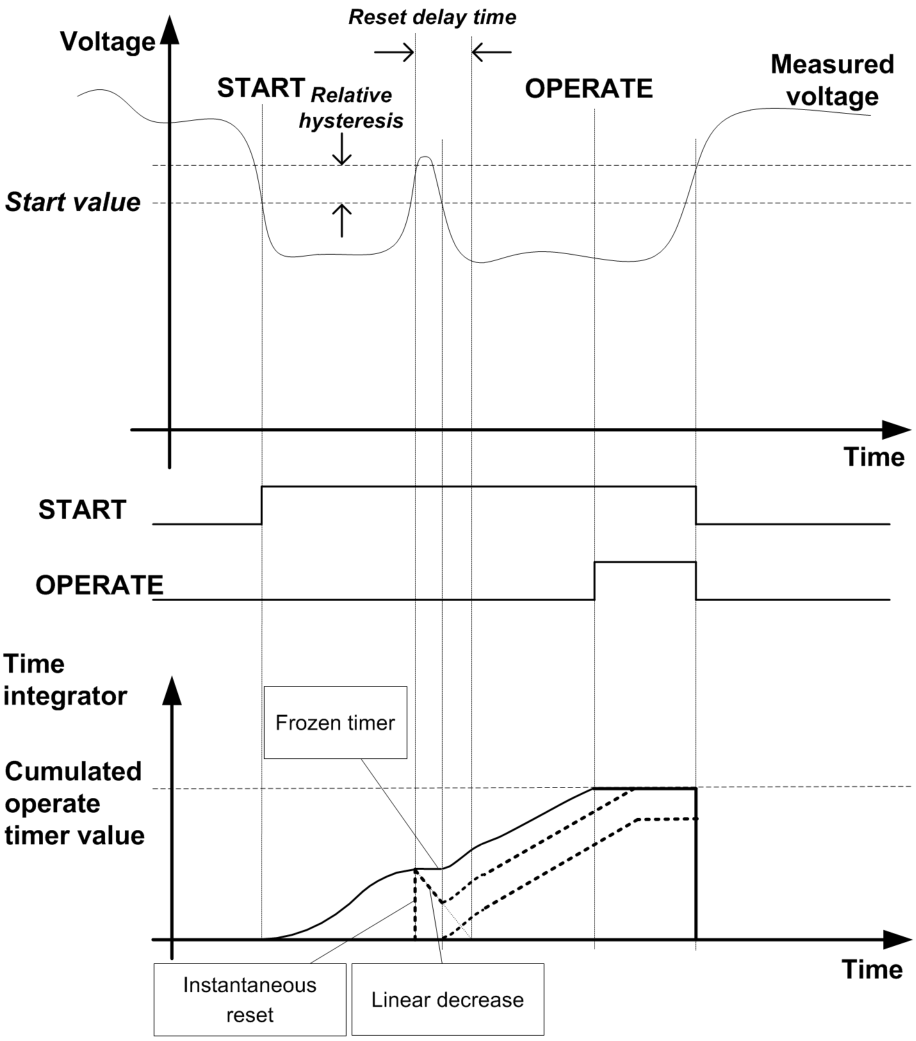


Figure 342: Behavior of different IDMT reset modes

Figure 342 shows the operate signal based on settings Type of reset curve = “Def time reset” and Type of time reset= “Freeze Op timer”. The effect of other reset modes is also presented.

The *Time multiplier* setting is used for scaling the IDMT operate times.

The *Minimum operate time* setting parameter 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 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 operate time. The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the relay program. The influence of the BLOCK input signal activation is preselected with the global *Blocking mode* setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

The “Freeze timers” mode of blocking has no effect during the Inverse reset mode.

4.5.4.5 Timer characteristics

PHAPTUV supports several operating curve types.

Table 604: Timer characteristics supported by IDMT operate curve types

Operating curve type
(5) ANSI Def. Time
(15) IEC Def. Time
(21) Inv. Curve A
(22) Inv. Curve B
(23) Programmable

4.5.4.6 Application

PHAPTUV detects low voltage conditions in power system elements, such as generators, transformers, motors and power lines. Low voltage conditions are caused by abnormal operation or a fault in the power system. PHAPTUV 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. PHAPTUV 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.

PHAPTUV can be used to disconnect damaged devices from the network. These are, for example, 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 the following issues.

- Malfunctioning of a voltage regulator or incorrect settings under manual control (symmetrical voltage decrease)
- Overload (symmetrical voltage decrease)
- Short circuits, often as phase-to-earth faults (unsymmetrical voltage increase).

PHAPTUV prevents sensitive equipment from running under conditions that could cause overheating and thus shorten their life time expectancy. In many cases, PHAPTUV is a useful function in circuits for local or remote automation processes in the power system.

4.5.4.7 Signals

Table 605: PHAPTUV Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 606: PHAPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.4.8 Settings

Table 607: PHAPTUV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.20	xUn	0.01	0.90	Start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	60...300000	ms	10	60	Operate delay time
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 21=Inv. Curve A 22=Inv. Curve B			15=IEC Def. Time	Selection of time delay curve type

Parameter	Values (Range)	Unit	Step	Default	Description
	23=Programmable				

Table 608: PHAPTUV Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset			1=Immediate	Selection of reset curve type
Type of time reset	1=Freeze Op timer 2=Decrease Op tim-er			1=Freeze Op timer	Selection of time reset

Table 609: PHAPTUV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.005...200.000		1	1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00		1	1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0		1	0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000		1	0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000		1	1.000	Parameter E for customer programmable curve
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages

Table 610: PHAPTUV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	60...60000	ms	1	60	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve Sat Relative	0.0...3.0		0.1	2.0	Tuning parameter to avoid curve discontinuities
Voltage block value	0.05...1.00	xUn	0.01	0.20	Low level blocking for undervoltage mode
Enable block value	0=False 1=True			1=True	Enable internal blocking
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.4.9 Monitored data

Table 611: PHAPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHAPTUV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.4.10 Technical data

Table 612: PHAPTUV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the voltage measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time ,	U_{Fault} = 0.9 × set *Start value*	Minimum	Typical	Maximum
		64 ms	68 ms	71 ms
Reset time		Typically 40 ms		
Reset ratio		Depends on 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		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.5.5 Residual overvoltage protection ROVPTOV

4.5.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual overvoltage protection	ROVPTOV	Uo>	59G

1 *Start value* = 1.0 × U_n, Voltage before fault = 1.1 × U_n, f_n = 50 Hz, undervoltage in one phase-to-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 Minimum *Start value* = 0.50, *Start value* multiples in range of 0.90...0.20

4.5.5.2 Function block

Figure 343: Function block

4.5.5.3 Functionality

The residual overvoltage protection function 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.

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 ROVPTOV can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

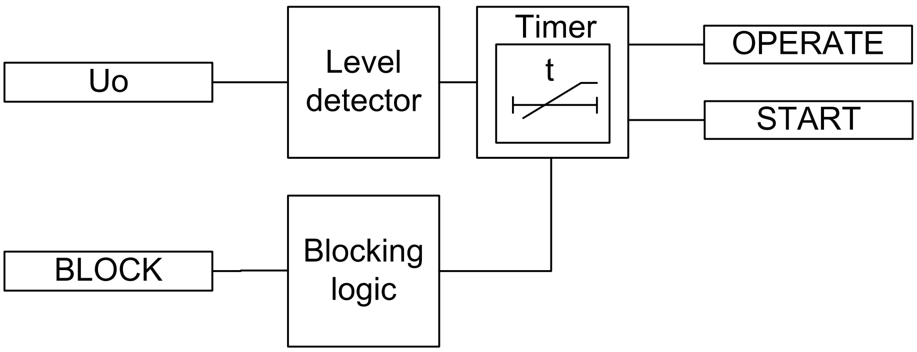


Figure 344: Functional module diagram

Level detector

The residual voltage is compared to the set *Start value*. If the value exceeds the set *Start value*, the level detector sends an enable signal to the timer. The residual voltage can be selected with the *Uo signal Sel* setting. The options are "Measured Uo" and "Calculated Uo". If "Measured Uo" is selected, the voltage ratio for Uo-channel is given in the global setting **Configuration** > **Analog inputs** > **Voltage (Uo,VT)**. If "Calculated Uo" is selected, the voltage ratio is obtained from phase-voltage channels given in the global setting **Configuration** > **Analog inputs** > **Voltage (3U,VT)**.

Example 1: Uo is measured from the open-delta connected VTs (20/sqrt(3) kV : 100/sqrt(3) V : 100/3 V). In this case, "Measured Uo" is selected. The nominal values for residual voltage is obtained from the VT ratios entered in Residual voltage Uo:

Configuration > **Analog inputs** > **Voltage (Uo,VT)**: 11.547 kV:100 V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 11.547 kV = 11.547 kV in the primary.

Example 2: Uo is calculated from the phase quantities. The phase VT-ratio is 20/ sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated Uo" is selected. The nominal value for residual voltage is obtained from the VT ratios entered in Residual voltage Uo: **Configuration** > **Analog inputs** > **Voltage (3U,VT)**: 20.000kV : 100V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 20.000 kV = 20.000 kV in the primary.

If "Calculated Uo" is selected, the nominal value of residual voltage is always phase-to-phase voltage. Thus, the valid maximum setting for residual voltage *Start value* is 0.577 × Un. The calculated Uo requires that all three phase-to-earth voltages are connected to the protection relay. Uo cannot be calculated from the phase-to-phase voltages.

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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.5.5.5 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.

4.5.5.6 Signals

Table 613: ROVPTOV Input signals

Name	Type	Default	Description
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 614: ROVPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.5.7 Settings

Table 615: ROVPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...1.000	xUn	0.001	0.030	Residual overvolt-age start value
Operate delay time	40...300000	ms	1	40	Operate delay time

Table 616: ROVPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Uo signal Sel	1=Measured Uo 2=Calculated Uo			1=Measured Uo	Selection for used Uo signal

Table 617: ROVPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.5.5.8 Monitored data

Table 618: ROVPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
ROVPTOV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.5.9 Technical data

Table 619: ROVPTOV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time[1, 2]	U_{Fault} = 2 × set *Start value*	Minimum	Typical	Maximum
		48 ms	51 ms	54 ms
Reset time		Typically 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,…		

4.5.5.10 Technical revision history

Table 620: ROVPTOV Technical revision history

Technical revision	Change
B	Added a setting parameter for the "Measured Uo" or "Calculated Uo" selection
C	Internal improvement
D	Internal improvement

1 Residual voltage before fault = 0.0 × U_n, f_n = 50 Hz, residual voltage 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

4.5.6 Negative-sequence overvoltage protection NSPTOV

4.5.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overvoltage protection	NSPTOV	U2>	47O-

4.5.6.2 Function block

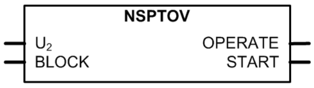


Figure 345: Function block

4.5.6.3 Functionality

The negative-sequence overvoltage protection function 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.

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 NSPTOV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

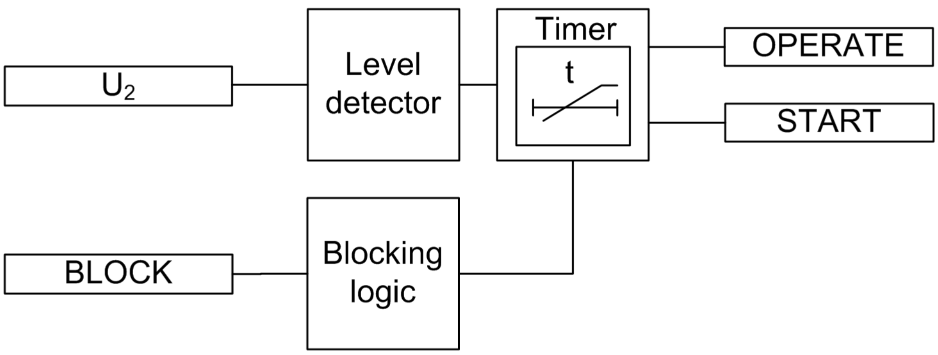


Figure 346: Functional module diagram

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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.5.6.5 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.

4.5.6.6 Signals

Table 621: NSPTOV Input signals

Name	Type	Default	Description
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 622: NSPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.6.7 Settings

Table 623: NSPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...1.000	xUn	0.001	0.030	Start value
Operate delay time	40...120000	ms	1	40	Operate delay time

Table 624: NSPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 625: NSPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.5.6.8 Monitored data

Table 626: NSPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
NSPTOV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.6.9 Technical data

Table 627: NSPTOV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the voltage measured: f_n		
		±1.5% of the set value or ±0.002 × U_n		
Start time[1, 2]		Minimum	Typical	Maximum
	U_{Fault} = 1.1 × set *Start value*	33 ms	35 ms	37 ms
	U_{Fault} = 2.0 × set *Start value*	24 ms	26 ms	28 ms
Reset time		Typically 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,…		

4.5.6.10 Technical revision history

Table 628: 47 Technical revision history

Technical revision	Change
B	Internal change
C	Internal improvement.
D	Internal improvement.

1 Negative-sequence voltage before fault = 0.0 × U_n, f_n = 50 Hz, negative-sequence overvoltage 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

4.5.7 Positive-sequence undervoltage protection PSPTUV

4.5.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Positive-sequence undervoltage protection	PSPTUV	U1<	47U+

4.5.7.2 Function block

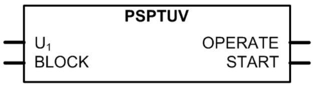


Figure 347: Function block

4.5.7.3 Functionality

The positive-sequence undervoltage protection function 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.

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 PSPTUV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

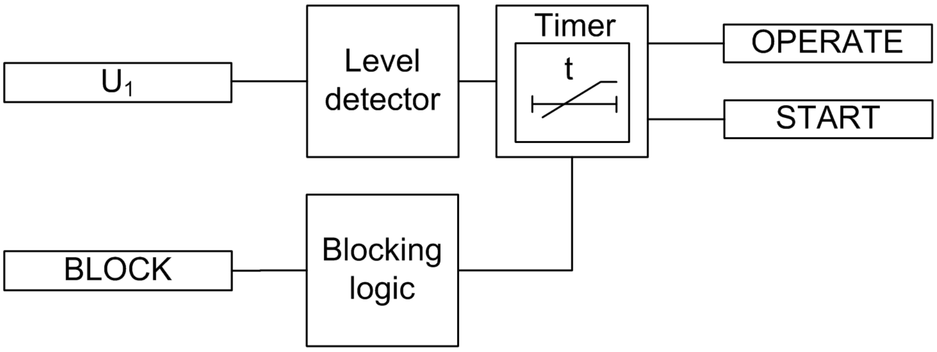


Figure 348: Functional module diagram. U1 is used for representing positive phase sequence voltage.

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.

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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

4.5.7.5 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.

4.5.7.6 Signals

Table 629: PSPTUV Input signals

Name	Type	Default	Description
U_1	SIGNAL	0	Positive phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 630: PSPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.7.7 Settings

Table 631: PSPTUV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...1.200	xUn	0.001	0.500	Start value
Operate delay time	40...120000	ms	10	40	Operate delay time

Table 632: PSPTUV Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage block value	0.01...1.00	xUn	0.01	0.20	Internal blocking level
Enable block value	0=False 1=True			1=True	Enable Internal Blocking

Table 633: PSPTUV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 634: PSPTUV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.7.8 Monitored data

Table 635: PSPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PSPTUV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.7.9 Technical data

Table 636: PSPTUV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time [1, 2]		Minimum	Typical	Maximum
	U_{Fault} = 0.99 × set *Start value*	52 ms	55 ms	58 ms
	U_{Fault} = 0.9 × set *Start value*	44 ms	47 ms	50 ms
Reset time		Typically 40 ms		
Reset ratio		Depends on the set *Relative hysteresis*		
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,…		

4.5.7.10 Technical revision history

Table 637: PSPTUV Technical revision history

Technical revision	Change
B	-
C	Internal improvement
D	Internal improvement

4.5.8 Overexcitation protection OEPVPH

4.5.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Overexcitation protection	OEPVPH	U/f>	24

1 *Start value* = 1.0 × U_n, positive-sequence voltage before fault = 1.1 × U_n, f_n = 50 Hz, positive sequence undervoltage 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

4.5.8.2 Function block

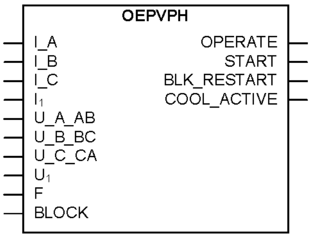


Figure 349: Function block

4.5.8.3 Functionality

The overexcitation protection function OEPVPH is used to protect 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.

4.5.8.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of OEPVPH can be described using a module diagram. All the modules in the diagram are explained in the next sections.

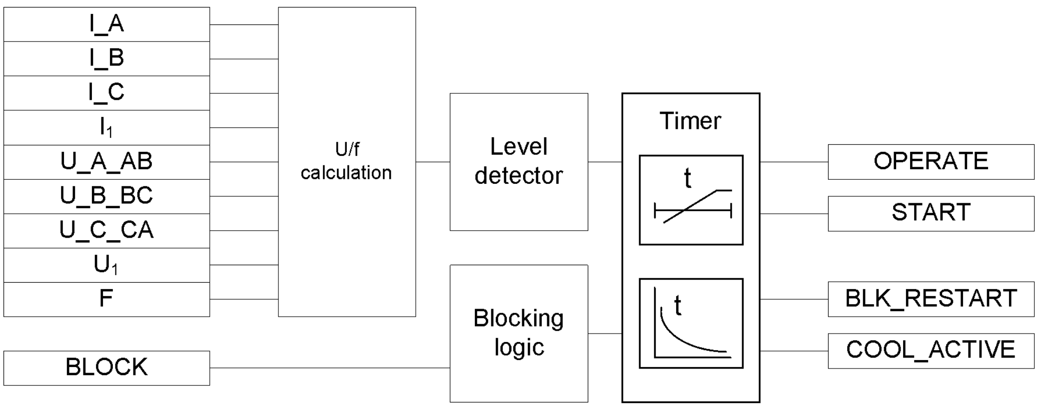


Figure 350: Functional module diagram

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 (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 used 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 638: Voltages and currents used for induced voltage (emf) 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	$\overline{E} = \sqrt{3}\cdot\left(\overline{U_1} + \overline{I_1}\cdot(j\cdot X_{leak})\right)$

If all three phase or phase-to-phase voltages and phase currents are fed to the protection relay, 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, then by setting the leakage reactance value to zero the calculated induced voltage (E) is 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 *Voltage Max Cont* 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:

[1] Voltages, currents and the leakage reactance X_{leak} in the calculations are given in volts, amps and ohms.

$$M = \frac{\frac{E}{f_m}}{\frac{U_n}{f_n} \cdot \frac{Volt\ Max\ continuous}{100}}$$

(Equation 133)

M	excitation level (U/f ratio or volts/hertz) in pu
E	internal induced voltage (emf)
f_m	measured frequency
U_n	nominal phase-to-phase voltage
f_n	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. This means that the function is blocked from starting and operating during a low-frequency condition.

The calculated excitation level (U/f ratio or volts/hertz) VOLTPERHZ is available in the Monitored data view.

Level detector

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 Timer.

Timer

Once activated, 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 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 *Chapter 4.5.8.5 Timer characteristics* .

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 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 T_ENARESTART output indicates in seconds the duration for which the BLK_RESTART output still remains active. The value is available in the Monitored data view.

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.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.5.8.5 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.

When START becomes active, the reset time is based on the following equation.

$$reset\ time = \left(\frac{START\_DUR}{100} \right) \cdot Cooling\ time$$

(Equation 134)

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 351*. 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.

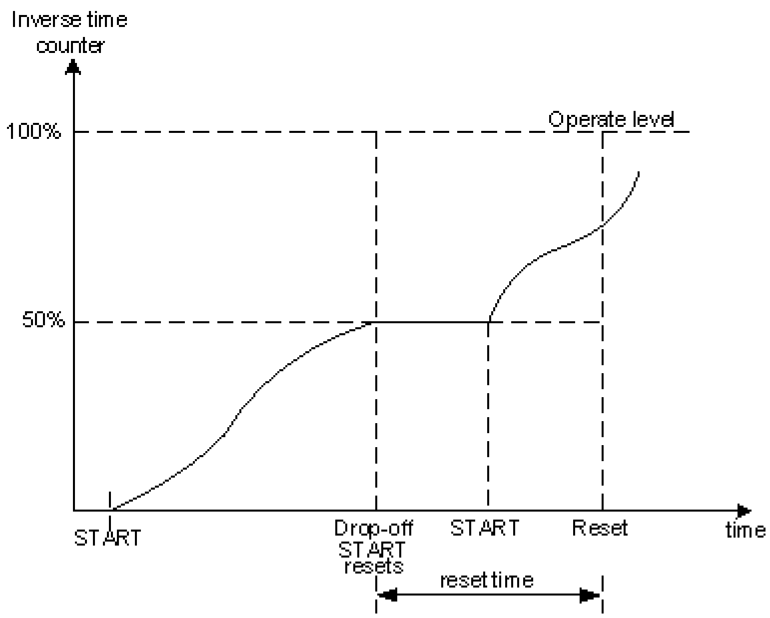


Figure 351: An example of a delayed reset in the inverse time characteristics. When the start becomes active during the reset period, the operate time counter continues from the level corresponding to the drop-off (reset time = 0.50 · Cooling time)

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 135)

t(s)	Operate time in seconds
M	Excitation level (U/f ratio or volts/hertz) in pu
k	*Time multiplier* setting

The constant "60" in *Equation 135* converts time from minutes to seconds.

Table 639: 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

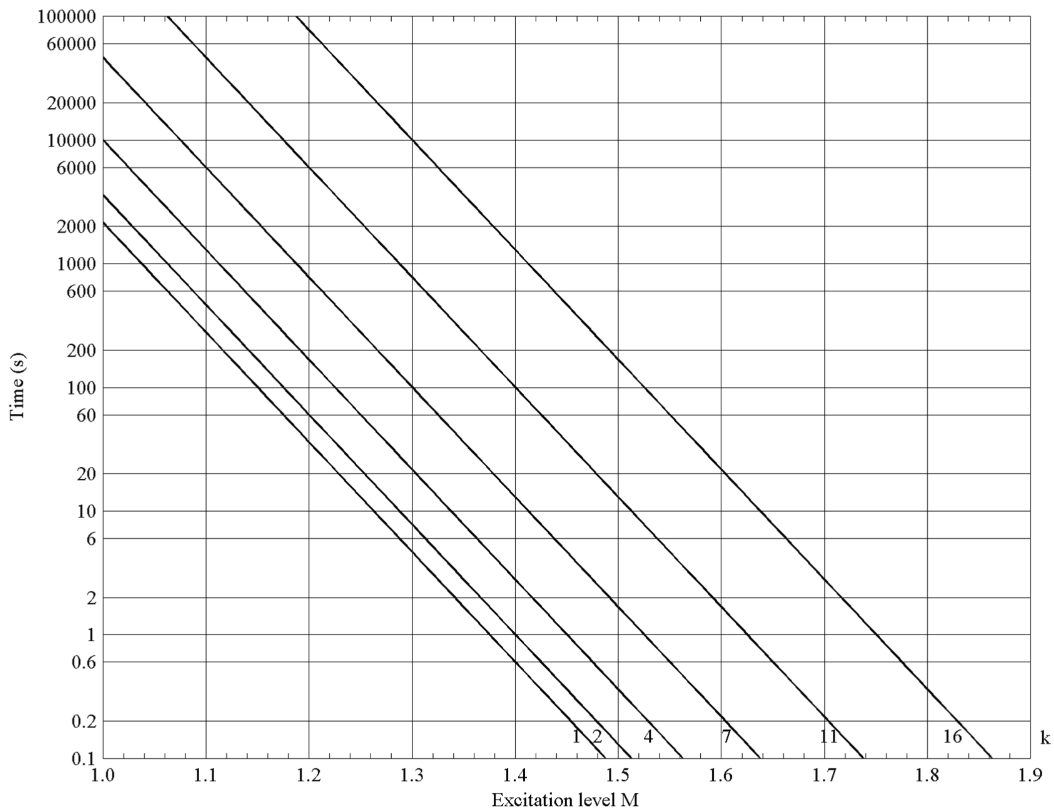


Figure 352: Operating time curves for the overexcitation IDMT curve ("OvExt IDMT Crv1") for parameters a = 2.5, b = 115.0 and c = 4.886

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 136)

t(s)	Operate time in seconds
d	*Constant delay* setting in milliseconds
M	Excitation value (U/f ratio or volts/hertz) in pu
k	*Time multiplier* setting

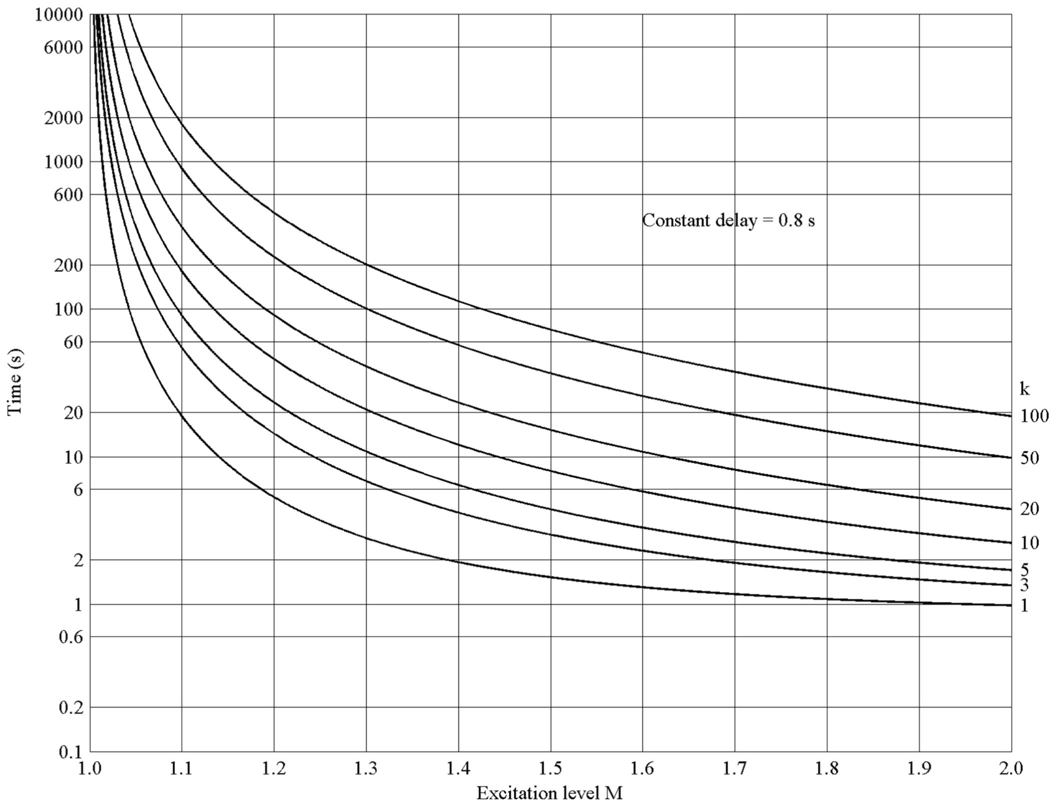


Figure 353: Operating time curves for the overexcitation IDMT curve 4 ("OvExt IDMT Crv4") for different values of the Time multiplier setting when the Constant delay is 800 milliseconds

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 *Restart Ena 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 137)

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 354. This compensates for the heating effect and makes the overall operate time shorter.

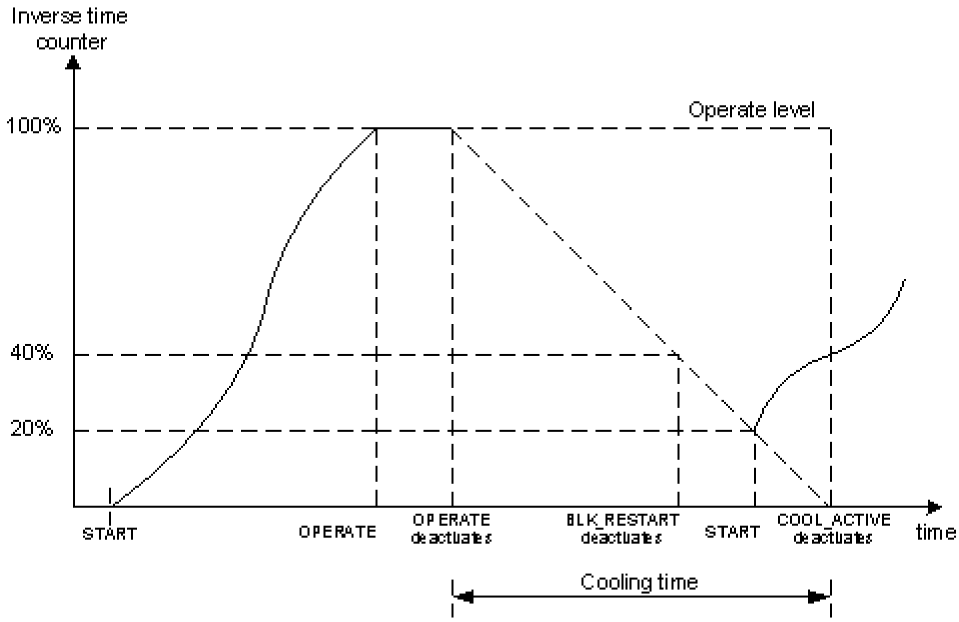


Figure 354: Example of an inverse time counter operation if START occurs when BLK_RESTART is inactive while COOL_ACTIVE is active. The Restart Ena level setting is considered to be 40 percent.

4.5.8.6 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 start-up 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 equipment.

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. 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 of the healthy two phases to earth but no overexcitation on any winding. The phase-to-phase voltages remain essentially unchanged. An important 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 *Voltage Max Cont*	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.

$$X_{leak\Omega} = X_{leakPU} \cdot \left(U_n \middle/ \left(I_n \cdot \sqrt{3} \right) \right) = 0.2 \cdot \left(11000 \middle/ \left(7455 \cdot \sqrt{3} \right) \right) = 0.170378\ Ohms$$

(Equation 138)

The internal induced voltage E of the machine is calculated.

$$\overline{E} = \overline{U_{AB}} + (\overline{I_A} - \overline{I_B}) \cdot (jX_{leak})$$

(Equation 139)

E = 11500∠0°+ (5600∠-63.57°- 5600∠176.42°) · (0.170378∠90°) = 12490 V

The excitation level M of the machine is calculated.

$$Excitation\,level\,M = \frac{12490/49.98}{11000/50 \cdot 1.00} = 1.1359$$

(Equation 140)

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 *Voltage Max Cont* is recommended.

If the *Voltage Max Cont* setting is 105 percent, the excitation level M of the machine is calculated with the equation.

$$Excitation\,level\,M = \frac{12490/49.98}{11000/50 \cdot 1.05} = 1.0818$$

(Equation 141)

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%, *Voltage Max Cont* = 100%, *Time multiplier* = 4, *Maximum operate time* = 1000000 milliseconds and *Minimum operate time* = 1000 milliseconds.

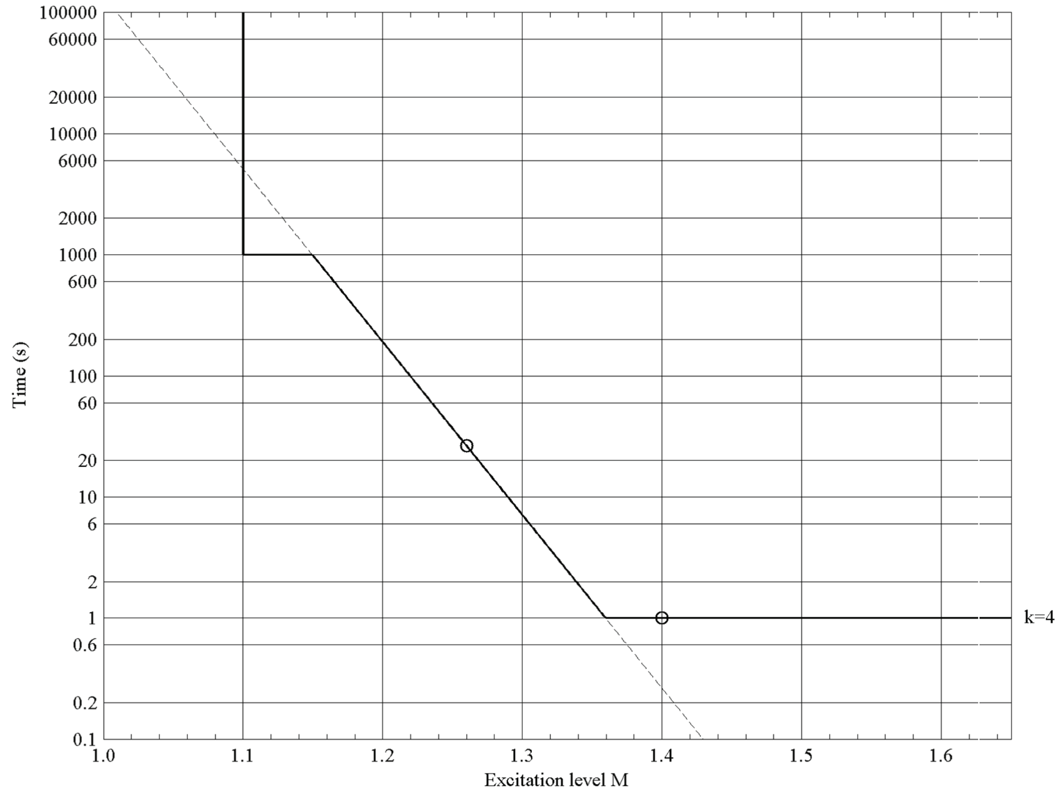


Figure 355: Operating curve of "OvExt IDMT Crv2" based on the settings specified in example 3. The two dots marked on the curve are referred to in the text.

If the excitation level stays at 1.26, the operation occurs after 26360 milliseconds as per the marked dot in *Figure 355*. For the excitation level of 1.4, the second dot in *Figure 355*, the curve "OvExt IDMT Crv2" gives 260 milliseconds as per Equation, but the *Minimum operate time* setting limits the operate time to 1000 milliseconds. The *Maximum operate time* setting limits the operate time to 1000000 milliseconds 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%, *Voltage Max Cont* = 100%, *Time multiplier* = 5, *Maximum operate time* = 3600000 milliseconds and *Constant delay* = 800 milliseconds.

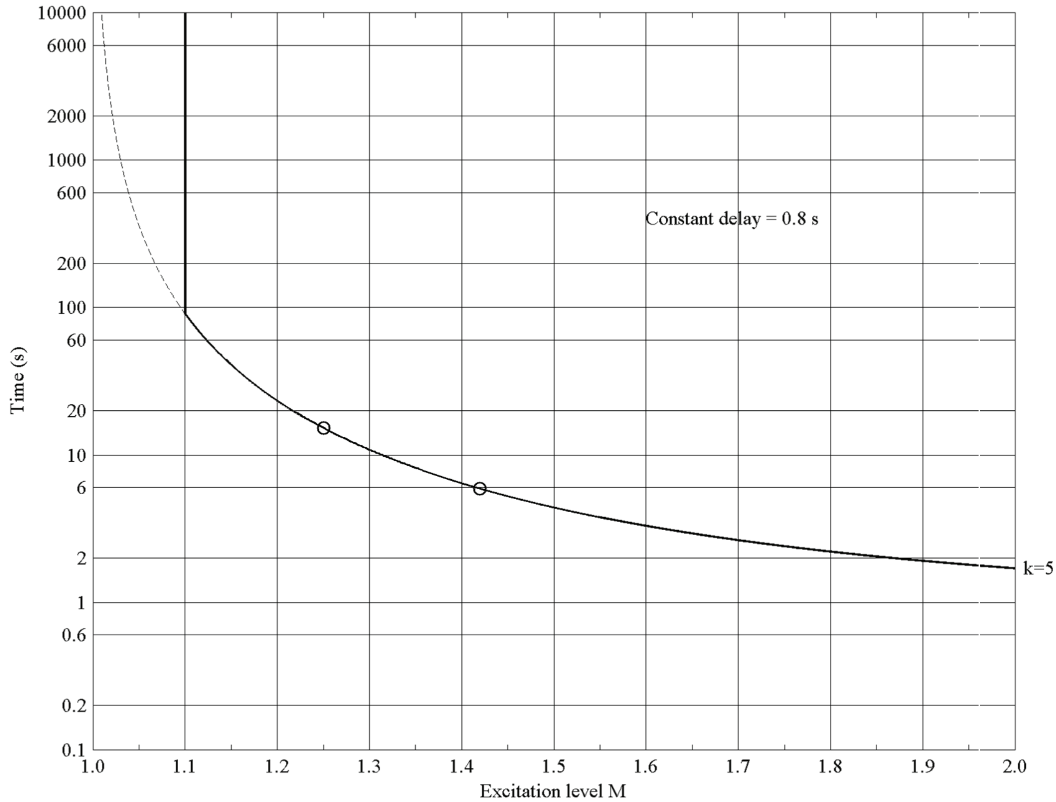


Figure 356: Operating curve of "OvExt IDMT Crv4" based on the specified settings. The two dots marked on the curve are referred to in the text.

If the excitation level stays at 1.25, the operation occurs after 15200 milliseconds. At the excitation level of 1.42, the time to operation would be 5900 milliseconds as per the two dots in *Figure 356*. In this case, the setting *Maximum operate time* 3600000 milliseconds does not limit the maximum operate time because the operate time at Start value = 110% (1.1 pu) is approximately 75000 milliseconds.

4.5.8.7 Signals

Table 640: OEPVPH Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_1	SIGNAL	0	Positive-phase sequence current
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB

Table continues on the next page

Name	Type	Default	Description
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
U_1	SIGNAL	0	Positive-phase sequence voltage
F	SIGNAL	0	Measured frequency
BLOCK	BOOLEAN	0=False	Block signal

Table 641: 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

4.5.8.8 Settings

Table 642: OEPVPH Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	100...200	%	1	100	Over excitation start value
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 17=OvExt IDMT Crv1 18=OvExt IDMT Crv2 19=OvExt IDMT Crv3 20=OvExt IDMT Crv4			15=IEC Def. Time	Selection of time delay curve type
Time multiplier	0.1...100.0		0.1	3.0	Time multiplier for Overexcitation IDMT curves
Operate delay time	200...200000	ms	10	500	Operate delay time in definite- time mode

Table 643: OEPVPH Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Mode Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Cooling time	5...10000	s	1	600	Time required to cool the machine
Constant delay	100...120000	ms	10	800	Parameter constant delay
Maximum operate time	500000...10000000	ms	10	1000000	Maximum operate time for IDMT curves
Voltage selection	1=phase-to-earth 2=phase-to-phase 3=pos sequence			3=pos sequence	Selection of phase / phase-to-phase / pos sequence voltages
Phase selection	1=A or AB 2=B or BC 3=C or CA			1=A or AB	Parameter for phase selection
Leakage React	0.0...50.0	%	0.1	0.0	Leakage reactance of the machine
Voltage Max Cont	80...160	%	1	110	Maximum allowed continuous operating voltage ratio

Table 644: OEPVPH Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	100	Resetting time of the operate time counter in DT mode
Minimum operate time	200...60000	ms	10	200	Minimum operate time for IDMT curves

4.5.8.9 Monitored data

Table 645: OEPVPH Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time (in %)
T_ENARESTART	INT32	0...10000	s	Estimated time to reset of block restart
VOLTPERHZ	FLOAT32	0.00...10.00	pu	Excitation level, i.e U/f ratio or Volts/Hertz
OEPVPH	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.8.10 Technical data

Table 646: OEPVPH Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±2.5% of the set value or 0.01 × Ub/f
Start time ,	Frequency change: Typically 200 ms (±20 ms)
	Voltage change: 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

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	LVRTPTUV	U<RT	27RT

4.5.9.2 Function block

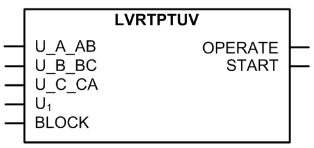


Figure 357: Function block

4.5.9.3 Functionality

The low-voltage ride-through protection function 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

[1] Results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

national grid codes. The LVRT curve can be defined accurately according to the requirements by setting the appropriate time-voltage coordinates.

The function contains a blocking functionality. LVRTPTUV can be blocked with the BLOCK input. Blocking resets timers and outputs.

4.5.9.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LVRTPTUV is described using a module diagram. All modules in the diagram are explained in the next sections.

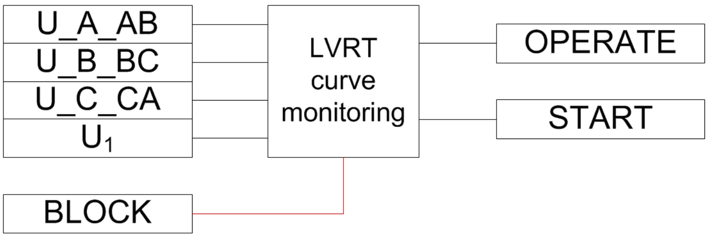


Figure 358: Functional module diagram

LVRT curve monitoring

LVRT curve monitoring starts with detection of undervoltage. Undervoltage 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*. 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.

The setting options available for *Num of start phases* are “Exactly 1 of 3”, "Exactly 2 of 3", and “Exactly 3 of 3”, which are different from conventional setting options available in other functions. For example, *Num of start phases* is set to "Exactly 2 of 3", any two voltages should drop below *Voltage start value* within one cycle network for the START output to activate. Even if more than two voltages drop below *Voltage start value*, START output is not activated.

When the *Voltage selection* setting is “Positive Seq”, the positive-sequence component is compared with the set *Voltage start value*. If it is lower than the set *Voltage start value*, 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 359* and *Figure 360* with corresponding settings in *Table 647*.

It is necessary to set the coordinate points correctly in order to avoid maloperation. 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.

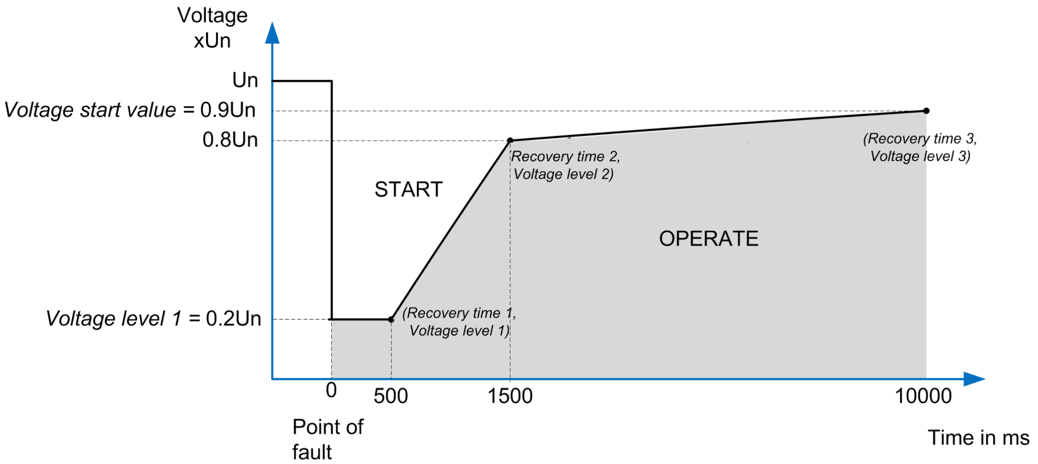


Figure 359: Low voltage ride through example curve A

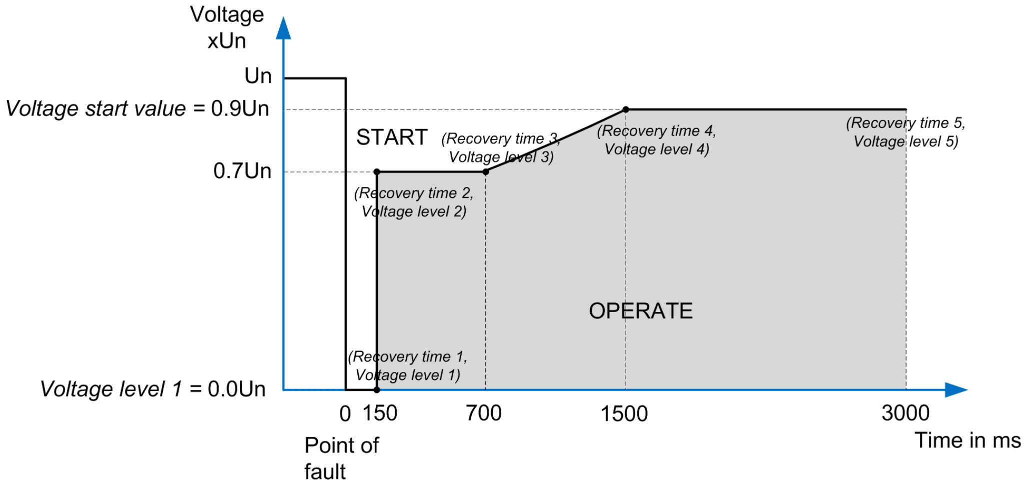


Figure 360: Low voltage ride through example curve B

Table 647: 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
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 is set greater than or equal to *Voltage start value*. Settings are not accepted if the last active *Voltage level X* setting is not set greater than or equal to *Voltage start value*.

Figure 361 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.

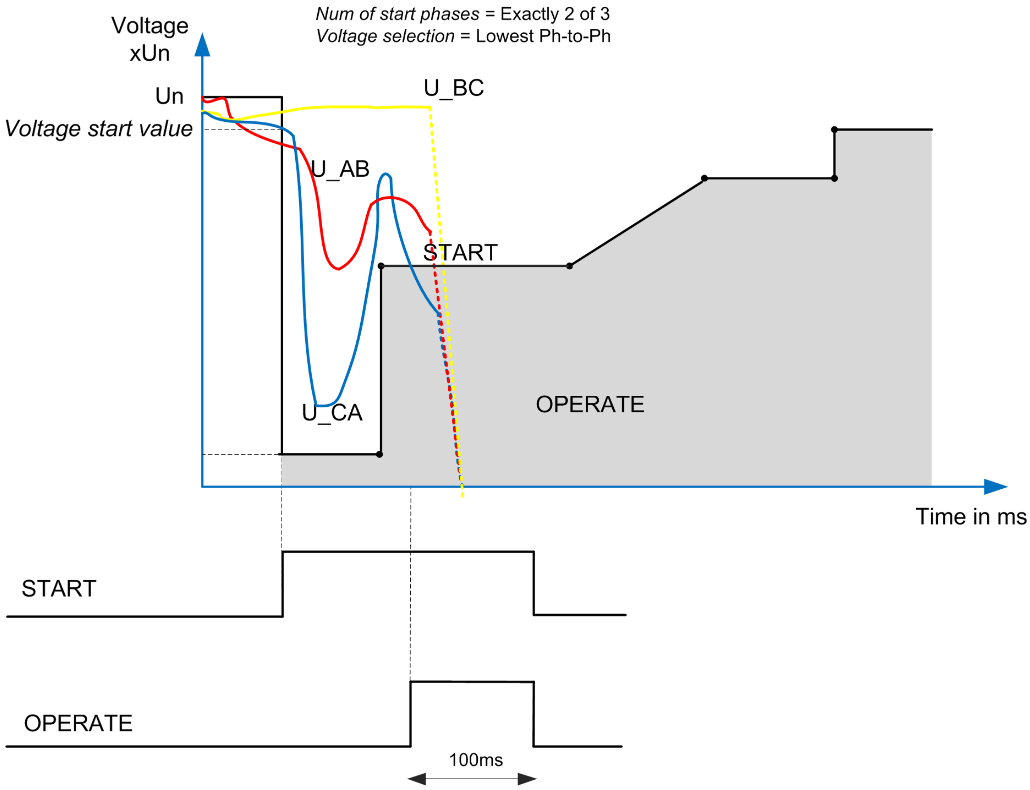


Figure 361: Typical example of operation of LVRTPTUV function

Activation of the BLOCK input resets the timers and deactivates the function outputs.

4.5.9.5 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 grids, and due to their large size may influence the behavior of the grid. These farms are now required to comply with stringent grid connection requirement, which was previously mandatory only for high capacity power plants. These requirements include helping grid in maintaining system stability, reactive power support, transient recovery and voltage-frequency regulation. These requirements make it 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 known as Low-Voltage Ride-Through (LVRT) or Fault-Ride-Through (FRT) and are described by a voltage versus time characteristics.

Typical LVRT behavior 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*.

The 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.

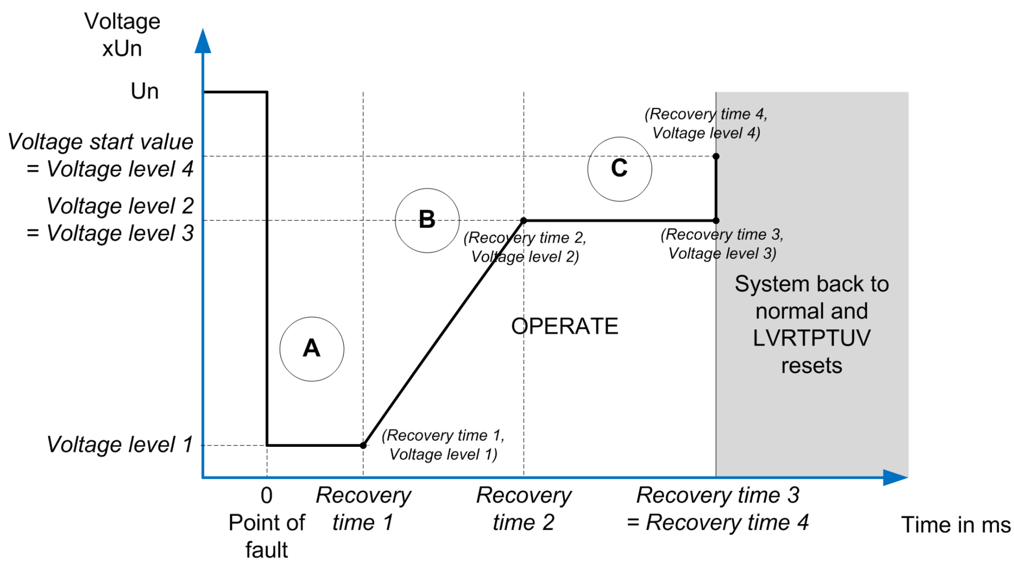


Figure 362: A typical required ride-through voltage capability of generating unit

The LVRT requirement depends on the power system characteristics and the protection employed, varying significantly from each other. The 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.

4.5.9.6 Signals

Table 648: LVRTPTUV Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_A_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC

Table continues on the next page

Name	Type	Default	Description
U_A_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
U_1	SIGNAL	0	Positive phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 649: LVRTPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.9.7 Settings

Table 650: LVRTPTUV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.05...1.20	xUn	0.01	0.90	Voltage value below which function starts

Table 651: LVRTPTUV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	4=Exactly 1 of 3 5=Exactly 2 of 3 6=Exactly 3 of 3			4=Exactly 1 of 3	Number of faulty phases
Voltage selection	1=Highest Ph-to-E 2=Lowest Ph-to-E 3=Highest Ph-to-Ph 4=Lowest Ph-to-Ph 5=Positive Seq			4=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	xUn	0.01	0.20	1st voltage coordinate for defining LVRT curve
Voltage level 2	0.00...1.20	xUn	0.01	0.80	2nd voltage coordinate for defining LVRT curve
Voltage level 3	0.00...1.20	xUn	0.01	0.90	3rd voltage coordinate for defining LVRT curve
Voltage level 4	0.00...1.20	xUn	0.01	0.90	4th voltage coordinate for defining LVRT curve

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage level 5	0.00...1.20	xUn	0.01	0.90	5th voltage coordinate for defining LVRT curve
Voltage level 6	0.00...1.20	xUn	0.01	0.90	6th voltage coordinate for defining LVRT curve
Voltage level 7	0.00...1.20	xUn	0.01	0.90	7th voltage coordinate for defining LVRT curve
Voltage level 8	0.00...1.20	xUn	0.01	0.90	8th voltage coordinate for defining LVRT curve
Voltage level 9	0.00...1.20	xUn	0.01	0.90	9th voltage coordinate for defining LVRT curve
Voltage level 10	0.00...1.20	xUn	0.01	0.90	10th voltage coordinate for defining LVRT curve
Recovery time 1	0...300000	ms	1	500	1st time coordinate for defining LVRT curve
Recovery time 2	0...300000	ms	1	1000	2nd time coordinate for defining LVRT curve
Recovery time 3	0...300000	ms	1	10000	3rd time coordinate for defining LVRT curve
Recovery time 4	0...300000	ms	1	10000	4th time coordinate for defining LVRT curve
Recovery time 5	0...300000	ms	1	10000	5th time coordinate for defining LVRT curve
Recovery time 6	0...300000	ms	1	10000	6th time coordinate for defining LVRT curve
Recovery time 7	0...300000	ms	1	10000	7th time coordinate for defining LVRT curve
Recovery time 8	0...300000	ms	1	10000	8th time coordinate for defining LVRT curve
Recovery time 9	0...300000	ms	1	10000	9th time coordinate for defining LVRT curve
Recovery time 10	0...300000	ms	1	10000	10th time coordinate for defining LVRT curve

4.5.9.8 Monitored data

Table 652: LVRTPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
LVRTPTUV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.9.9 Technical data

Table 653: LVRTPTUV Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × U_n
Start time [1, 2]	Typically 40 ms
Reset time	Based on maximum value of *Recovery time* setting
Operate time accuracy	±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,…

4.5.10 Voltage vector shift protection VVSPPAM

4.5.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage vector shift protection	VVSPPAM	VS	78V

4.5.10.2 Function block

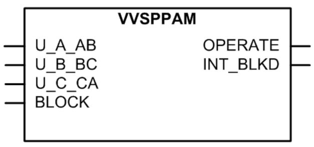


Figure 363: Function block

4.5.10.3 Functionality

The voltage vector shift protection function VVSPPAM, also known as 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 an instantaneous trip when the shift in voltage vector exceeds the set value.

The function can be blocked with BLOCK input. Blocking resets timers and outputs.

[1] Tested for *Number of Start phases* = 1 out of 3, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

4.5.10.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”.

The operation of VVSPPAM can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

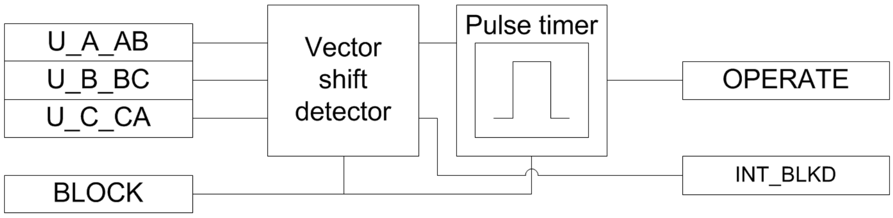


Figure 364: Functional module diagram

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, considered as reference. When the mains is lost, a sudden change is seen in the cycle length, 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 *Figure 365*.

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 detecting vector shift. The available *Phase supervision* options are “All” and “Pos sequence”. If the calculated value of Δδ exceeds the set *Start value* setting for all the defined phases, the module sends an enabling 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 voltage.

The recommended and the default value for *Phase supervision* is “Pos sequence”.

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 phase-to-earth or phase-to-phase voltages, USHIFT_A_AB, USHIFT_B_BC and USHIFT_C_CA or positive sequence voltage U1SHIFT, which resulted in the activation of last OPERATE output, are available in the Monitored data view.

The activation of BLOCK input deactivates the INT_BLKD output.

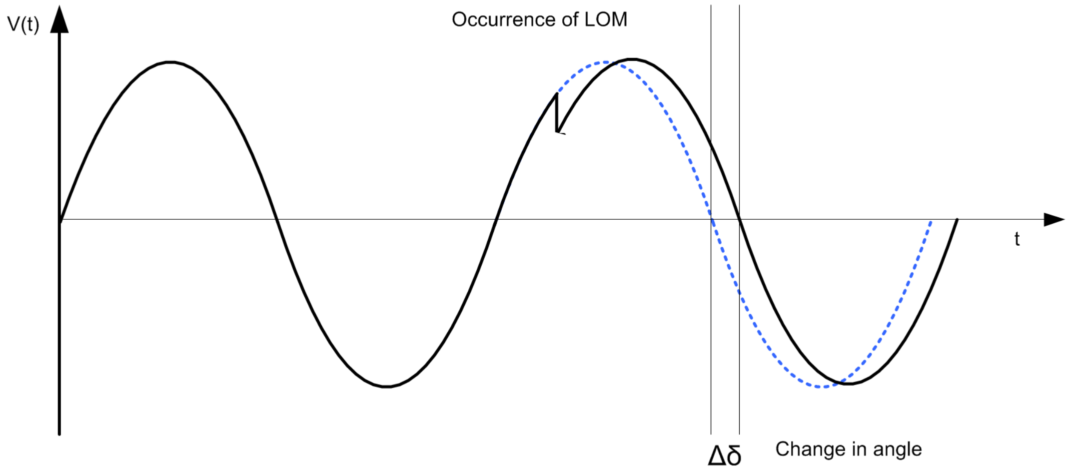


Figure 365: Vector shift during Loss of Mains

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 the timer.

4.5.10.5 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...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 the 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 or the frequency is controlled by the utility supply. 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 which causes undefined voltage magnitudes during islanding situations and frequency instability. 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 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 neighboring network.

To avoid these technical challenges, protection is needed to disconnect 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.

Chosen protection criteria can be included in the Application Configuration tool to create multicriteria loss of mains alarm or trip.

4.5.10.6 Signals

Table 654: VVSPPAM Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 655: VVSPPAM Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
INT_BLKD	BOOLEAN	Protection function internally blocked

4.5.10.7 Settings

Table 656: VVSPPAM Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	2.0...30.0	deg	0.1	6.0	Start value for vector shift

Table 657: VVSPPAM Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Over Volt Blk value	0.40...1.50	xUn	0.01	1.20	Voltage above which function will be internally blocked
Under Volt Blk value	0.15...1.00	xUn	0.01	0.80	Voltage below which function will be internally blocked

Table 658: VVSPPAM Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 659: VVSPPAM Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Phase supervision	7=Ph A + B + C 8=Pos sequence			8=Pos sequence	Monitored voltage phase

4.5.10.8 Monitored data

Table 660: VVSPPAM Monitored data

Name	Type	Values (Range)	Unit	Description
VEC_SHT_A_AB	FLOAT32	-180.00...180.00	deg	Vector shift for phase to earth voltage A or phase to phase voltage AB
VEC_SHT_B_BC	FLOAT32	-180.00...180.00	deg	Vector shift for phase to earth voltage B or phase to phase voltage BC
VEC_SHT_C_CA	FLOAT32	-180.00...180.00	deg	Vector shift for phase to earth voltage C or phase to phase voltage CA
VEC_SHT_U1	FLOAT32	-180.00...180.00	deg	Vector shift for positive sequence voltage
VVSPPAM	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.10.9 Technical data

Table 661: VVSPPAM Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f_n ±1 Hz
	±1°
Operate time [1, 2]	Typically 53 ms

[1] f_n = 50 Hz, results based on statistical distribution of 1000 measurements

4.6 Frequency protection

4.6.1 Frequency protection FRPFRQ

4.6.1.1 Identification

Function description	**IEC 61850 identification**	**IEC 60617 identification**	**ANSI/IEEE C37.2 device number**
Frequency protection	FRPFRQ	f>/f<,df/dt	81

4.6.1.2 Function block

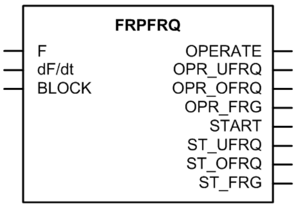


Figure 366: Function block

4.6.1.3 Functionality

The frequency protection function FRPFRQ is used to protect network components against abnormal frequency conditions.

The function provides basic overfrequency, underfrequency and frequency rate-of-change protection. Additionally, it is possible to use combined criteria to achieve even more sophisticated protection schemes for the system.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

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 FRPFRQ can be described using a module diagram. All the modules in the diagram are explained in the next sections.

[2] Includes the delay of the signal output contact

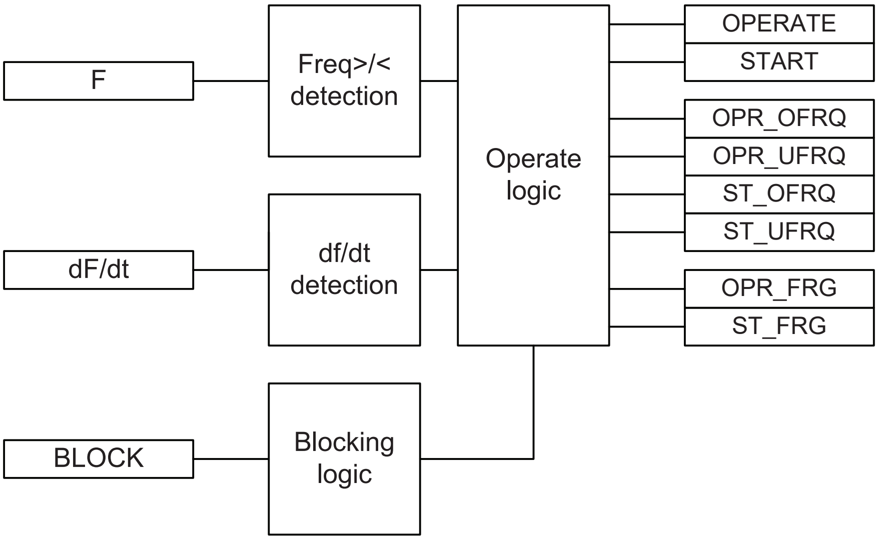


Figure 367: Functional module diagram

Freq>/< detection

The frequency detection module includes an overfrequency or underfrequency detection based on the *Operation mode* setting.

In the “Freq>” mode, the measured frequency is compared to the set *Start value Freq>*. If the measured value exceeds the set value of the *Start value Freq>* setting, the module reports the exceeding of the value to the operate logic module.

In the “Freq<” mode, the measured frequency is compared to the set *Start value Freq<*. If the measured value is lower than the set value of the *Start value Freq<* setting, the module reports the value to the operate logic module.

df/dt detection

The frequency gradient detection module includes a detection for a positive or negative rate-of-change (gradient) of frequency based on the set *Start value df/dt* value. The negative rate-of-change protection is selected when the set value is negative. The positive rate-of-change protection is selected when the set value is positive. When the frequency gradient protection is selected and the gradient exceeds the set *Start value df/dt* value, the module reports the exceeding of the value to the operate logic module.

The protection relay does not accept the set value "0.00" for the *Start value df/dt* setting.

Operate logic

This module is used for combining different protection criteria based on the frequency and the frequency gradient measurement to achieve a more sophisticated behavior of the function. The criteria are selected with the *Operation mode* setting.

Table 662: Operation modes for operation logic

Operation mode	**Description**
Freq<	The function operates independently as the underfrequency ("Freq<") protection function. When the measured frequency is below the set value of the *Start value Freq<* setting, the module activates the START and STR_UFRQ outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm Freq* setting, the OPERATE and OPR_UFRQ outputs are activated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the operate timer resets and the START and STR_UFRQ outputs are deactivated.
Freq>	The function operates independently as the overfrequency ("Freq>") protection function. When the measured frequency exceeds the set value of the *Start value Freq>* setting, the module activates the START and STR_OFRQ outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm Freq* setting, the OPERATE and OPR_OFRQ outputs are activated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the operate timer resets and the START and STR_OFRQ outputs are deactivated.
df/dt	The function operates independently as the frequency gradient ("df/dt"), rate-of-change, protection function. When the frequency gradient exceeds the set value of the *Start value df/dt* setting, the module activates the START and STR_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm df/dt* setting, the OPERATE and OPR_FRG outputs are activated. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the START and STR_FRG outputs are deactivated.
Freq< + df/dt	A consecutive operation is enabled between the protection methods. When the measured frequency is below the set value of the *Start value Freq<* setting, the frequency gradient protection is enabled. After the frequency has dropped below the set value, the frequency gradient is compared to the set value of the *Start value df/dt* setting. When the frequency gradient exceeds the set value, the module activates the START and STR_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm df/dt* setting, the OPERATE and OPR_FRG outputs are activated. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the START

Table continues on the next page

Operation mode	Description
	and STR_FRG outputs are deactivated. The OPR_UFRQ output is not active when this operation mode is used.
Freq> + df/dt	A consecutive operation is enabled between the protection methods. When the measured frequency exceeds the set value of the *Start value Freq>* setting, the frequency gradient protection is enabled. After the frequency exceeds the set value, the frequency gradient is compared to the set value of the *Start value df/dt* setting. When the frequency gradient exceeds the set value, the module activates the START and STR_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm df/dt* setting, the OPERATE and OPR_FRG outputs are activated. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the START and STR_FRG outputs are deactivated. The OPR_OFRQ output is not active when this operation mode is used.
Freq< OR df/dt	A parallel operation between the protection methods is enabled. The START output is activated when either of the measured values of the protection module exceeds its set value. Detailed information about the active module is available at the STR_UFRQ and STR_FRG outputs. The shortest operate delay time from the set *Operate Tm Freq* or *Operate Tm df/dt* is dominant regarding the OPERATE output. The time characteristic is according to DT. The characteristic that activates the OPERATE output can be seen from the OPR_UFRQ or OPR_FRG output. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the STR_FRG output is deactivated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the operate timer resets and the STR_UFRQ output is deactivated.
Freq> OR df/dt	A parallel operation between the protection methods is enabled. The START output is activated when either of the measured values of the protection module exceeds its set value. A detailed information from the active module is available at the STR_OFRQ and STR_FRG outputs. The shortest operate delay time from the set *Operate Tm Freq* or *Operate Tm df/dt* is dominant regarding the OPERATE output. The time characteristic is according to DT. The characteristic that activates the OPERATE output can be seen from the OPR_OFRQ or OPR_FRG output. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the STR_FRG output is deactivated. If the frequency restores before the module operates, the reset timer is activated. If the timer

Operation mode	Description
	reaches the value set by the *Reset delay Tm Freq* setting, the operate timer resets and the STR_UFRQ output is deactivated.

The module calculates the start duration value which indicates the percentage ratio of the start situation and set operate time (DT). The start duration is available according to the selected value of the *Operation mode* setting.

Table 663: Start duration value

Operation mode in use	Available start duration value
Freq<	ST_DUR_UFRQ
Freq>	ST_DUR_OFRQ
df/dt	ST_DUR_FRG

The combined start duration START_DUR indicates the maximum percentage ratio of the active protection modes. The values are available via the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.6.1.5 Application

The frequency protection function uses the positive phase-sequence voltage to measure the frequency reliably and accurately.

The system frequency stability is one of the main principles in the distribution and transmission network maintenance. To protect all frequency-sensitive electrical apparatus in the network, the departure from the allowed band for a safe operation should be inhibited.

The overfrequency protection is applicable in all situations where high levels of the fundamental frequency of a power system voltage must be reliably detected. The high fundamental frequency in a power system indicates 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 underfrequency is applicable in all situations where a reliable detection of a low fundamental power system voltage frequency is needed. The low fundamental frequency in a power system indicates that the generated power is too low to meet the demands of the load connected to the power grid.

The underfrequency can occur as a result of the overload of 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 the transmission lines that link two parts of the system. As a result, the system splits into two with one part having the excess load and the other part the corresponding deficit.

The frequency gradient is applicable in all the situations where the change of the fundamental power system voltage frequency should be detected reliably. The frequency gradient can be used for both increasing and decreasing the frequencies. This function provides an output signal suitable for load shedding, generator shedding, generator boosting, set point change in sub-transmission DC systems 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 large generator requires quick remedial actions to secure the power system integrity. In such situations, the load shedding actions are required at a rather high frequency level. However, in combination with a large negative frequency gradient, the underfrequency protection can be used at a high setting.

4.6.1.6 Signals

Table 664: FRPFRQ Input signals

Name	Type	Default	Description
F	SIGNAL	0	Measured frequency
dF/dt	SIGNAL	0	Rate of change of frequency
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 665: FRPFRQ Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_OFRQ	BOOLEAN	Operate signal for overfrequency
OPR_UFRQ	BOOLEAN	Operate signal for underfrequency
OPR_FRG	BOOLEAN	Operate signal for frequency gradient
START	BOOLEAN	Start
ST_OFRQ	BOOLEAN	Start signal for overfrequency
ST_UFRQ	BOOLEAN	Start signal for underfrequency
ST_FRG	BOOLEAN	Start signal for frequency gradient

4.6.1.7 Settings

Table 666: FRPFRQ Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	1=Freq< 2=Freq> 3=df/dt 4=Freq< + df/dt 5=Freq> + df/dt 6=Freq< OR df/dt 7=Freq> OR df/dt			1=Freq<	Frequency protection operation mode selection
Start value Freq>	0.9000...1.2000	xFn	0.0001	1.0500	Frequency start value overfrequency
Start value Freq<	0.8000...1.1000	xFn	0.0001	0.9500	Frequency start value underfrequency
Start value df/dt	-0.2000...0.2000	xFn /s	0.0025	0.0100	Frequency start value rate of change
Operate Tm Freq	80...200000	ms	10	200	Operate delay time for frequency
Operate Tm df/dt	120...200000	ms	10	400	Operate delay time for frequency rate of change

Table 667: FRPFRQ Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 668: FRPFRQ Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay Tm Freq	0...60000	ms	1	0	Reset delay time for frequency
Reset delay Tm df/dt	0...60000	ms	1	0	Reset delay time for rate of change

4.6.1.8 Monitored data

Table 669: FRPFRQ Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Start duration
ST_DUR_OFRQ	FLOAT32	0.00...100.00	%	Start duration
ST_DUR_UFRQ	FLOAT32	0.00...100.00	%	Start duration
ST_DUR_FRG	FLOAT32	0.00...100.00	%	Start duration
FRPFRQ	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Name	Type	Values (Range)	Unit	Description
		5=off		

4.6.1.9 Technical data

Table 670: FRPFRQ Technical data

Characteristic		Value
Operation accuracy	f>/f<	±5 mHz
	df/dt	±50 mHz/s (in range |df/dt| <5 Hz/s) ±2.0% of the set value (in range 5 Hz/s < |df/dt| < 15 Hz/s)
Start time	f>/f<	<80 ms
	df/dt	<120 ms
Reset time		<150 ms
Operate time accuracy		±1.0% of the set value or ±30 ms

4.6.1.10 Technical revision history

Table 671: FRPFRQ Technical revision history

Technical revision	Change
B	Step value changed from 0.001 to 0.0001 for the *Start value Freq>* and *Start value Freq<* settings.
C	df/dt setting step changed from 0.005 ×Fn /s to 0.0025 ×Fn /s.
D	Internal improvement.

4.6.2 Load-shedding and restoration LSHDPFRQ

4.6.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Load-shedding and restoration	LSHDPFRQ	UFLS/R	81LSH

4.6.2.2 Function block

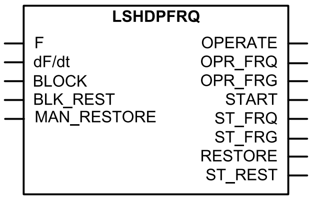


Figure 368: Function block

4.6.2.3 Functionality

The load-shedding and restoration 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.

Throughout this document, “high df/dt” is used to mean “a high rate of change of the frequency in negative direction.”

Once the frequency has stabilized, LSHDPFRQ can restore the load that is shed during the frequency disturbance. The restoration is possible manually or automatically.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

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 LSHDPFRQ can be described using a module diagram. All the modules are explained in the next sections.

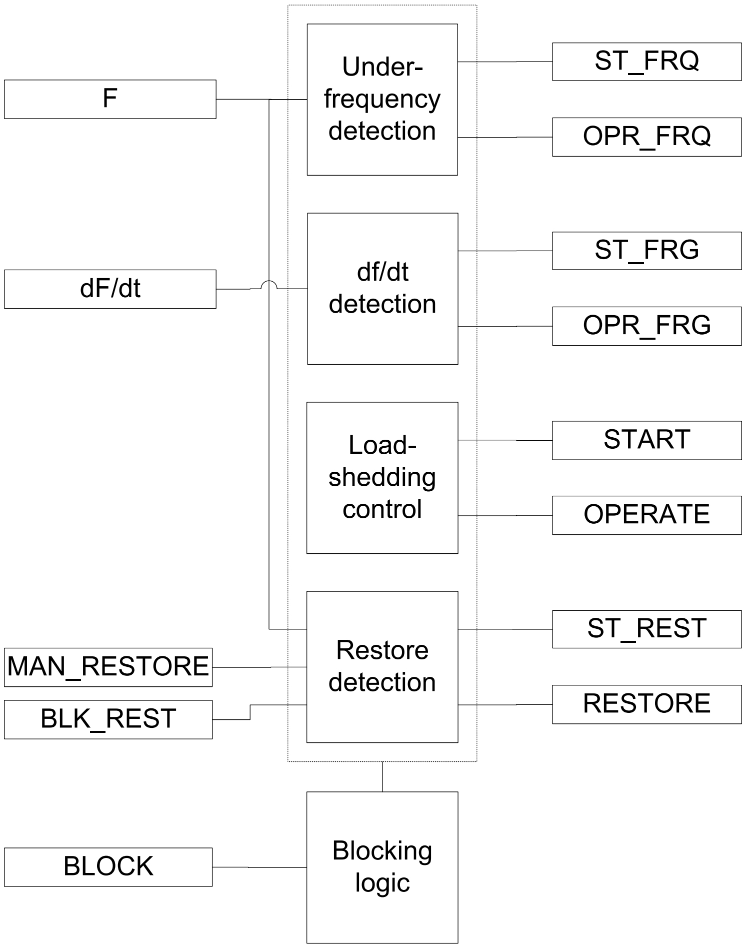


Figure 369: Functional module diagram

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 Value Freq* 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 *Operate Tm Freq*, 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.

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 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 *Operate Tm df/dt*, 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.

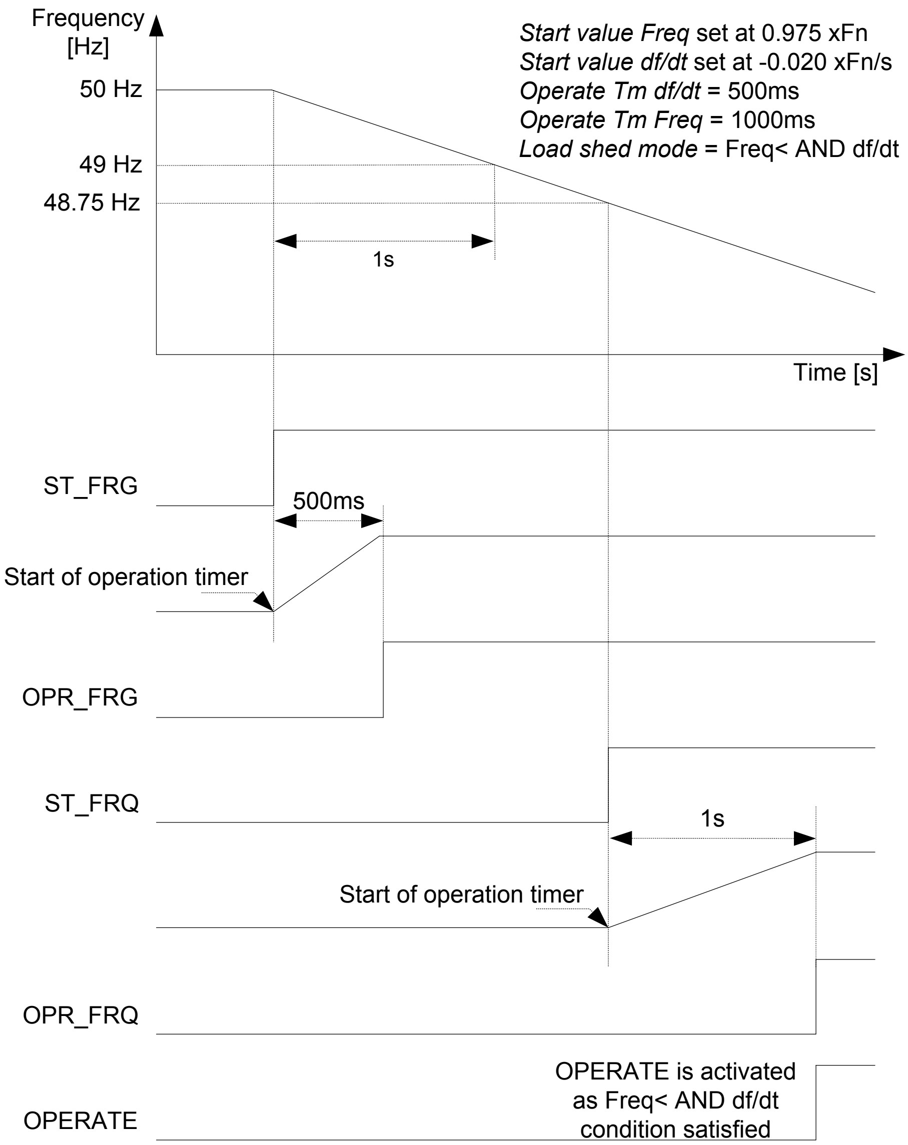


Figure 370: Load-shedding operation in the "Freq< AND df/dt>" mode when both Freq< and df/dt conditions are satisfied (Rated frequency=50 Hz)

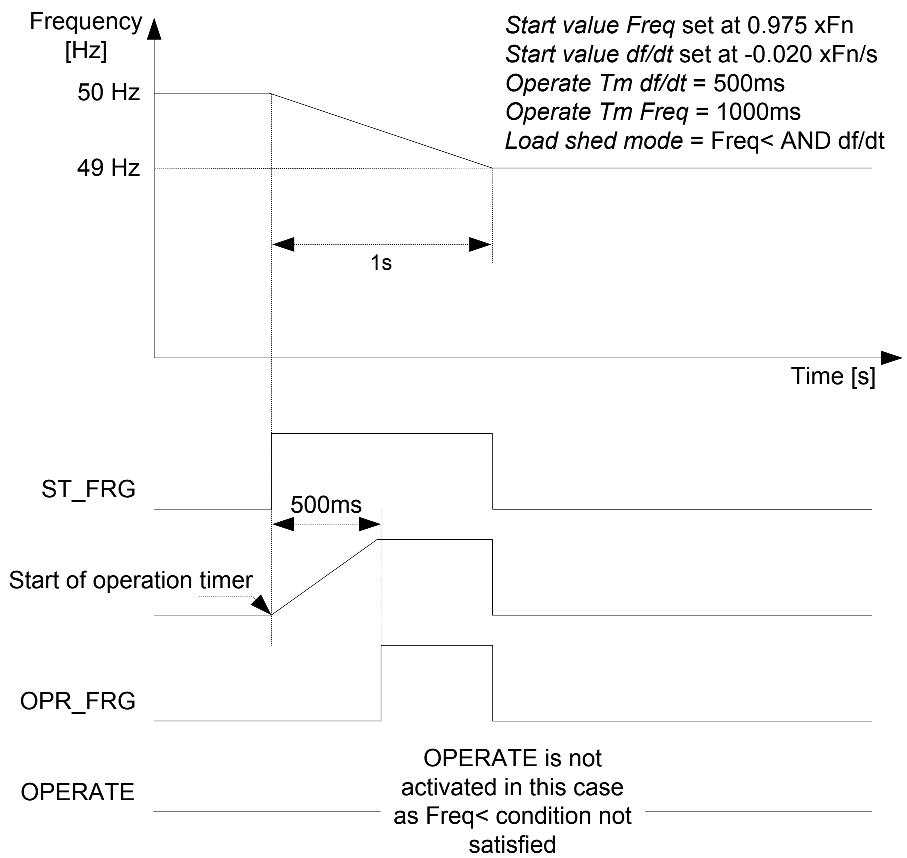


Figure 371: Load-shedding operation in the "Freq< AND df/dt>" mode when only the df/dt condition is satisfied (Rated frequency=50 Hz)

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 frequen-

Restoring mode	Description
	cy 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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** that selects the blocking mode. The BLOCK input can be controlled with a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK input signal activation is preselected with the *Blocking mode* global setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE, OPR_FRQ and OPR_FRG outputs are not activated.

4.6.2.5 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 system operation is such that the operating frequency 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.

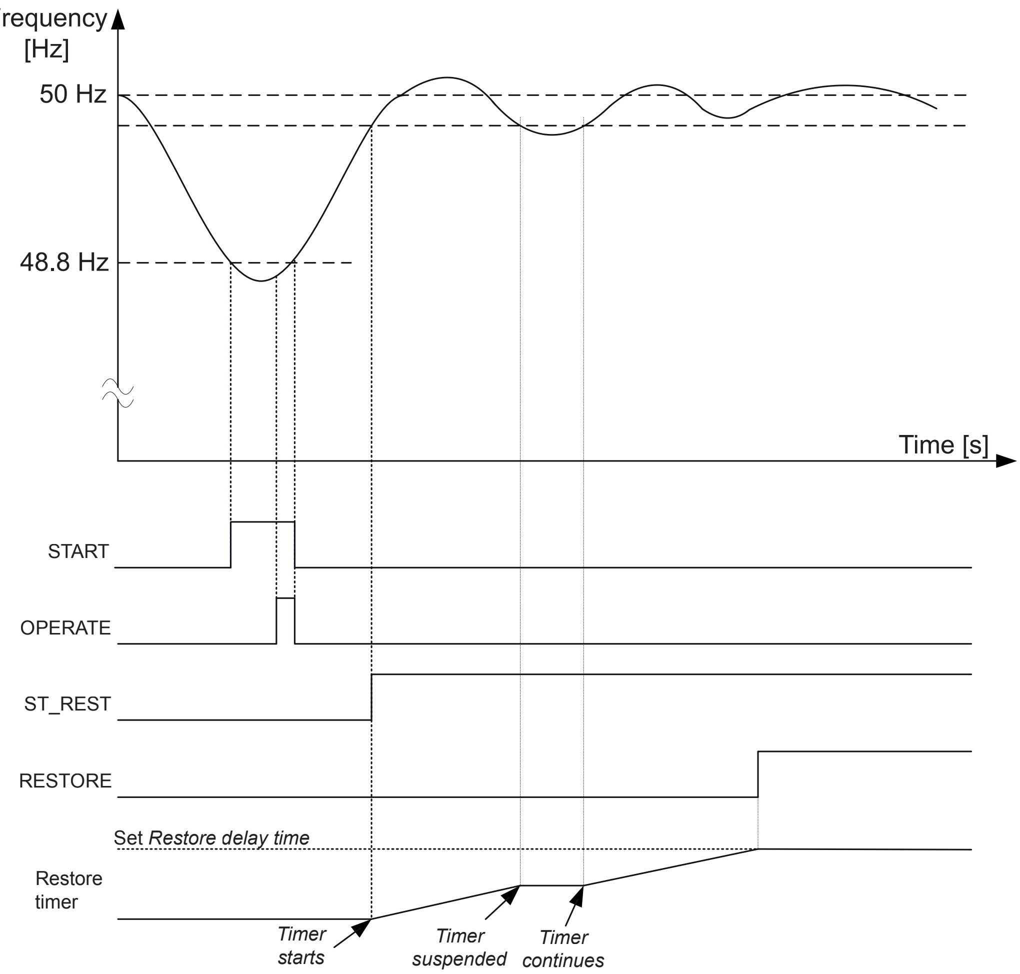


Figure 372: Operation of the load-shedding function

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 672: Setting for a five-step underfrequency operation

Load-shedding steps	Start value Freq setting	Operate Tm Freq setting
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 673: Setting for a five-step df/dt< operation

Load-shedding steps	Start value df/dt setting	Operate Tm df/dt setting
1	-0.005 · Fn /s (-0.25 Hz/s)	8000 ms
2	-0.010 · Fn /s (-0.50 Hz/s)	2000 ms
3	-0.015 · Fn /s (-0.75 Hz/s)	1000 ms
4	-0.020 · Fn /s (-1.00 Hz/s)	500 ms
5	-0.025 · Fn /s (-1.25 Hz/s)	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 674: Setting for a five-step restoring operation

Load-shedding steps	Restoring start Val setting	Restore delay time setting
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

4.6.2.6 Signals

Table 675: LSHDPFRQ Input signals

Name	Type	Default	Description
F	SIGNAL	0	Measured frequency
dF/dt	SIGNAL	0	Rate of change of frequency
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_REST	BOOLEAN	0=False	Block restore
MAN_RESTORE	BOOLEAN	0=False	Manual restore signal

Table 676: 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	Start
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

4.6.2.7 Settings

Table 677: LSHDPFRQ Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Load shed mode	1=Freq< 6=Freq< OR df/dt 8=Freq< AND df/dt			1=Freq<	Set the operation mode for load shedding function
Restore mode	1=Disabled 2=Auto 3=Manual			1=Disabled	Mode of operation of restore functionality
Start value Freq	0.800...1.200	xFn	0.001	0.975	Frequency setting/start value
Start value df/dt	-0.200...-0.005	xFn /s	0.005	-0.010	Setting of frequency gradient for df/dt detection

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operate Tm Freq	80...200000	ms	10	200	Time delay to operate for under frequency stage
Operate Tm df/dt	120...200000	ms	10	200	Time delay to operate for df/dt stage
Restore start Val	0.800...1.200	xFn	0.001	0.998	Restore frequency setting value
Restore delay time	80...200000	ms	10	300	Time delay to restore

Table 678: LSHDPFRQ Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 679: LSHDPFRQ Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	50	Time delay after which the definite timers will reset

4.6.2.8 Monitored data

Table 680: LSHDPFRQ Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Start duration
LSHDPFRQ	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.6.2.9 Technical data

Table 681: LSHDPFRQ Technical data

Characteristic		Value
Operation accuracy	f<	±10 mHz
	df/dt	±100 mHz/s (in range $\lvert df/dt \rvert$ < 5 Hz/s) ± 2.0% of the set value (in range 5 Hz/s < $\lvert df/dt \rvert$ < 15 Hz/s)
Start time	f<	<80 ms
	df/dt	<120 ms
Reset time		<150 ms
Operate time accuracy		±1.0% of the set value or ±30 ms

4.7 Impedance protection

4.7.1 Three-phase underexcitation protection UEXPDIS

4.7.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase underexcitation protection	UEXPDIS	X<	40

4.7.1.2 Function block

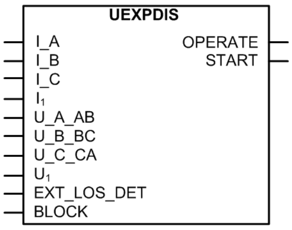


Figure 373: Function block

4.7.1.3 Functionality

The three-phase underexcitation protection function 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.

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 operation of UEXPDIS can be described using a module diagram. All the modules in the diagram are explained in the next sections.

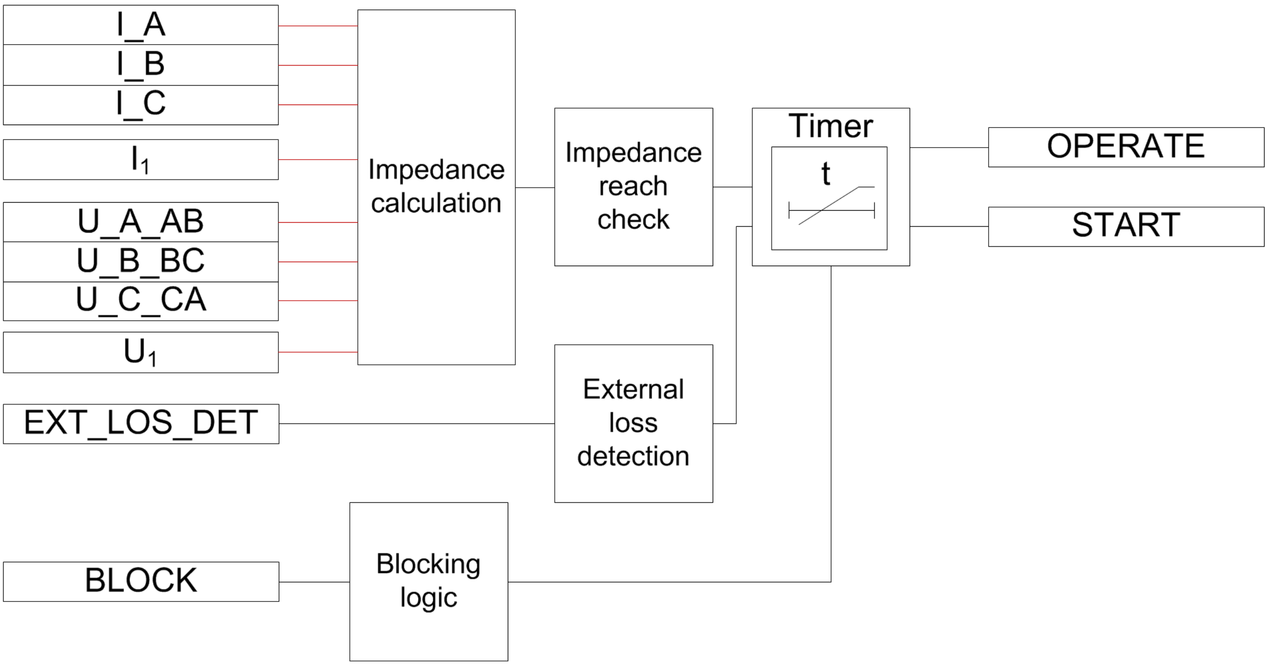


Figure 374: Functional module diagram

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 682: 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 protection relay, 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...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.

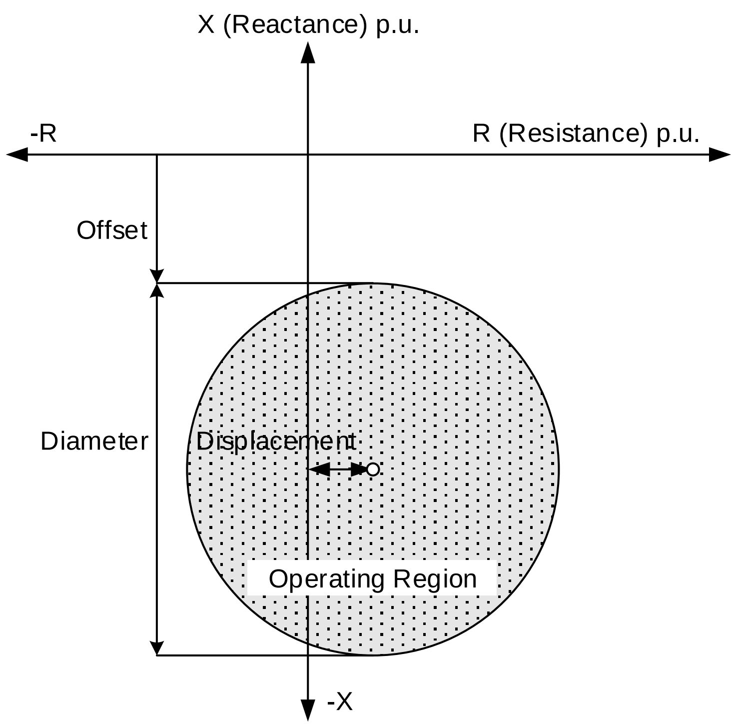


Figure 375: Operating region of the impedance mho circle

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 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

The module checks the status information of the excitation system. It 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 pickup situation and the set operating time (DT). The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.7.1.5 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 start to operate like an induction machine, which increases the consumption of the reactive power. Even if the machine does not lose synchronism, it is not recommended to operate in this state. 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, for example voltage dip, stability and power swings. Power swings stress the prime mover, causing for example turbine blade cavitation and mechanical stress in the gearbox.

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.

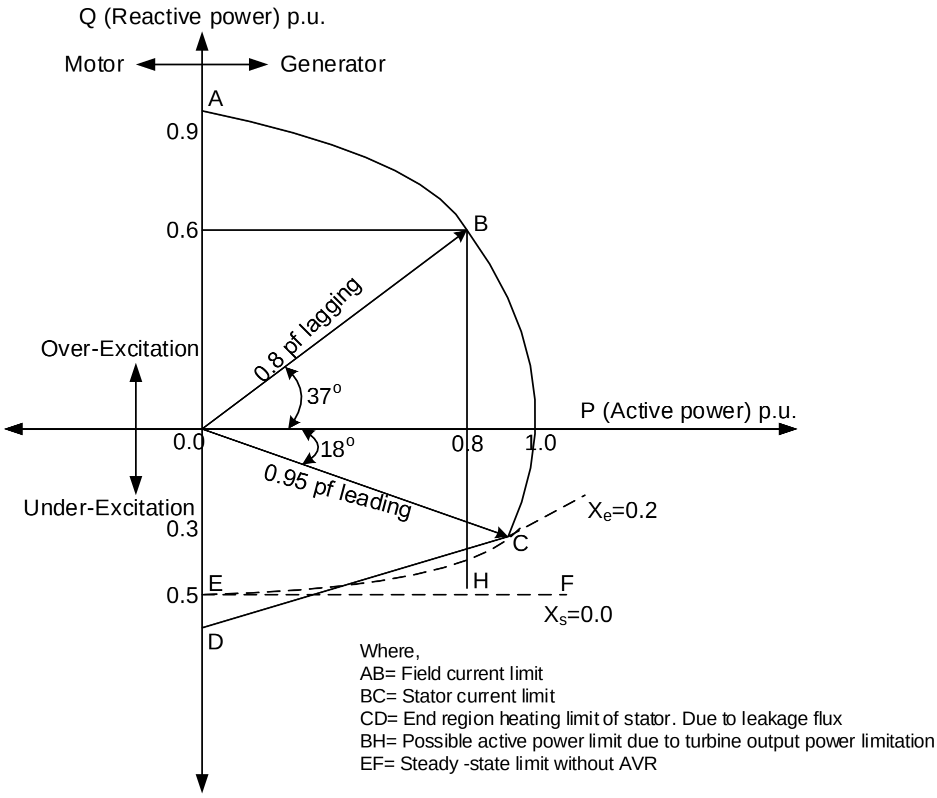


Figure 376: Capability curve of a synchronous generator

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 683: 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:

$$Z_N = \left| \frac{U_N^{\;2}}{S_N} \right|$$

(Equation 142)

U_N	rated (phase-to-phase) voltage in kV
S_N	rated power of the protected machine in MVA

he corresponding calculation to convert ohms to pu values is:

$$X_{pu} = \frac{X_{ohm}}{Z_N}$$

(Equation 143)

X_{pu}	pu value
X_{ohm}	reactance in ohms
Z_N	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.

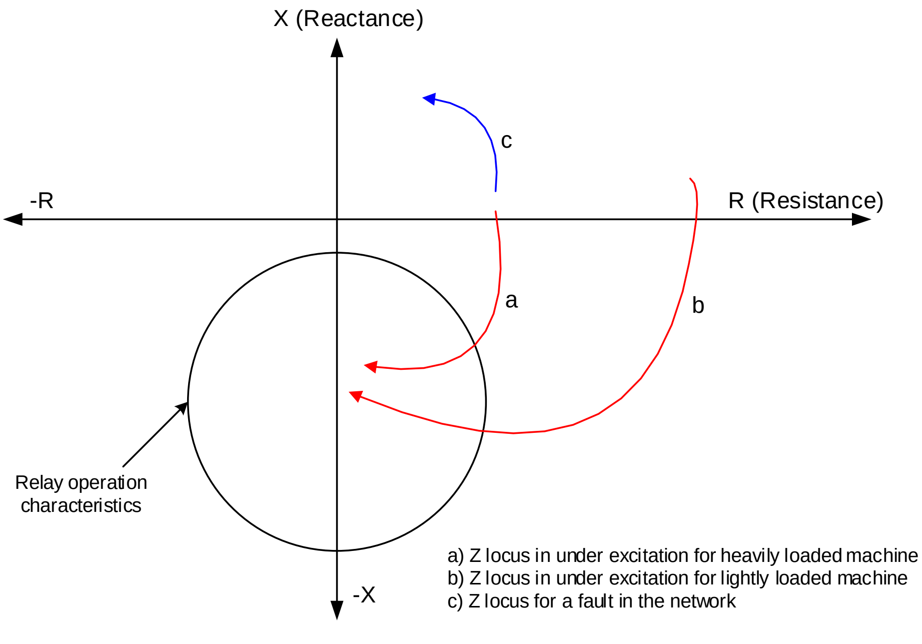


Figure 377: Typical impedance locus in underexcitation: a) heavy load b) light load c) fault in the network

4.7.1.6 Signals

Table 684: UEXPDIS Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
EXT_LOS_DET	BOOLEAN	0=False	External signal for excitation loss detection

Table 685: UEXPDIS Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.7.1.7 Settings

Table 686: UEXPDIS Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Diameter	1...6000	%Zn	1	200	Diameter of the Mho diagram
Offset	-1000...1000	%Zn	1	-10	Offset of top of the impedance circle from the R-axis
Displacement	-1000...1000	%Zn	1	0	Displacement of impedance circle centre from the X-axis
Operate delay time	60...200000	ms	10	5000	Operate delay time

Table 687: UEXPDIS Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
External Los Det Ena	0=Disable 1=Enable			1=Enable	Enable external excitation loss detection
Voltage reversal	0=No 1=Yes			0=No	Rotate voltage signals by 180 degrees
Impedance Meas mode	1=1Phase-to-earth 2=1Phase-to-phase 3=3Phase-to-earth 4=3Phase-to-phase 5=Pos sequence			5=Pos sequence	Select voltage and currents for impedance calculation
Phase Sel for Z Clc	1=A or AB 2=B or BC 3=C or CA			1=A or AB	Voltage phase selection

Table 688: UEXPDIS Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	3000	Reset delay time

4.7.1.8 Monitored data

Table 689: UEXPDIS Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time (in %)
Z_AMPL_A	FLOAT32	0.00...200.00	xZn	Impedance amplitude phase A
Z_ANGLE_A	FLOAT32	-180.00...180.00	deg	Impedance angle phase A
Z_AMPL_B	FLOAT32	0.00...200.00	xZn	Impedance amplitude phase B
Z_ANGLE_B	FLOAT32	-180.00...180.00	deg	Impedance angle phase B
Z_AMPL_C	FLOAT32	0.00...200.00	xZn	Impedance amplitude phase C
Z_ANGLE_C	FLOAT32	-180.00...180.00	deg	Impedance angle phase C
Z_AMPL_AB	FLOAT32	0.00...200.00	xZn	Phase-to-phase A-B impedance amplitude
Z_ANGLE_AB	FLOAT32	-180.00...180.00	deg	Phase-to-phase A-B impedance phase angle

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Z_AMPL_BC	FLOAT32	0.00...200.00	xZn	Phase-to-phase B-C impedance amplitude
Z_ANGLE_BC	FLOAT32	-180.00...180.00	deg	Phase-to-phase B-C impedance phase angle
Z_AMPL_CA	FLOAT32	0.00...200.00	xZn	Phase-to-phase C-A impedance amplitude
Z_ANGLE_CA	FLOAT32	-180.00...180.00	deg	Phase-to-phase C-A impedance phase angle
Z1_AMPL	FLOAT32	0.00...200.00	xZn	Positive sequence impedance amplitude
Z1_ANGLE	FLOAT32	-180.00...180.00	deg	Positive sequence impedance phase angle
UEXPDIS	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.7.1.9 Technical data

Table 690: UEXPDIS Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current and voltage: $f = f_n \pm 2$ Hz
	±3.0% of the set value or ±0.2% Zb
Start time [1, 2]	Typically 45 ms
Reset time	Typically 30 ms
Reset ratio	Typically 1.04
Retardation time	Total retardation time when the impedance returns from the operating circle <40 ms
Operate time accuracy	±1.0% 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 f_n= 50Hz, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact

4.8 Power protection

4.8.1 Underpower protection DUPPDPR

4.8.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Underpower protection	DUPPDPR	P<	32U

4.8.1.2 Function block

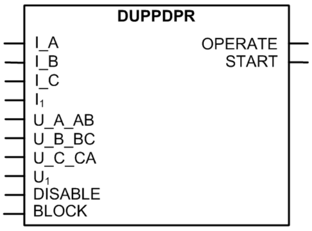


Figure 378: Function block

4.8.1.3 Functionality

The underpower protection function DUPPDPR is used for protecting generators and prime movers against the effects of very low power outputs or reverse power condition.

The function operates when the measured active power falls below the set value. The operating 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.

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 DUPPDPR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

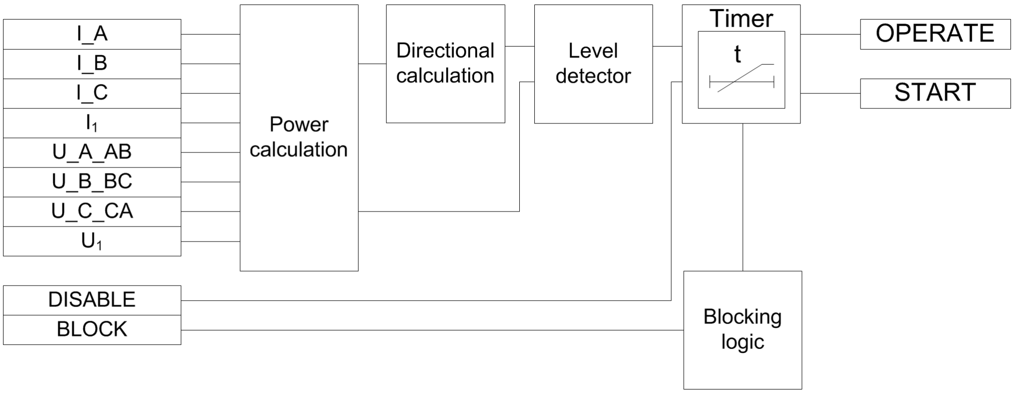


Figure 379: Functional module diagram

Power calculation

This module calculates the apparent power based on the selected voltage and current measurements as described in *Table 691*. 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 691: Power calculation

Measurement mode setting	Power calculation
PhsA, PhsB, PhsC	$\bar{S} = \bar{U}_a \cdot \bar{I}_a^* + \bar{U}_b + \bar{I}_b^* + \bar{U}_c \cdot \bar{I}_c^*$ $P = Re(\bar{S})$
Arone	$\bar{S} = \bar{U}_{ab} \cdot \bar{I}_a^* - \bar{U}_{bc} \cdot \bar{I}_c^*$ $P = Re(\bar{S})$
Pos Seq	$\bar{S} = 3 \cdot \bar{U}_1 \cdot \bar{I}_1^*$ $P = Re(\bar{S})$
PhsAB	$\bar{S} = \sqrt{3} \cdot \bar{U}_{ab} \cdot (\bar{I}_a^* - \bar{I}_b^*)$ $P = Re(\bar{S})$
PhsBC	$\bar{S} = \sqrt{3} \cdot \bar{U}_{bc} \cdot (\bar{I}_b^* - \bar{I}_c^*)$

Table continues on the next page

Measurement mode setting	Power calculation
	$P = Re(\bar{S})$
PhsCA	$\bar{S} = \sqrt{3} \cdot \bar{U}_{ca} \cdot (\bar{I}_c^* - \bar{I}_a^*)$ $P = Re(\bar{S})$
PhsA	$\bar{S} = 3 \cdot \bar{U}_a \cdot \bar{I}_a^*$ $P = Re(\bar{S})$
PhsB	$\bar{S} = 3 \cdot \bar{U}_b \cdot \bar{I}_b^*$ $P = Re(\bar{S})$
PhsC	$\bar{S} = 3 \cdot \bar{U}_c \cdot \bar{I}_c^*$ $P = Re(\bar{S})$

If all three phase voltages and phase currents are fed to the protection relay, 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 setting *Pol reversal* to "True", 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.

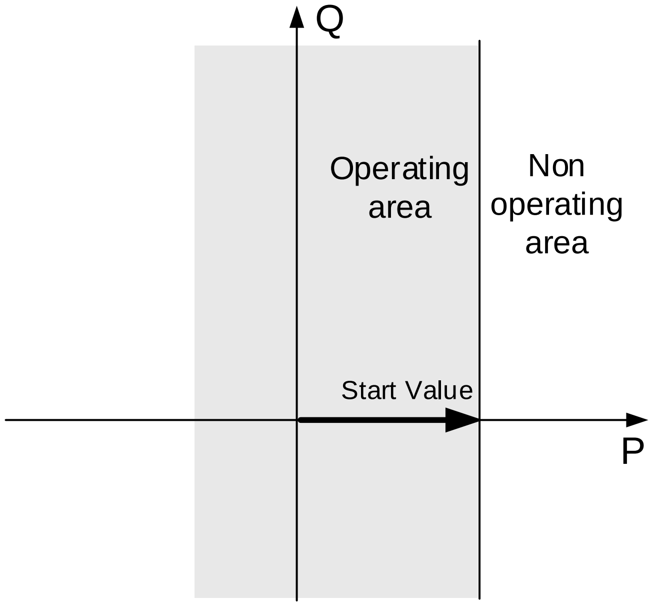


Figure 380: Operating characteristics of DUPPDPR with setting Start value

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. In a drop-off situation, 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 start-up 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*.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.8.1.5 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 become easily 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 surfs on the water and sets 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%.

4.8.1.6 Signals

Table 692: DUPPDPR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_1	SIGNAL	0	Positive sequence current
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB

Table continues on the next page

Name	Type	Default	Description
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
U_1	SIGNAL	0	Positive phase sequence voltage
DISABLE	BOOLEAN	0=False	Signal to block the function during generator startup
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 693: DUPPDPR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.8.1.7 Settings

Table 694: DUPPDPR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...2.00	xSn	0.01	0.10	Start value
Operate delay time	40...300000	ms	10	40	Operate delay time

Table 695: DUPPDPR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On/Off

Table 696: DUPPDPR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=PhsA, PhsB, PhsC 2=Arone 3=Pos Seq 4=PhsAB 5=PhsBC 6=PhsCA 7=PhsA 8=PhsB			3=Pos Seq	Selection of power calculation method

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	9=PhsC				
Reset delay time	0...60000	ms	10	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Reverse the definition of the power direction
Disable time	0...60000	ms	1000	0	Additional wait time after CB closing

4.8.1.8 Monitored data

Table 697: DUPPDPR Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
P	FLOAT32	-160.000...160.000	xSn	Active power
Q	FLOAT32	-160.000...160.000	xSn	Reactive power
S	FLOAT32	0.000...160.000	xSn	Apparent power
PF_ANGLE	FLOAT32	-180.00...180.00	deg	Power factor angle
DUPPDPR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.8.1.9 Technical data

Table 698: DUPPDPR Technical data

Characteristic	Value
Operation accuracy [1]	Depending on the frequency of the measured current and voltage: f_n ±2 Hz
	Power measurement accuracy ±3% of the set value or ±0.002 × S_n Phase angle: ±2°
Start time [2, 3]	Typically 45 ms

Table continues on the next page

[1] *Measurement mode* = “Pos Seq” (default)

Characteristic	Value
Reset time	Typically 30 ms
Reset ratio	Typically 1.04
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,…

4.8.2 Reverse power-directional overpower protection DOPPDPR

4.8.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Reverse power/directional over-power protection	DOPPDPR	P>/Q>	32R/32O

4.8.2.2 Function block

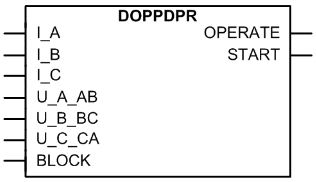


Figure 381: Function block

4.8.2.3 Functionality

The reverse power/directional overpower protection function 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, and against the motor running like a generator and for protecting a motor which consumes more reactive power due to loss of field. It 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.

The function 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.

[2] $U = U_n$, f_n = 50 Hz, results based on statistical distribution of 1000 measurements
[3] Includes the delay of the signal output contact

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 DOPPDPR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

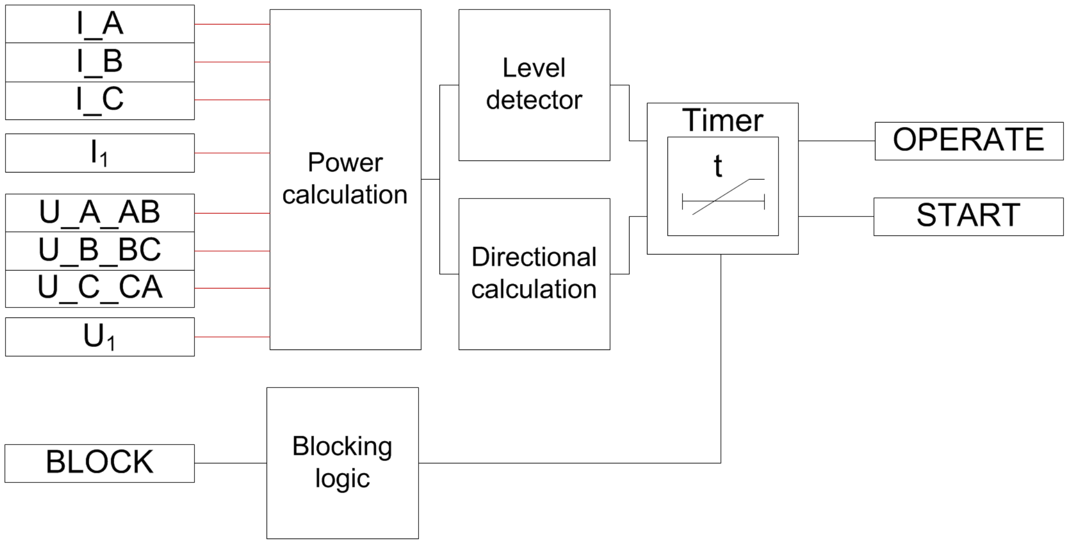


Figure 382: Functional module diagram

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 699: Power calculation

Measurement mode setting	Power calculation
PhsA, PhsB, PhsC	$\bar{S} = \bar{U}_a \cdot \bar{I}_a^* + \bar{U}_b + \bar{I}_b^* + \bar{U}_c \cdot \bar{I}_c^*$ $P = Re(\bar{S})$
Arone	$\bar{S} = \bar{U}_{ab} \cdot \bar{I}_a^* - \bar{U}_{bc} \cdot \bar{I}_c^*$ $P = Re(\bar{S})$
Pos Seq	$\bar{S} = 3 \cdot \bar{U}_1 \cdot \bar{I}_1^*$ $P = Re(\bar{S})$

Table continues on the next page

Measurement mode setting	Power calculation
PhsAB	$\bar{S} = \sqrt{3} \cdot \bar{U}_{ab} \cdot \left(\bar{I}_a^* - \bar{I}_b^*\right)$ $P = Re\left(\bar{S}\right)$
PhsBC	$\bar{S} = \sqrt{3} \cdot \bar{U}_{bc} \cdot \left(\bar{I}_b^* - \bar{I}_c^*\right)$ $P = Re\left(\bar{S}\right)$
PhsCA	$\bar{S} = \sqrt{3} \cdot \bar{U}_{ca} \cdot \left(\bar{I}_c^* - \bar{I}_a^*\right)$ $P = Re\left(\bar{S}\right)$
PhsA	$\bar{S} = 3 \cdot \bar{U}_a \cdot \bar{I}_a^*$ $P = Re\left(\bar{S}\right)$
PhsB	$\bar{S} = 3 \cdot \bar{U}_b \cdot \bar{I}_b^*$ $P = Re\left(\bar{S}\right)$
PhsC	$\bar{S} = 3 \cdot \bar{U}_c \cdot \bar{I}_c^*$ $P = Re\left(\bar{S}\right)$

If all three phase voltages and phase currents are fed to the protection relay, the positive-sequence alternative is recommended.

The calculated powers S, P, 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 "True", the measured apparent power is turned 180 degrees.

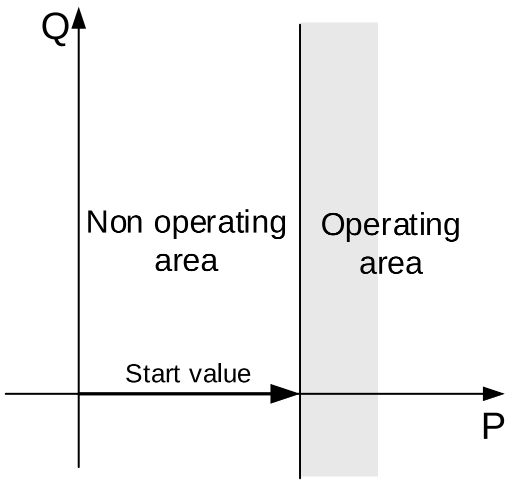


Figure 383: Operating characteristics with the Start Value setting, the Power angle setting being 0 and Directional mode "Forward"

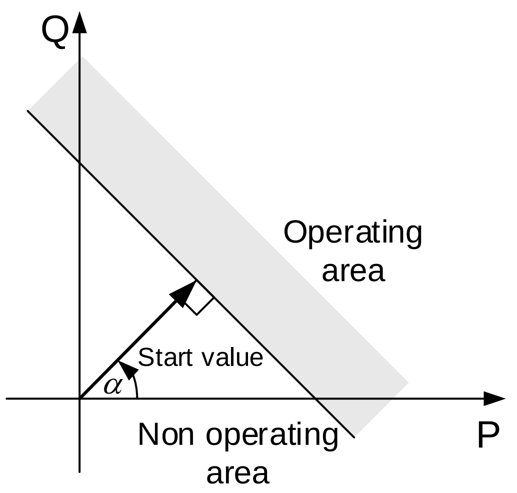


Figure 384: Operating characteristics with the Start Value setting, Power angle (α) being +45 and Directional mode "Forward"

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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode**, which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.8.2.5 Application

DOPPDPR is used to provide protection against an excessive power flow in the set operating direction. The 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 DOPPDPR function has many applications when used as 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 % 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 %. 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 % or more of its rated power from the system. A stiff engine may require 25 % of the rated power to motor it. A well run engine may need no more than 5 %. 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, DOPPDPR 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.

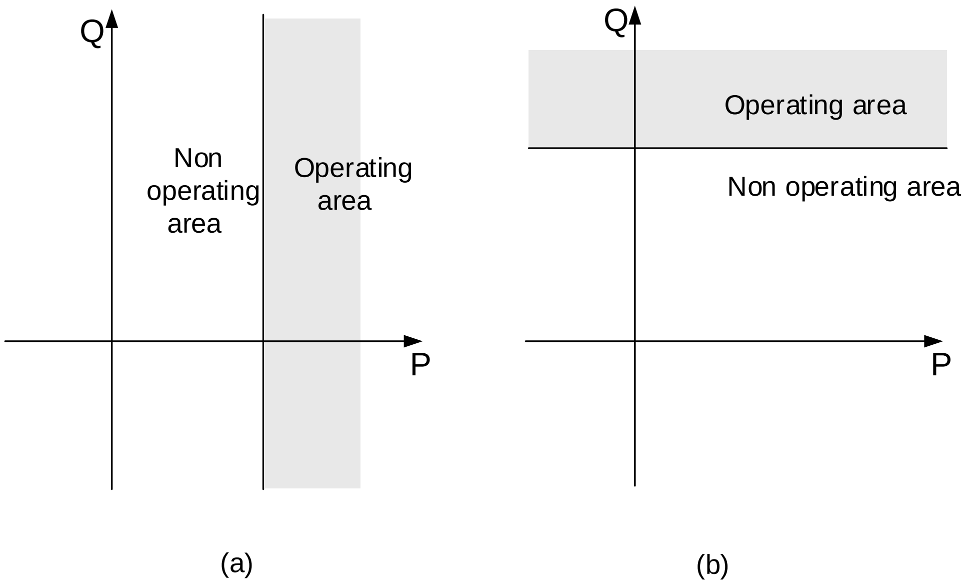


Figure 385: Forward active overpower characteristics (a) and forward reactive overpower characteristics (b)

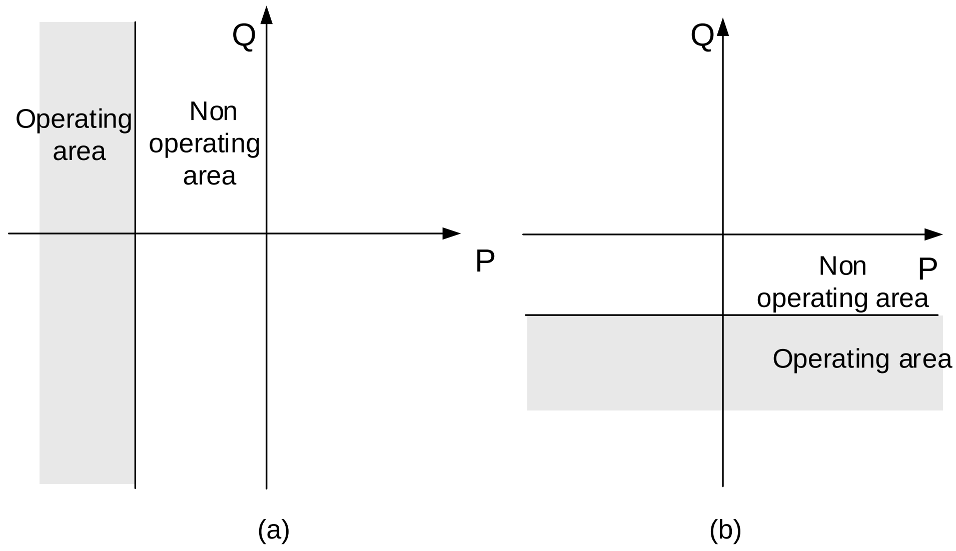


Figure 386: Reverse active overpower characteristics (a) and reverse reactive overpower characteristics (b)

4.8.2.6 Signals

Table 700: DOPPDPR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_A_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_A_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 701: DOPPDPR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.8.2.7 Settings

Table 702: DOPPDPR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...2.00	xSn	0.01	1.00	Start value
Operate delay time	40...300000	ms	10	40	Operate delay time
Directional mode	2=Forward 3=Reverse			2=Forward	Directional mode
Power angle	-90...90	deg	1	0	Adjustable angle for power

Table 703: DOPPDPR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On/Off
Measurement mode	1=PhsA, PhsB, PhsC 2=Arone 3=Pos Seq 4=PhsAB 5=PhsBC 6=PhsCA 7=PhsA 8=PhsB 9=PhsC			3=Pos Seq	Selection of power calculation method

Table 704: DOPPDPR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Reverse the definition of the power direction

4.8.2.8 Monitored data

Table 705: DOPPDPR Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
P	FLOAT32	-160.000...160.000	xSn	Active power
Q	FLOAT32	-160.000...160.000	xSn	Reactive power
S	FLOAT32	0.000...160.000	xSn	Apparent power

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
PF_ANGLE	FLOAT32	-180.00...180.00	deg	Power factor angle
DOPPDPR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.8.2.9 Technical data

Table 706: DOPPDPR Technical data

Characteristic	Value
Operation accuracy [1]	Depending on the frequency of the measured current and voltage: $f = f_n$ ±2 Hz
	Power measurement accuracy ±3% of the set value or ±0.002 × S_n Phase angle: ±2°
Start time [2, 3]	Typically 45 ms
Reset time	Typically 30 ms
Reset ratio	Typically 0.94
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,…

4.8.3 Directional reactive power undervoltage protection DQPTUV

4.8.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional reactive power undervoltage protection	DQPTUV	Q> ->,3U<	32Q,27

1 *Measurement mode* = “Pos Seq” (default)
2 $U = U_n$, f_n = 50 Hz, results based on statistical distribution of 1000 measurements
3 Includes the delay of the signal output contact

4.8.3.2 Function block

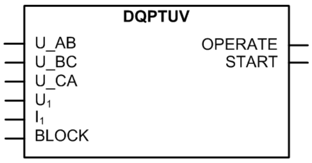


Figure 387: Function block

4.8.3.3 Functionality

The directional reactive power undervoltage protection function 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).

The function contains a blocking functionality to block function outputs, timer or the function itself.

4.8.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DQPTUV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

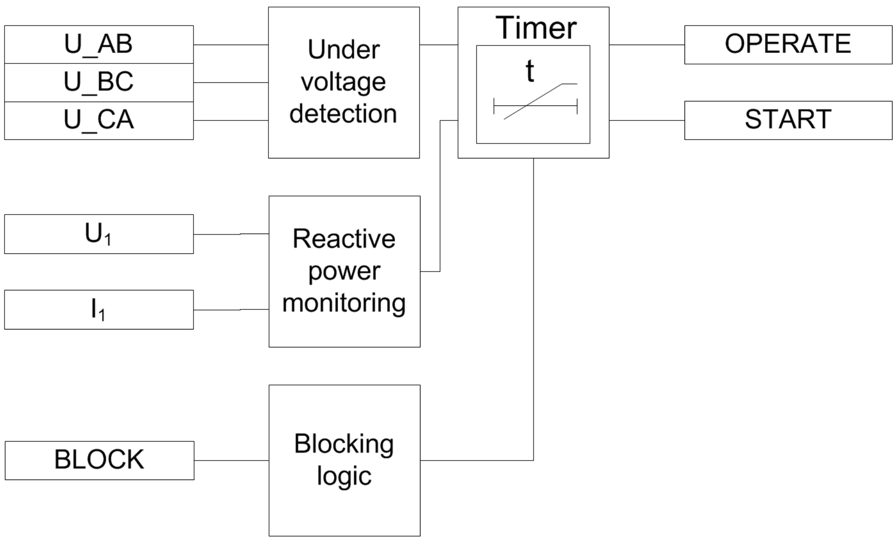


Figure 388: Functional module diagram

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 undervoltage 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 use 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.

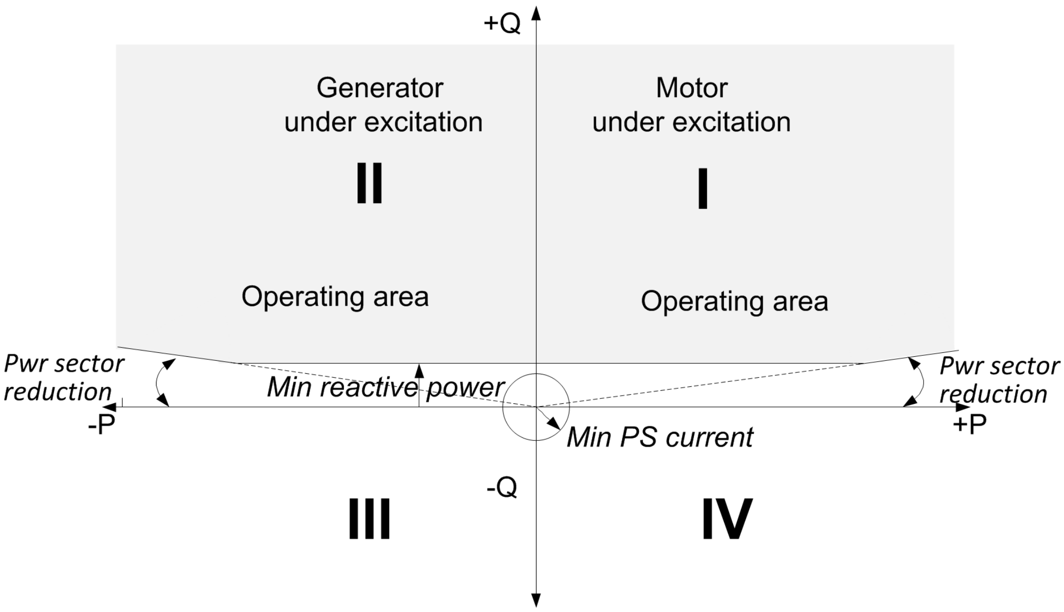


Figure 389: Operating area of DQPTUV function

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 Timer is reset instantaneously.

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 through the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode setting* has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

4.8.3.5 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 there is a considerable loss in the power generation, it may affect the system’s ability to recover. To ensure power system stability, various grid codes have revised their requirements and therefore require that the distributed PGUs have to make a contribution to network support. In case of network faults, the distributed power generator should not be immediately disconnected from the network. Instead, as a matter of principle, generating plants connected to the medium-voltage network must be capable of participating in steady-state voltage control and dynamic network support. 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 BDEW Technical Guideline “Generating Plants Connected to the Medium-Voltage Network” (June 2008 issue, Germany), it is stated that if all three phase-to-phase voltages at the grid connection point decrease and remain at and below a value of 85% 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 s.

4.8.3.6 Signals

Table 707: DQPTUV Input signals

Name	Type	Default	Description
U_AB	SIGNAL	0	Phase-to-phase voltage AB
U_BC	SIGNAL	0	Phase-to-phase voltage BC
U_CA	SIGNAL	0	Phase-to-phase voltage CA
U_1	SIGNAL	0	Positive phase sequence voltage
I_1	SIGNAL	0	Positive sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 708: DQPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.8.3.7 Settings

Table 709: DQPTUV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.20...1.20	xUn	0.01	0.85	Start value for under voltage detection
Operate delay time	100...300000	ms	10	500	Operate delay time

Table 710: DQPTUV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On/Off

Table 711: DQPTUV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Min reactive power	0.01...0.50	xSn	0.01	0.05	Minimum reactive power needed for function to operate
Min Ps Seq current	0.02...0.20	xIn	0.01	0.05	Minimum positive sequence current

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Pwr sector reduction	0...10	deg	1	3	Power sector reduction
Pol reversal	0=False 1=True			0=False	Reverse the definition of the positive reactive power direction

4.8.3.8 Monitored data

Table 712: DQPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
Q	FLOAT32	-160.000...160.000	xSn	Reactive power
DQPTUV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.8.3.9 Technical data

Table 713: DQPTUV Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current and voltage: f_n ±2 Hz Reactive power range |PF| <0.71
	Power: ±3.0 % or ±0.002 × Q_n Voltage: ±1.5 % of the set value or ±0.002 × U_n
Start time [1, 2]	Typically 46 ms
Reset time	<50 ms
Reset ratio	Typically 0.96
Operate time accuracy	±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 *Start value* = 0.05 × S_n, reactive power before fault = 0.8 × *Start value*, reactive power overshoot 2 times, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact

4.9 Arc protection ARCSARC

4.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Arc protection	ARCSARC	ARC	50L/50NL

4.9.2 Function block

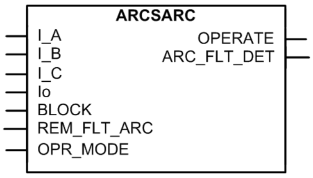


Figure 390: Function block

4.9.3 Functionality

The arc protection function ARCSARC detects arc situations in air-insulated metal-clad switchgears caused by, for example, human errors during maintenance or insulation breakdown during operation.

The function detects light from an arc either locally or via a remote light signal. The function also monitors phase and residual currents to be able to make accurate decisions on ongoing arcing situations.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

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 ARCSARC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

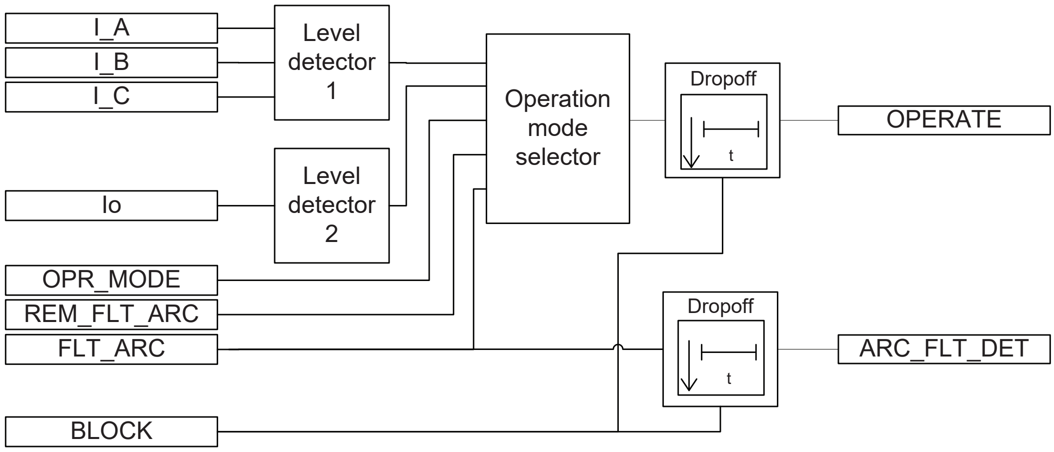


Figure 391: Functional module diagram

Level detector 1

The measured phase currents are compared phasewise to the set *Phase start value*. If the measured value exceeds the set *Phase start value*, the level detector reports the exceeding of the value to the operation mode selector.

Level detector 2

The measured residual currents are compared to the set *Ground start value*. If the measured value exceeds the set *Ground start value*, the level detector reports the exceeding of the value to the operation mode selector.

Operation mode selector

Depending on the *Operation mode* setting, the operation mode selector makes sure that all required criteria are fulfilled for a reliable decision of an arc fault situation. The user can select either "Light+current", "Light only" or "BI controlled" operation mode. The operation is based on both current and light information in “Light+current” mode, on light information only in “Light only” mode or on remotely controlled information in “BI controlled” mode. When the "BI controlled" mode is in use and the `OPR_MODE` input is activated, the operation of the function is based on light information only. When the `OPR_MODE` input is deactivated, the operation of the function is based on both light and current information. When the required criteria are met, the drop-off timer is activated.

Drop-off timer

Once activated, the drop-off timer remains active until the input is deactivated or at least during the drop-off time. The `BLOCK` signal can be used to block the `OPERATE` signal or the light signal output `ARC_FLT_DET`.

4.9.5 Application

The arc protection can be realized as a stand-alone function in a single relay or as a station-wide arc protection, including several protection relays. If realized as a station-wide arc protection, different tripping schemes can be selected for the operation of the circuit breakers of the incoming and outgoing feeders.

Consequently, the relays in the station can, for example, be set to trip the circuit breaker of either the incoming or the outgoing feeder, depending on the fault location in the switchgear. For maximum safety, the relays can be set to always trip both the circuit breaker of the incoming feeder and that of the outgoing feeder.

The arc protection consists of:

- Optional arc light detection hardware with automatic backlight compensation for lens type sensors
- Light signal output `ARC_FLT_DET` for routing indication of locally detected light signal to another relay
- Protection stage with phase- and earth-fault current measurement.

The function detects light from an arc either locally or via a remote light signal. Locally, the light is detected by lens sensors connected to the inputs Light sensor 1, Light sensor 2, or Light sensor 3 on the serial communication module of the relay. The lens sensors can be placed, for example, in the busbar compartment, the breaker compartment, and the cable compartment of the metal-clad cubicle.

The light detected by the lens sensors is compared to an automatically adjusted reference level. Light sensor 1, Light sensor 2, and Light sensor 3 inputs have their own reference levels. When the light exceeds the reference level of one of the inputs, the light is detected locally. When the light has been detected locally or remotely and, depending on the operation mode, if one or several phase currents exceed the set *Phase start value* limit, or the earth-fault current the set *Ground start value* limit, the arc protection stage generates an operation signal. The stage is reset in 30 ms, after all three-phase currents and the earth-fault current have fallen below the set current limits.

The light signal output from an arc protection stage `ARC_FLT_DET` is activated immediately in the detection of light in all situations. A station-wide arc protection is realized by routing the light signal output to an output contact connected to a binary input of another relay, or by routing the light signal output through the communication to an input of another relay.

It is possible to block the tripping and the light signal output of the arc protection stage with a binary input or a signal from another function block.

Cover unused inputs with dust caps.

Arc protection with one protection relay

In installations, with limited possibilities to realize signalling between protection relays protecting incoming and outgoing feeders, or if only the protection relay for the incoming feeder is to be exchanged, an arc protection with a lower protective level can be achieved with one protection relay. An arc protection with one protection relay only is realized by installing two arc lens sensors connected to the protection relay protecting the incoming feeder to detect an arc on the busbar. In arc detection, the arc protection stage trips the circuit breaker of the incoming feeder. The maximum recommended installation distance between the two lens sensors in the busbar area is six meters and the maximum distance from a lens sensor to the end of the busbar is three meters.

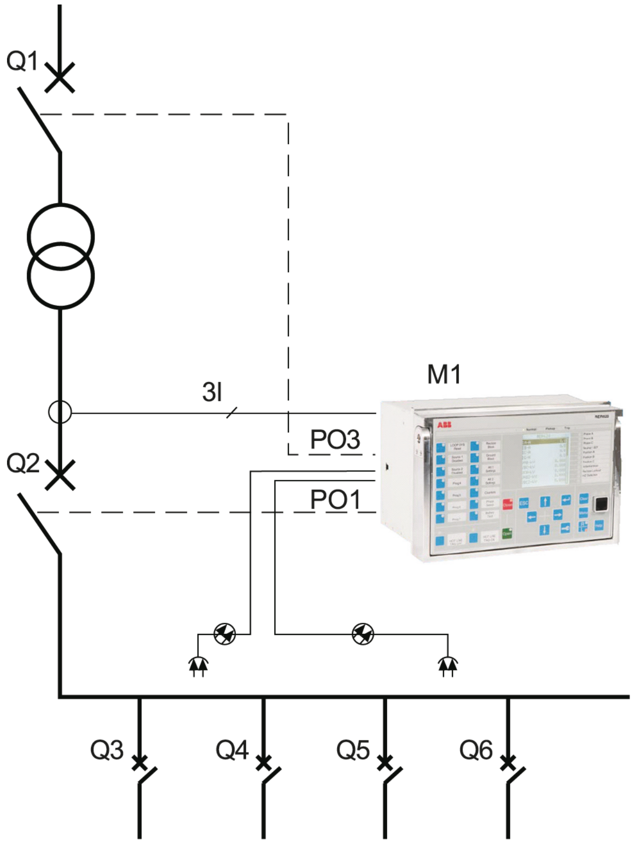


Figure 392: Arc protection with one protection relay

Arc protection with several protection relays

When using several protection relays, the protection relay protecting the outgoing feeder trips the circuit breaker of the outgoing feeder when detecting an arc at the cable terminations. If the protection relay protecting the outgoing feeder detects an arc on the busbar or in the breaker compartment via one of the other lens sensors, it will generate a signal to the protection relay protecting the incoming feeder. When detecting the signal, the protection relay protecting the incoming feeder trips the circuit breaker of the incoming feeder and generates an external trip signal to all protection relays protecting the outgoing feeders, which in turn results in tripping of all circuit breakers of the outgoing feeders. For maximum safety, the protection relays can be configured to trip all the circuit breakers regardless of where the arc is detected.

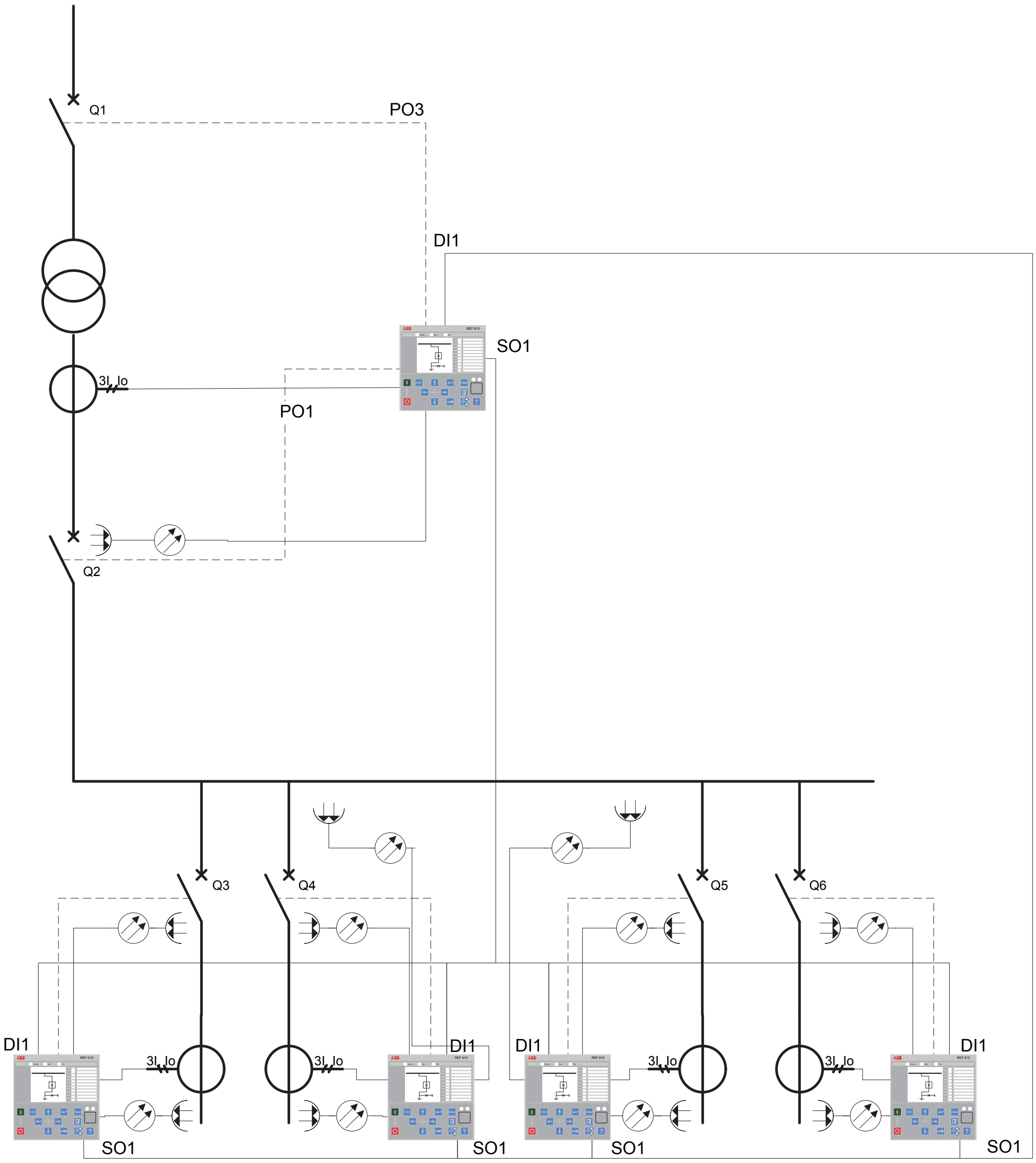


Figure 393: Arc protection with several protection relays and normal outputs

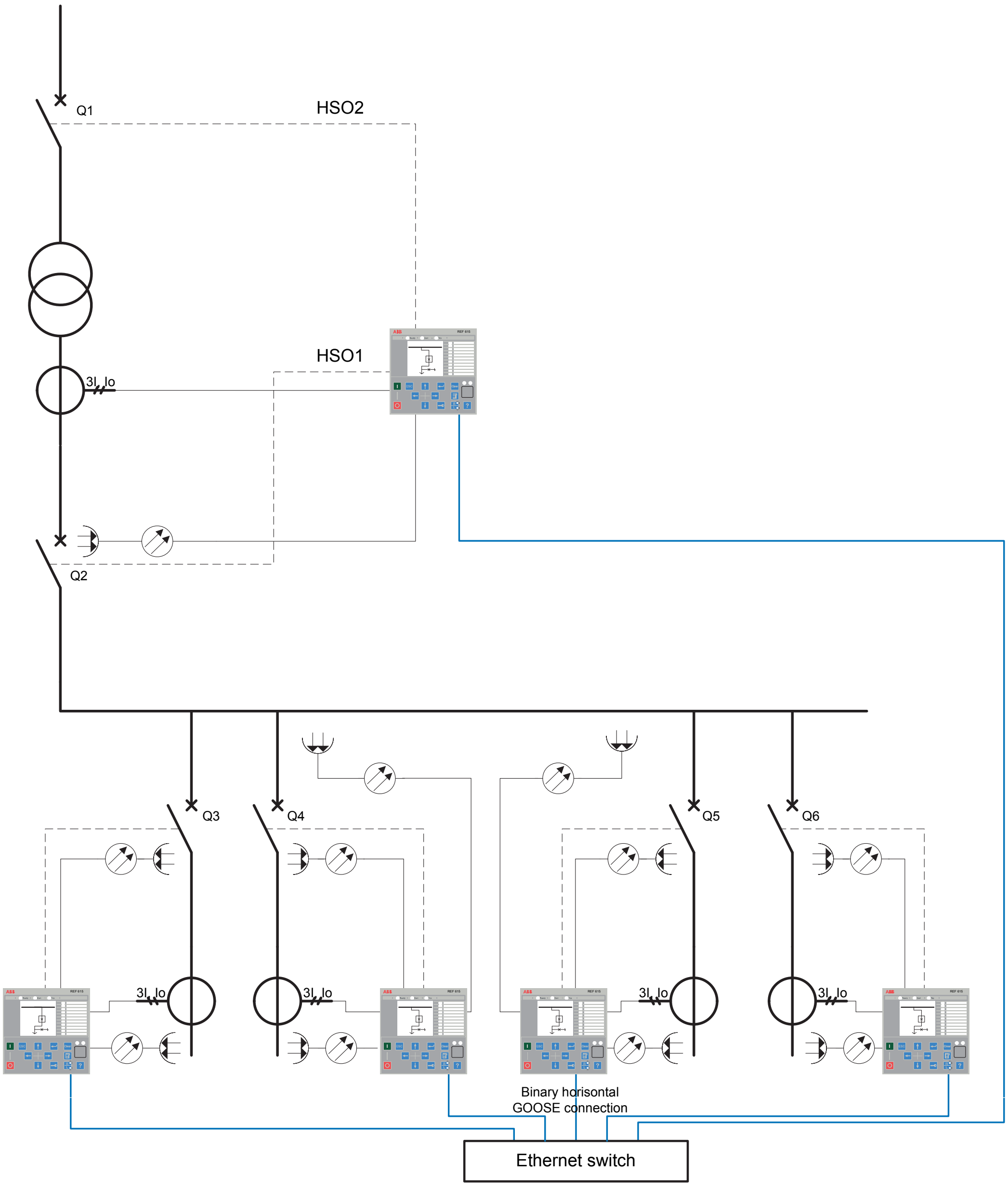


Figure 394: Arc protection with several protection relays and high-speed outputs and GOOSE

Arc protection with several protection relays and a separate arc protection system

When realizing an arc protection with both protection relays and a separate arc protection system, the cable terminations of the outgoing feeders are protected by protection relays using one lens sensor for each protection relay. The busbar and the incoming feeder are protected by the sensor loop of the separate arc protection system. With arc detection at the cable terminations, an protection relay trips the circuit breaker of the outgoing feeder. However, when detecting an arc on the busbar, the separate arc protection system trips the circuit breaker of the incoming feeder and generates an external trip signal to all protection relays protecting the outgoing feeders, which in turn results in tripping of all circuit breakers of the outgoing feeders.

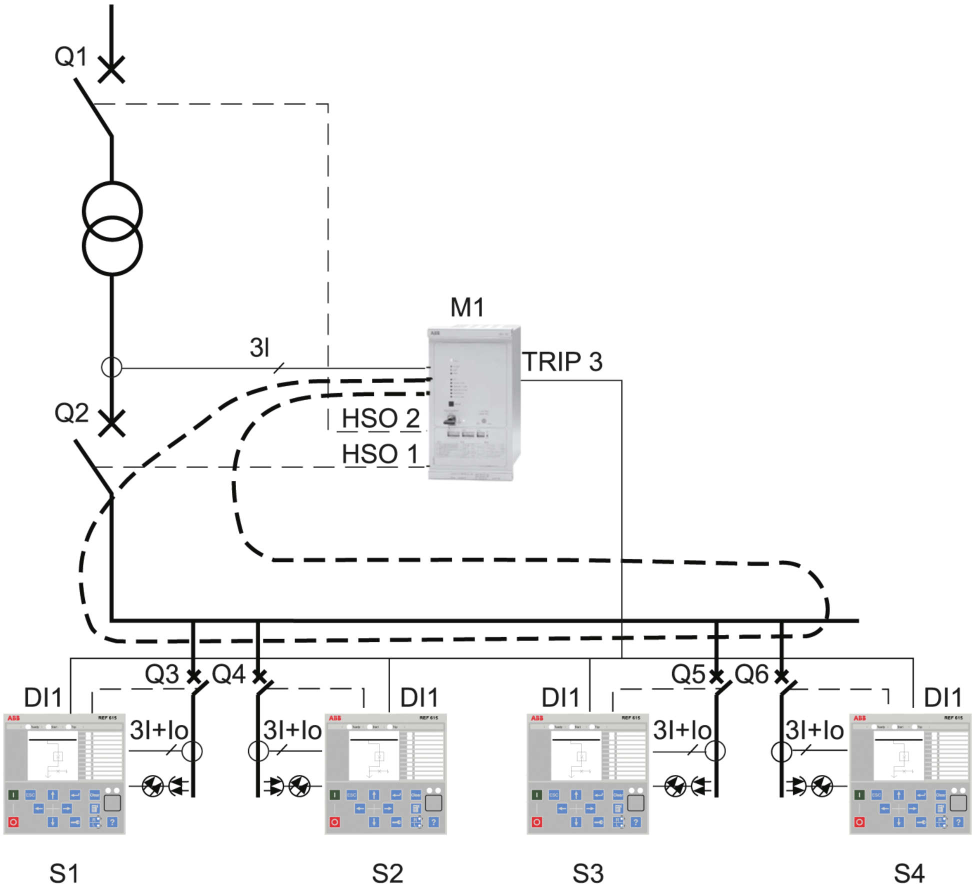


Figure 395: Arc protection with several protection relays and a separate arc protection system

4.9.6 Signals

Table 714: ARCSARC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs
REM_FLT_ARC	BOOLEAN	0=False	Remote Fault arc detected
OPR_MODE	BOOLEAN	0=False	Operation mode input

Table 715: ARCSARC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
ARC_FLT_DET	BOOLEAN	Fault arc detected=light signal output

4.9.7 Settings

Table 716: ARCSARC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Phase start value	0.50...40.00	xIn	0.01	2.50	Operating phase current
Ground start value	0.05...8.00	xIn	0.01	0.20	Operating residual current
Operation mode	1=Light+current 2=Light only 3=BI controlled			1=Light+current	Operation mode

Table 717: ARCSARC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

4.9.8 Monitored data

Table 718: ARCSARC Monitored data

Name	Type	Values (Range)	Unit	Description
ARCSARC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.9.9 Technical data

Table 719: ARCSARC Technical data

Characteristic		Value		
Operation accuracy		±3% of the set value or ±0.01 × I_n		
Operate time		Minimum	Typical	Maximum

Table continues on the next page

Characteristic		Value		
	Operation mode = "Light+current" ,	9 ms 4 ms	12 ms [3] 6 ms [4]	15 ms [3] 9 ms [4]
	Operation mode = "Light only" [2]	9 ms [3] 4 ms [4]	10 ms [3] 6 ms [4]	12 ms [3] 7 ms [4]
Reset time		Typically 40 ms [3] <55 ms [4]		
Reset ratio		Typically 0.96		

4.9.10 Technical revision history

Table 720: ARCSARC Technical revision history

Technical revision	Change
B	Internal Improvement.

4.10 Motor start-up supervision STTPMSU

4.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor start-up supervision	STTPMSU	Is2t n<	49,66,48,51LR

4.10.2 Function block

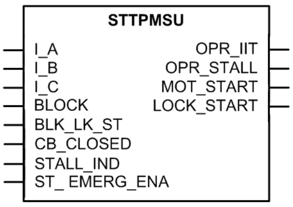


Figure 396: Function block

[1] *Phase start value* = 1.0 × I_n, current before fault = 2.0 × set *Phase start value*, f_n = 50 Hz, fault with nominal frequency, results based on statistical distribution of 200 measurements
[2] Includes the delay of the heavy-duty output contact
[3] Normal power output
[4] High-speed output

4.10.3 Functionality

The motor start-up 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 start-up 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 start-ups. Upon exceeding the specified number of start-ups 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.

4.10.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of STTPMSU can be described with a module diagram. All the modules in the diagram are explained in the next sections.

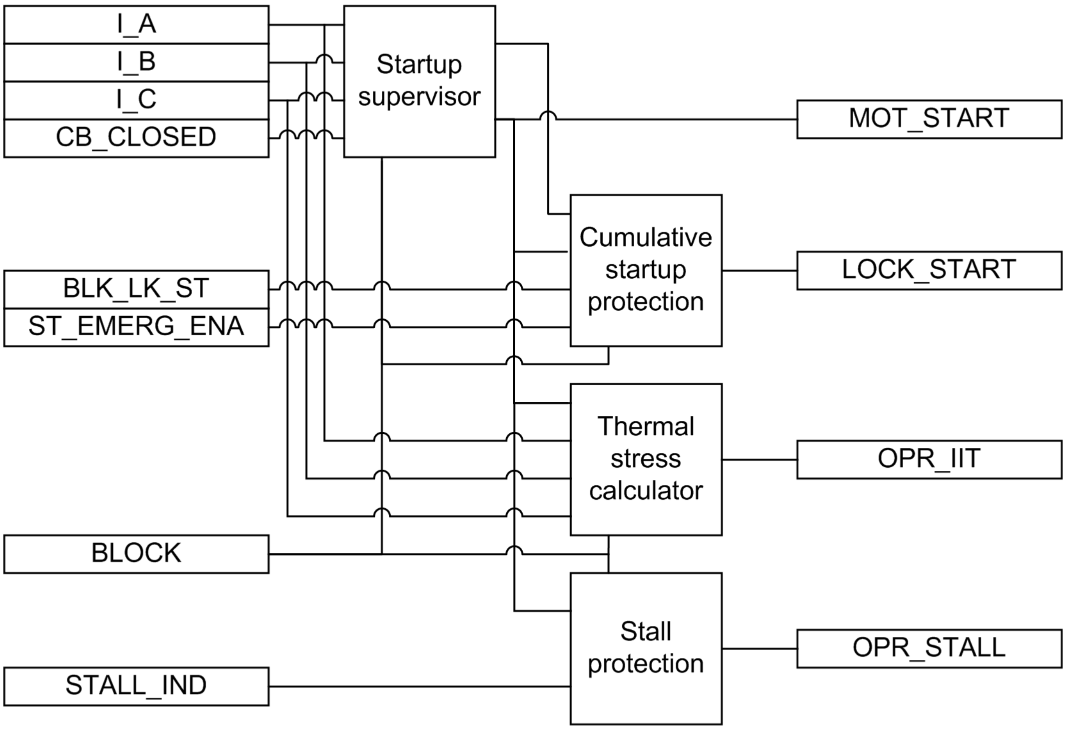


Figure 397: Functional module diagram

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 start-up condition. In this mode, the start-up 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 start-up 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 start-up condition. The start-up condition is detected by monitoring the TRMS currents.

In the "IIt & stall, CB" mode, the function calculates the thermal stress of the motor during the start-up condition but the start-up condition is detected by monitoring the TRMS current as well as the circuit breaker status.

In both the "IIt & stall" and "IIt & stall, CB" mode, the function also checks for motor stalling by monitoring the speed switch.

When the measured current value is used for start-up 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 *Motor standstill A* for longer than 100 milliseconds. If any of the phase currents of the de-energized condition rises to a value equal to or greater than *Motor standstill A*, the MOT_START output signal is activated indicating that the motor start-up is in progress. The MOT_START output remains active until the values of all three phase currents drop below 90 percent of the set value of *Start detection A* and remain below that level for a time of *Str over delay time*, that is, until the start-up situation is over.

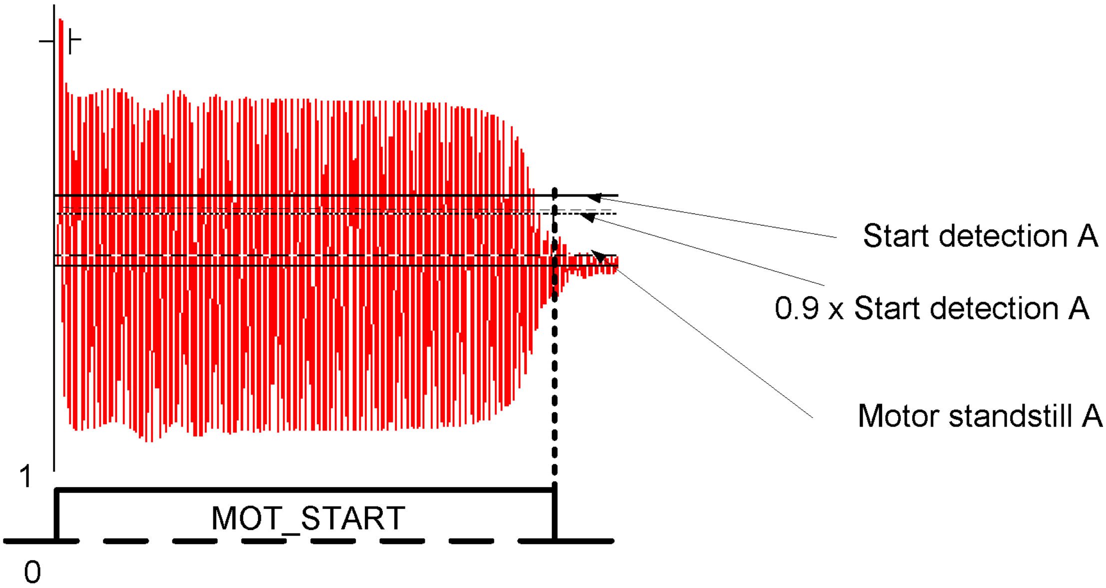


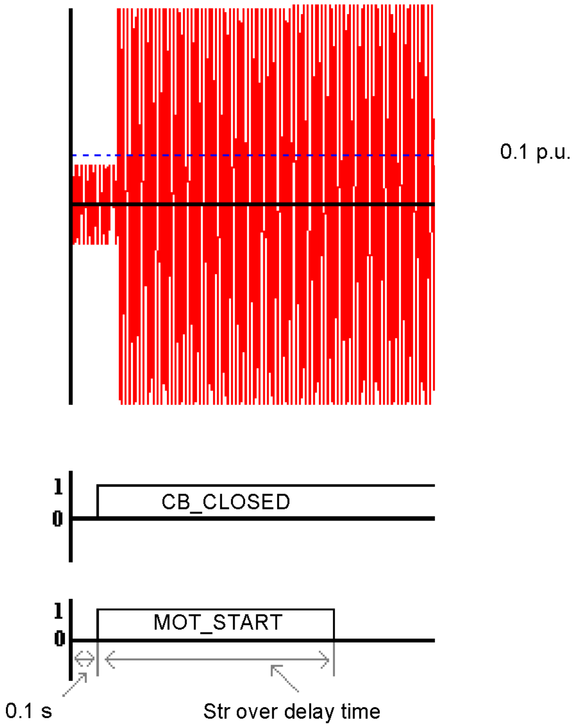
Figure 398: Functionality of start-up supervision in the "IIt and IIt&stall" mode

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 *Motor standstill A* setting for 100 milliseconds. The beginning of the motor start-up is recognized when CB is closed, that is, when the CB_CLOSED input is activated and at least one phase current value exceeds the *Motor standstill A* setting.

These two events do not take place at the same instant, that is, 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 start-up is recognized.

The motor start-up ends either within the value of the *Str over delay time* setting from the beginning of the start-up or the opening of CB or when the CB_CLOSED input is deactivated. The operation of the MOT_START output signal in this operation mode is as illustrated in *Figure 399*.

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.



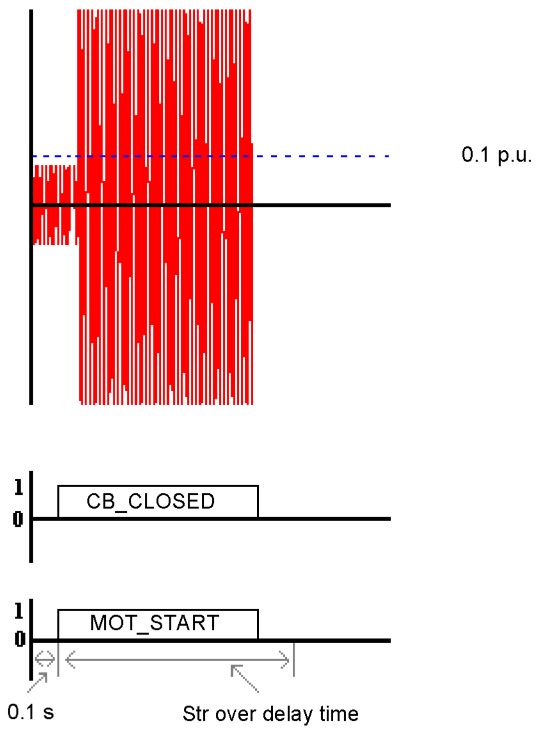


Figure 399: Functionality of start-up supervision in the "IIt, CB" mode and the "IIt and stall, CB" mode

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 start-up 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 start-up period cannot be judged. So 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 activation of the BLOCK input signal deactivates the MOT_START output.

Thermal stress calculator

Because of the high current surges during the start-up period, a 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 even worse. Consequently, a long start-up causes a rapid heating of the rotor.

This module calculates the thermal stress developed in the motor during start-up. The heat developed during the starting can be calculated with the equation.

$$W = R_s \int_0^t i_s^2 (t)\, dt$$

(Equation 144)

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 protection 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 activation of the BLOCK input signal resets the thermal stress calculator and deactivates 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 start-up current is specific to each motor and depends on the start-up method used, such as direct online, autotransformer and rotor resistance insertion. The start-up time is dependent on 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 start-up 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 indicates that 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 activation of the BLOCK input signal resets the operation time and deactivates the OPR_STALL output.

Cumulative start-up protection

This module protects the motor from an excessive number of start-ups.

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 start-up 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*.

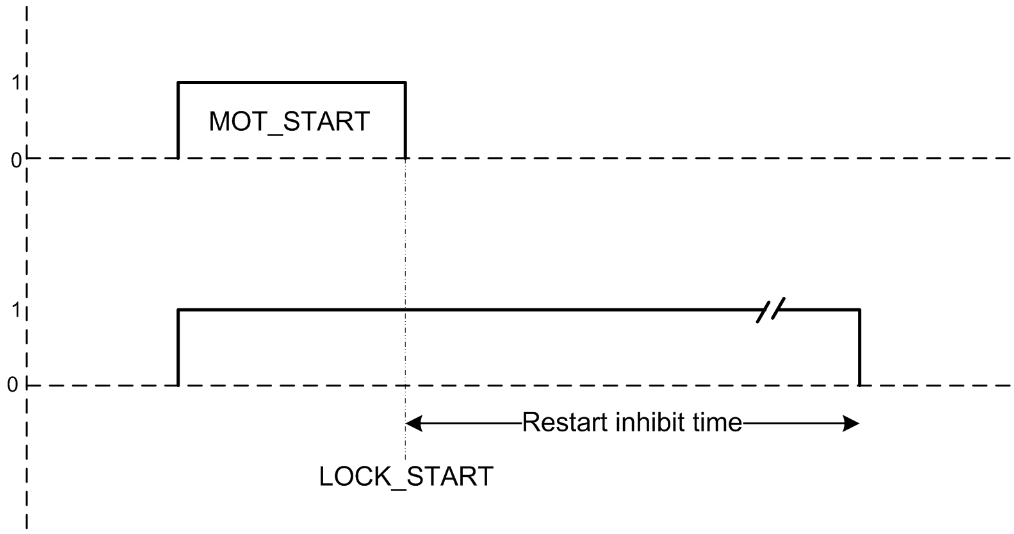


Figure 400: Time delay for cumulative start

This module also protects the motor from consecutive start-ups. 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 start-up time counter is set to *Cumulative time Lim* - 60s · *Emg start Red rate*. This disables LOCK_START and in turn makes the restart of the motor possible.

This module also calculates the total number of start-ups occurred, START_CNT. The value can be reset from the Clear menu.

The old *Number of motor start-ups occurred* counter value (START_CNT) can be taken into use by writing the value to the *Ini start up counter* parameter and resetting the value via the Clear menu from WHMI or LHMI.

The calculated values of T_RST_ENA, T_ST_CNT and START_CNT are available in the Monitored data view.

The activation of the BLK_LK_ST input signal deactivates the LOCK_START output. The activation of the BLOCK input signal resets the cumulative start-up counter module.

4.10.5 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.

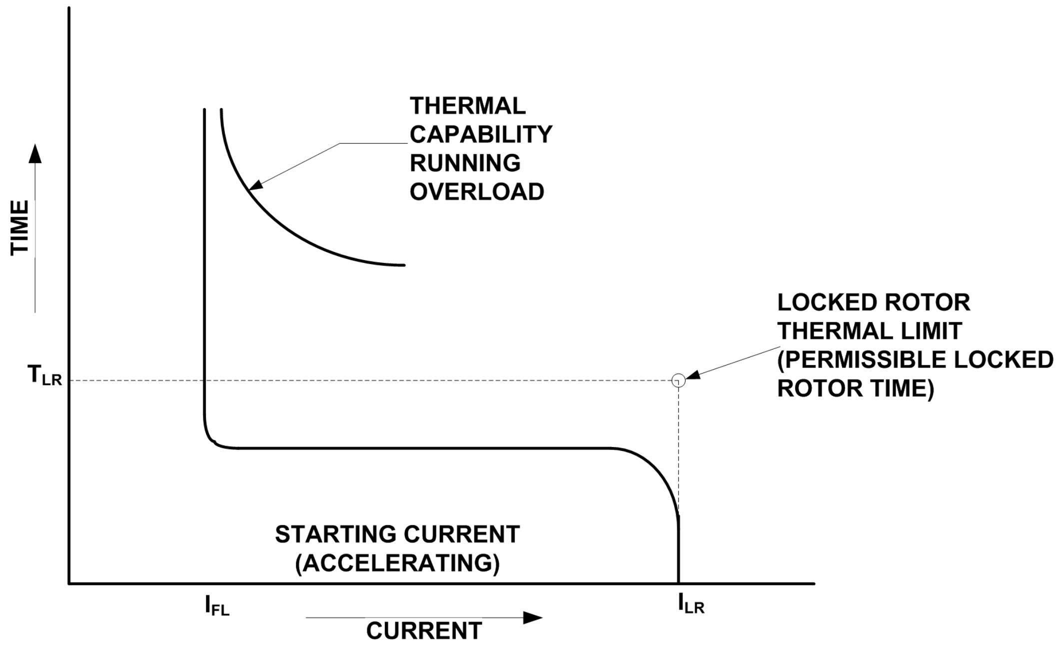


Figure 401: Typical motor starting and capability curves

The start-up supervision of a motor is an important function because of the higher thermal stress developed during starting. During the start-up, 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 start-up 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 start-up 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 start-up 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.

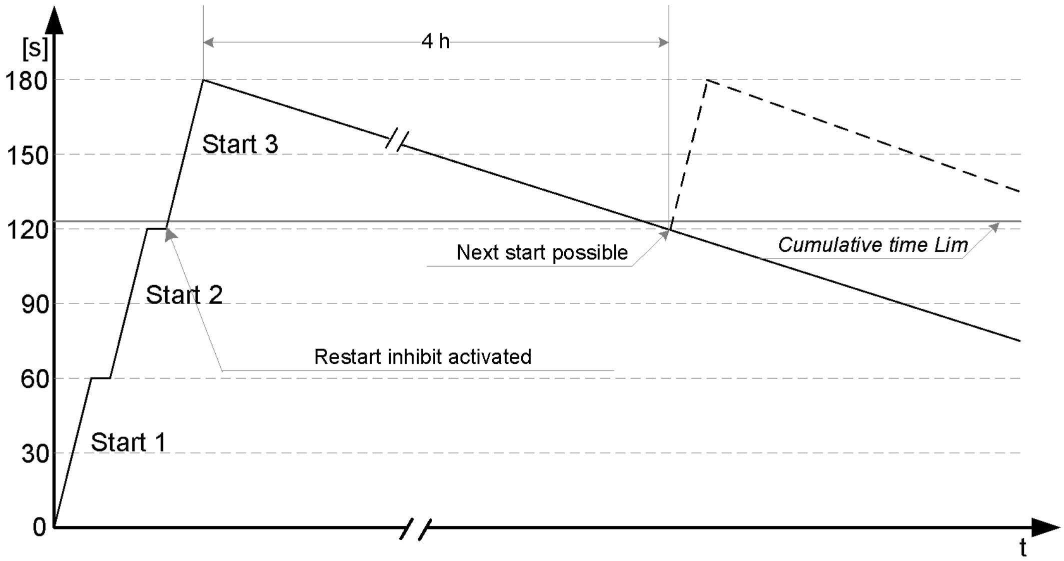


Figure 402: Typical motor-starting and capability curves

Setting of *Cumulative time Lim*

Cumulative time Lim is calculated by

$$\sum t_{si} = (n-1) \times t + margin$$

(Equation 145)

n	specified maximum allowed number of motor start-ups
t	start-up 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 146)

t	specified start time of the motor in seconds
t_{reset}	duration during which the maximum number of motor start-ups stated by the manufacturer can be made; time in hours

4.10.6 Signals

Table 721: STTPMSU Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block of function
BLK_LK_ST	BOOLEAN	0=False	Blocks lock out condition for restart of motor
CB_CLOSED	BOOLEAN	0=False	Input showing the status of motor circuit breaker
STALL_IND	BOOLEAN	0=False	Input signal for showing the motor is not stalling
ST_EMERG_ENA	BOOLEAN	0=False	Enable emergency start to disable lock of start of motor

Table 722: 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.

4.10.7 Settings

Table 723: STTPMSU Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Motor start-up A	1.0...10.0	xIn	0.1	2.0	Motor starting current
Motor start-up time	1...80	s	1	5	Motor starting time
Lock rotor time	2...120	s	1	10	Permitted stalling time
Str over delay time	0...60000	ms	1	100	Time delay to check for completion of motor startup period

Table 724: STTPMSU Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Start detection A	0.1...10.0	xIn	0.1	1.5	Current value for detecting starting of motor.

Table 725: STTPMSU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=IIt 2=IIt, CB 3=IIt + stall 4=IIt + stall, CB			1=IIt	Motor start-up operation mode
Counter Red rate	2.0...250.0	s/h	0.1	60.0	Start time counter reduction rate
Cumulative time Lim	1...500	s	1	10	Cumulative time based restart inhibit limit
Emg start Red rate	0.00...100.00	%	0.01	20.00	Start time reduction factor when emergency start is On
Restart inhibit time	0...250	min	1	30	Time delay between consecutive startups
Ini start up counter	0...999999		1	0	Initial value for the START_CNT

Table 726: STTPMSU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Motor standstill A	0.05...0.20	xIn	0.01	0.12	Current limit to check for motor standstill condition

4.10.8 Monitored data

Table 727: STTPMSU Monitored data

Name	Type	Values (Range)	Unit	Description
START_CNT	INT32	0...999999		Number of motor start-ups occurred
START_TIME	FLOAT32	0.0...999.9	s	Measured motor latest startup time in sec
T_ST_CNT	FLOAT32	0.0...99999.9	s	Cumulated start-up time in sec
T_RST_ENA	INT32	0...999	min	Time left for restart when lockstart is enabled in minutes
IIT_RL	FLOAT32	0.00...100.00	%	Thermal stress relative to set maximum thermal stress
STALL_RL	FLOAT32	0.00...100.00	%	Start time relative to the operate time for stall condition
STTPMSU	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.10.9 Technical data

Table 728: STTPMSU Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5 % of the set value or ±0.002 × I_n		
Start time [1, 2]		Minimum	Typical	Maximum

Table continues on the next page

[1] Current before = 0.0 × I_n, f_n = 50 Hz, overcurrent in one phase, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

Characteristic		Value		
	I_{Fault} = 1.1 × set *Start detection A*	27 ms	30 ms	34 ms
Operate time accuracy		±1.0 % of the set value or ±20 ms		
Reset ratio		Typically 0.90		

4.10.10 Technical revision history

Table 729: STTPMSU Technical revision history 66/51LRS Technical revision history

Technical revision	Change
B	Internal improvement
C	Added setting *Ini start up counter*.

4.11 Multipurpose protection MAPGAPC

4.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Multipurpose protection	MAPGAPC	MAP	MAP

4.11.2 Function block

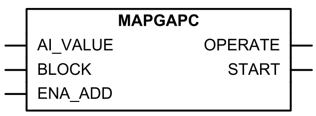


Figure 403: Function block

4.11.3 Functionality

The multipurpose 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 under- 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.

4.11.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MAPGAPC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

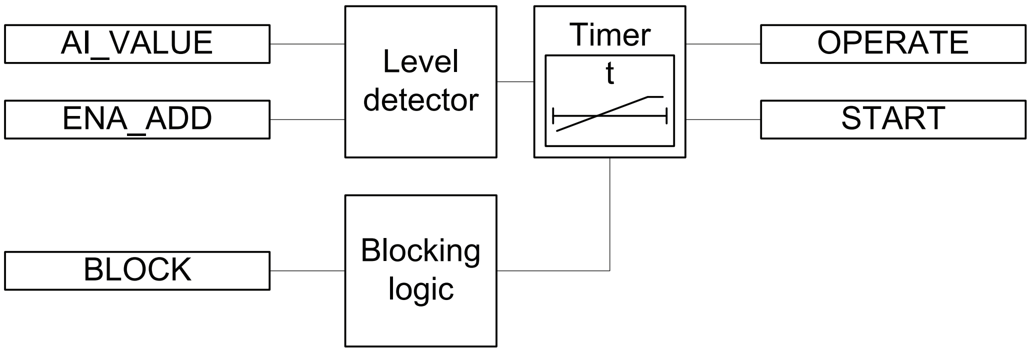


Figure 404: Functional module diagram

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 730: *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.

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.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.11.5 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.

4.11.6 Signals

Table 731: MAPGAPC Input signals

Name	Type	Default	Description
AI_VALUE	FLOAT32	0.0	Analogue input value
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_ADD	BOOLEAN	0=False	Enable start added

Table 732: MAPGAPC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.11.7 Settings

Table 733: MAPGAPC Group settings (Basic)

Parameter	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	Start value Add
Operate delay time	0...200000	ms	100	0	Operate delay time

Table 734: MAPGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Over 2=Under			1=Over	Operation mode

Table 735: MAPGAPC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	100	0	Reset delay time
Absolute hysteresis	0.01...100.00		0.01	0.10	Absolute hysteresis for operation

4.11.8 Monitored data

Table 736: MAPGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
MAPGAPC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.11.9 Technical data

Table 737: MAPGAPC Technical data

Characteristic	Value
Operation accuracy	±1.0 % of the set value or ±20 ms

4.12 Capacitor bank protection

4.12.1 Three-phase overload protection for shunt capacitor banks COLPTOC

4.12.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase overload protection for shunt capacitor banks	COLPTOC	3I> 3I<	51C/37

4.12.1.2 Function block

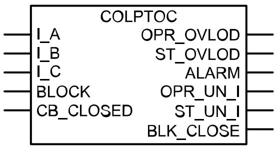


Figure 405: Function block symbol

4.12.1.3 Functionality

The three-phase overload protection for shunt capacitor banks function COLPTOC provides single-phase, two-phase and three-phase protection against overloads caused by harmonic currents and overvoltages in shunt capacitor banks. The operation of overload and alarm is based on the peak value of the integrated current which is proportional to the voltage across the capacitor.

The overload function operates with IDMT characteristic and an alarm function operates with DT characteristic.

COLPTOC provides undercurrent protection to detect disconnection of the capacitor. COLPTOC has breaker reclosing inhibit feature to enable complete capacitor discharging before breaker reclosing after it has operated.

COLPTOC contains blocking functionality. It is possible to block the function outputs, timers or the function itself.

4.12.1.4 Operation principle

The function can be enabled and disabled with the Operation setting. The corresponding parameter values are “On” and “Off”.

The operation of COLPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

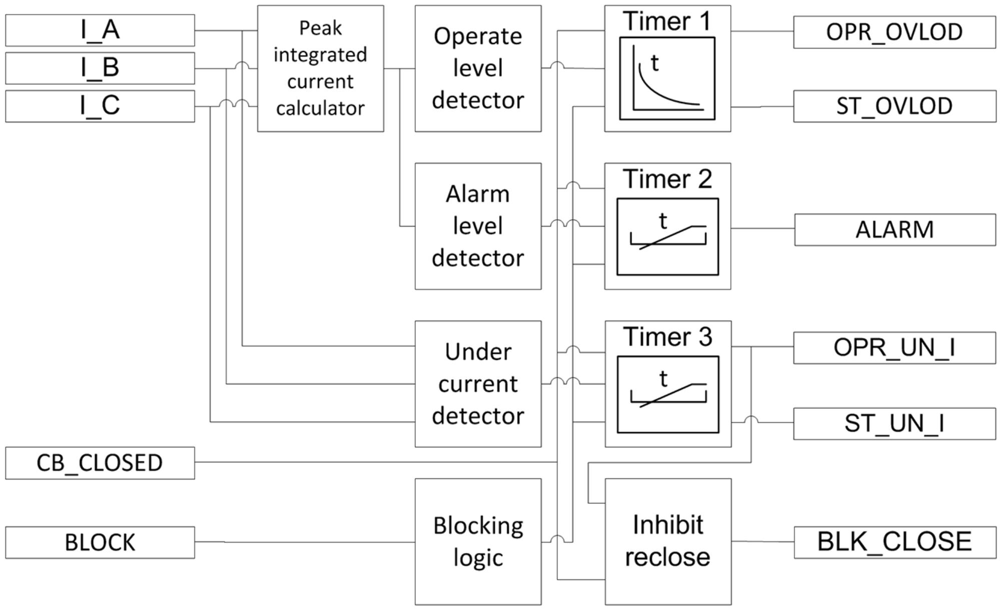


Figure 406: Functional module diagram

Peak integrated current calculator

The peak integrated current calculator calculates peak value of integrated current (`I_PEAK_INT_A`, `I_PEAK_INT_B` and `I_PEAK_INT_C`) which is proportional to the voltage over capacitor. The `I_PEAK_INT_A`, `I_PEAK_INT_B` and `I_PEAK_INT_C` values are available in monitored data view. The frequency response of the peak integrated current calculator can be seen in *Figure 407*.

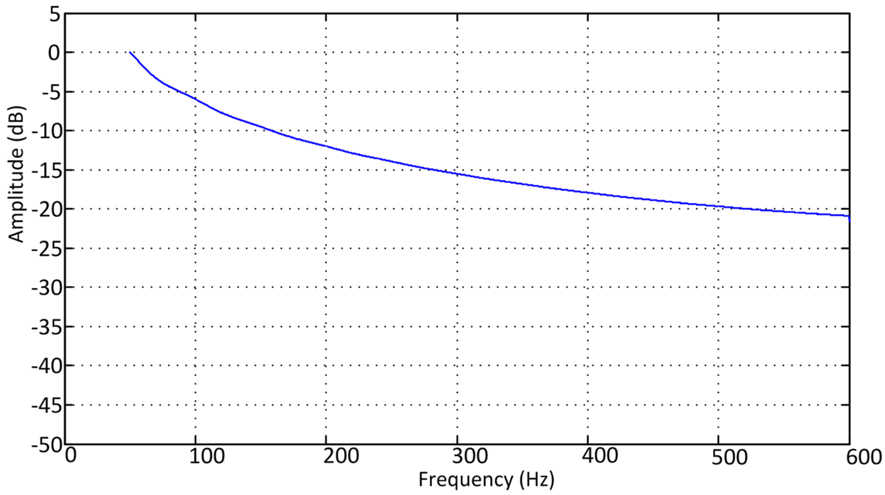


Figure 407: Frequency response of the peak integrated current calculator

Operate level detector

The Operate level detector compares `I_PEAK_INT_x` value to *Start value overload*. If the phase or phases in which `I_PEAK_INT_x` exceeds the setting matches the *Num of start phases* setting, the Operate level detector module activates the Timer 1 module.

Timer 1

Once activated, the Timer 1 module activates the ST_OVLOD output. The operation time depends on the overload level and *Time multiplier*. The operation time under standard characteristics is based on ANSI/IEEE 37.99 and IEC 60871-1 recommendations.

Table 738: Standard Curve characteristics for IDMT Curve

Overload value	IED operate time(s) with k = 1	Standard
1.10	43200	IEC60871-1
1.15	1800	IEC60871-1
1.20	300	IEC60871-1
1.30	60	ANSI/IEEE37.99,IEC60871-1
1.40	15	ANSI/IEEE37.99
1.70	1	ANSI/IEEE37.99
2.20	0.120	ANSI/IEEE37.99

Operate time is based on maximum value of I_PEAK_INT_A, I_PEAK_INT_B and I_PEAK_INT_C. From maximum value calculated , operate time between any two consecutive points in the standard table is based on logarithmic interpolation.

The operate time can be scaled using the *Time multiplier* setting. The OPR_OVLOD output is activated if the overload situation lasts long enough to exceed the operation time.

The operate time for the operation overload stage is limited between 0.1 s to 43200 s (12 hours) if *Time multiplier* is used.

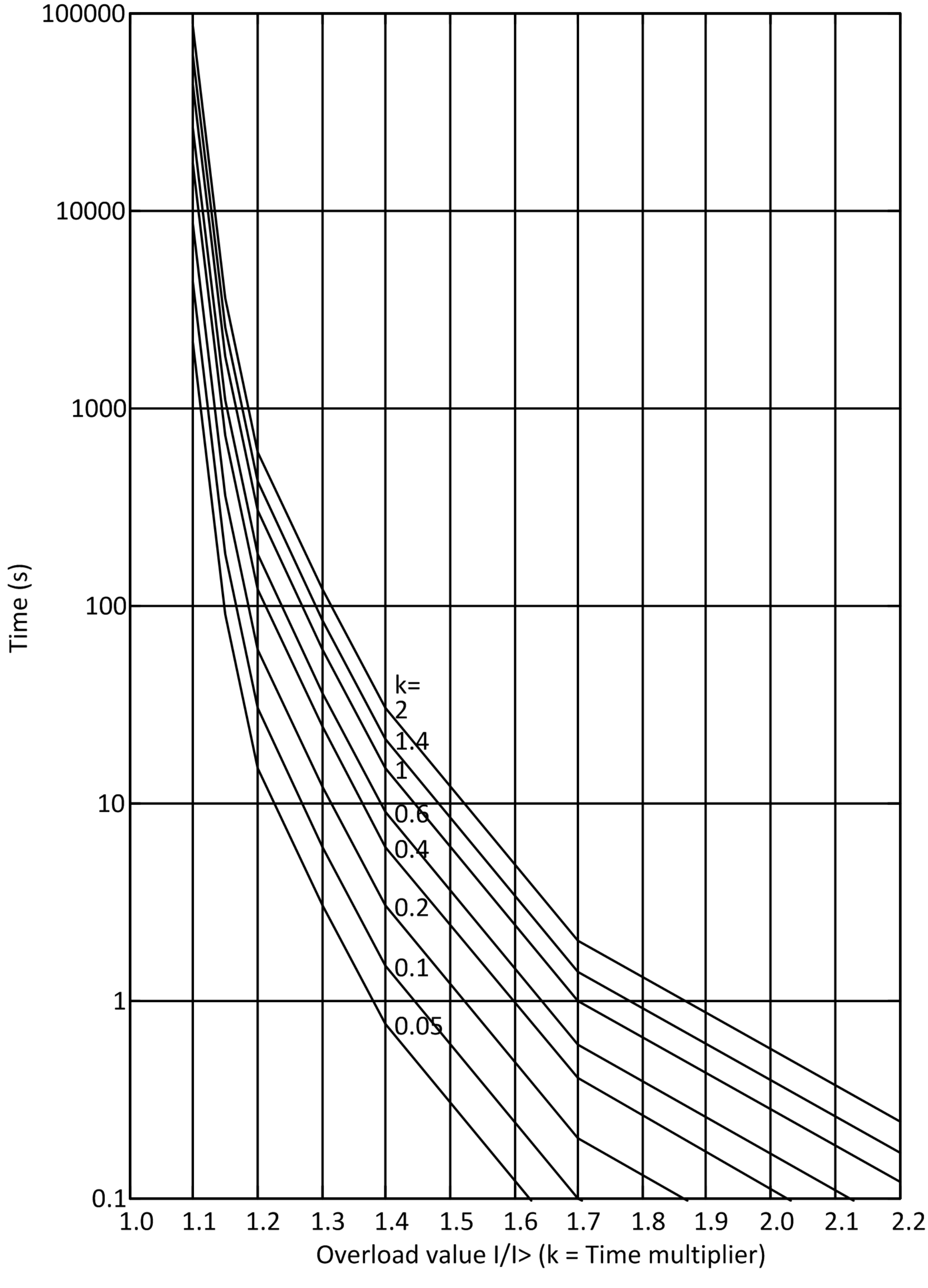


Figure 408: Inverse-time characteristic curves for overload stage

If the integrated current exceeds 1.1 times the setting *Start value overload* for a short period but does not operate as the current decreases within *Start value overload*, the output ST_OVLOD is kept active but the operation timer is frozen. However, if the integrated current exceeds 1.1 times the *Start value overload* setting value again, the operation timer continue from the freezing point. Thus, the operation timer is cumulative. If the integrated current exceeds 1.1 times the setting

Start value overload only once and remains within the *Start value overload* area for 24 hours, the operation timer and the output ST_OVLOD are reset.

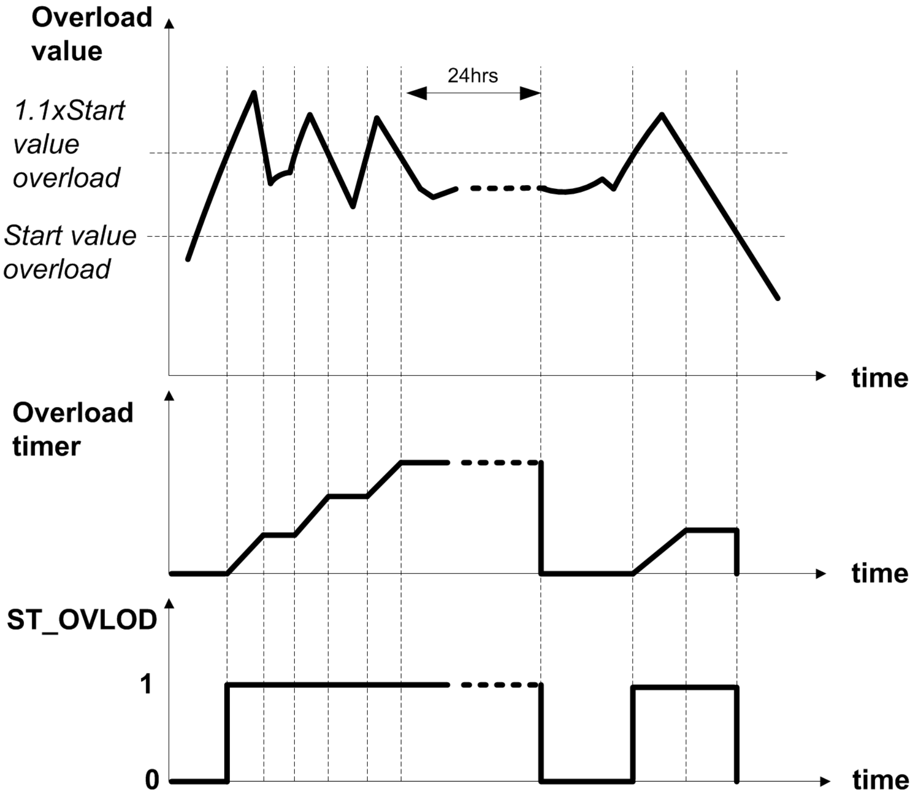


Figure 409: The behavior of the IDMT timer and the output ST_OVLOD

The ST_DUR_OVLOD output indicates the percentage ratio of the start situation and the operation time in the Timer 1 module and is available in the monitored data view.

The Timer 1 module is internally blocked for one second after the capacitor bank is connected by detecting the rising edge of the CB_CLOSED signal. The CB_CLOSED signal is True when the CB position is closed.

Alarm level detector

The Alarm level detector compares I_PEAK_INT_x value to *Alarm start value*. If the phase or phases in which I_PEAK_INT_x exceeds the setting matches the *Num of start phases* setting, the Alarm level detector module activates the Timer 2 module.

The *Num of start phases* setting is a common setting for both Operate level detector and Alarm level detector.

Timer 2

The Timer 2 characteristics are according to Definite Time (DT) .When the operation timer has reached the value of *Alarm delay time*, the ALARM output is activated.

If a drop-off situation happens, the timer is reset.

The Timer 2 module is internally blocked for one second after the capacitor bank is connected by detecting the rising edge of the CB_CLOSED signal. The CB_CLOSED signal is True when the CB position is closed.

Under current detector

The Under current detector module can be enabled by setting *Enable under current* to “Enable” and disabled by setting it to “Disable”. The Under current detector module is also disabled when CB_CLOSED is FALSE, that is, when circuit breaker is open.

The fundamental frequency component of phase currents is compared to the setting *Start value Un Cur*. If all the three-phase currents are below the setting *Start value Un Cur*, the Under current detector module enables the Timer 3 module.

Timer 3

Once activated, the Timer 3 module activates the ST_UN_I output. The operation is based on DT characteristics. When the operation timer has reached the value of *Un Cur delay time*, the OPR_UN_I output is activated.

If the undercurrent situation disappears, the operation timer is reset. The ST_DUR_UN_I output indicates the percentage ratio of the undercurrent start situation and the set operation time in the Timer 3 module and is available in the monitored data view.

The OPR_UN_I output is of pulse type and remains TRUE for 150 ms. After that, ST_DUR_UN_I and OPR_UN_I are deactivated and ST_DUR_UN_I is reset.

If the circuit breaker closed status signal is not detected, the constant value TRUE has to be connected to CB_CLOSED input to enable the undercurrent detector.

If the circuit breaker status signal is not connected to CB_CLOSED input, the OPR_UN_I output is activated even if the circuit breaker is open and undercurrent is detected.

Inhibit reclose

When the output OPR_UN_I becomes active or when the CB_CLOSED state changes from TRUE to FALSE, that is, when circuit breaker opens, the reclosing inhibition module activates output BLK_CLOSE.

If *Enable under current* is set to “Disable”, the reclosing inhibition operation is based purely on the CB_CLOSED input.

The behavior of the BLK_CLOSE output depends on *Reclose inhibit mode*. If *Reclose inhibit mode* is set to “Lockout”, the BLK_CLOSE output needs to be reset manually from the clearing menu parameter *COLPTOC inhibit recl*. If *Reclose inhibit mode* is set to “Non-latched”, the BLK_CLOSE output resets after the set *Reclose inhibit time* has elapsed.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, COLPTOC is executed normally but the OPR_OVLOD and OPR_UN_I outputs are not allowed to activate.

The BLOCK input does not block the BLK_CLOSE signal.

4.12.1.5 Application

The application area for three-phase overload protection function of shunt capacitor bank is the protection of power capacitor banks intended for reactive power compensation and filtering of the harmonics. Shunt capacitor banks provide a low-impedance path to harmonic currents and hence attract harmonic currents flowing in the system. Increased harmonic currents result in excessive voltage stress across the capacitor bank. According to the standards, a high-voltage capacitor shall be able to withstand 10% overload. Loading beyond that can cause damage to the capacitor bank and in turn to the system. Hence, COLPTOC is specially designed for the protection against overloads produced by harmonic currents and overvoltage.

Undercurrent protection is used to disconnect the capacitor bank from the rest of the power system when the voltage at the capacitor bank terminals is too low for too long a period of time. To avoid an undercurrent trip operation when the capacitor bank is disconnected from the power system, the undercurrent functionality is blocked by using the capacitor bank circuit breaker status signal.

Furthermore, the reclosing inhibition feature provides protection against the reconnection of a charged capacitor to a live network. Whenever the capacitor bank circuit breaker is opened, the reclosing is inhibited for the duration of the discharge time of the capacitor. The reclosing inhibition functionality can be disabled manually or automatically. In the manual mode, the inhibition reclosing has to be manually reset and in automatic mode, the reclosing inhibitionl resets automatically after the set time.

4.12.1.6 Signals

Table 739: COLPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current

Table continues on the next page

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
CB_CLOSED	BOOLEAN	0=False	Input showing the status of capacitor circuit breaker

Table 740: COLPTOC Output signals

Name	Type	Description
OPR_OVLOD	BOOLEAN	Overload operated
OPR_UN_I	BOOLEAN	Operate under current
ST_OVLOD	BOOLEAN	Overload started
ST_UN_I	BOOLEAN	Under current started
ALARM	BOOLEAN	Alarm
BLK_CLOSE	BOOLEAN	Inhibit re-close of capacitor bank

4.12.1.7 Settings

Table 741: COLPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value overload	0.30...1.50	xIn	0.01	1.00	Start value for overload stage
Alarm start value	80...120	%	1	105	Alarm start value (% of Start value overload)
Start value Un Cur	0.10...0.70	xIn	0.01	0.50	Start value for under current operation
Time multiplier	0.05...2.00		0.01	1.00	Time multiplier for Capacitor Bank protection curves
Alarm delay time	500...6000000	ms	100	300000	Alarm delay time
Un Cur delay time	100...120000	ms	100	1000	Delay time for under current operation

Table 742: COLPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reclose inhibit time	1...6000	s	1	1	Reclose inhibit time

Table 743: COLPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reclose inhibit mode	1=Non-latched			1=Non-latched	Reclose inhibit mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Lockout				
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation

Table 744: COLPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Enable under current	0=Disable 1=Enable			1=Enable	Enable under current functionality

4.12.1.8 Monitored data

Table 745: COLPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
ST_DUR_OVLOD	FLOAT32	0.00...100.00	%	Start duration for overload stage
ST_DUR_UN_I	FLOAT32	0.00...100.00	%	Start duration for under current operation
I_PEAK_INT_A	FLOAT32	0.00...40.00		Phase A peak value of the integrated current of the capacitor
I_PEAK_INT_B	FLOAT32	0.00...40.00		Phase B peak value of the integrated current of the capacitor
I_PEAK_INT_C	FLOAT32	0.00...40.00		Phase C peak value of the integrated current of the capacitor
COLPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.12.1.9 Technical data

Table 746: COLPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz, and no harmonics
	5 % of the set value or 0.002 × I_n
Start time for overload stage [1, 2]	Typically 75 ms
Start time for under current stage [2, 3]	Typically 26 ms
Reset time for overload and alarm stage	Typically 60 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	1 % of the set value or ±20 ms
Operate time accuracy in inverse time mode	10 % of the theoretical value or ±20 ms
Suppression of harmonics for under current stage	DFT: -50 dB at f = n × fn, where n = 2,3,4,5,..

4.12.1.10 Technical revision history

Table 747: COLPTOC Technical revision history

Technical revision	Change
B	Internal improvement.

4.12.2 Current unbalance protection for capacitor banks CUBPTOC

4.12.2.1 Identification

Table 748: Function identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current unbalance protection for shunt capacitor banks	CUBPTOC	dI>C	51NC-1

[1] Harmonics current before fault = 0.5 × I_n, harmonics fault current 1.5 × *Start value*, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact
[3] Harmonics current before fault = 1.2 × I_n, harmonics fault current 0.8 × *Start value*, results based on statistical distribution of 1000 measurements

4.12.2.2 Function block

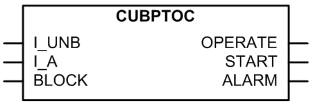


Figure 410: Function block symbol

4.12.2.3 Functionality

The current unbalance protection for shunt capacitor banks function CUBPTOC is used to protect the double-Y-connected capacitor banks from internal faults. CUBPTOC is suitable for the protection of internally fused, externally fused and fuseless applications.

CUBPTOC has two stages of operation, that is, operation stage and alarm stage. In the operating stage, CUBPTOC starts when the measured unbalance current exceeds the set limit. The operation time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The operation under alarm stage is either based on the DT characteristics or the faulty element counter of a capacitor bank.

CUBPTOC has a blocking functionality. It is possible to block the function outputs, timers or the function itself.

4.12.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”. The current unbalance protection for shunt capacitor banks operates on the DFT measurement mode.

The operation of CUBPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

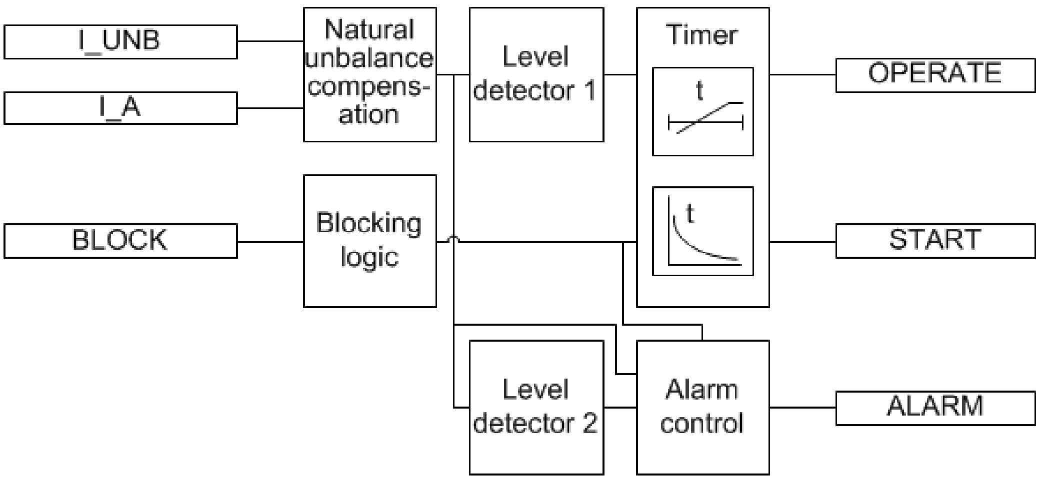


Figure 411: Functional module diagram

Natural unbalance Compensation

A standard double-Y-connected shunt capacitor bank configuration is shown in *Figure 412*. The fundamental frequency component of an unbalance current is measured on the common neutral connecting the two balanced parts of a shunt capacitor bank, that is, between star point 1 and star point 2.

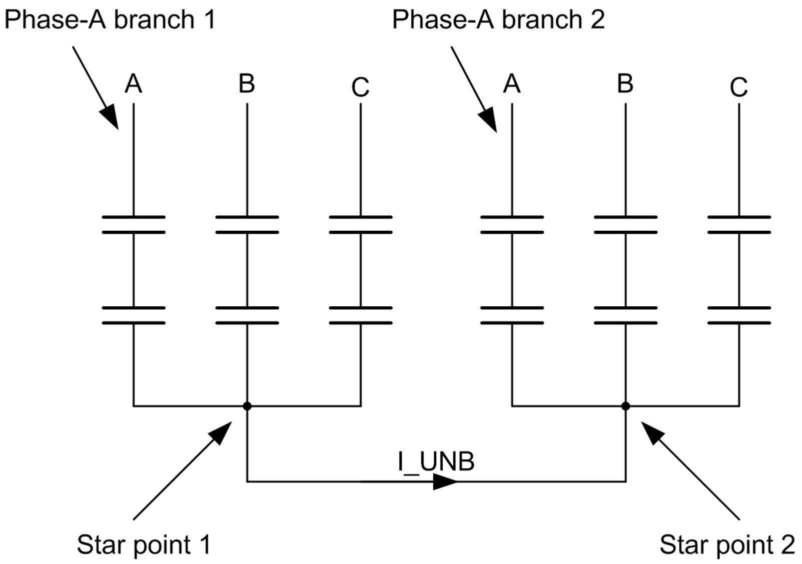


Figure 412: Double-Y-connected capacitor bank

The phase angle of the measured fundamental frequency component of the unbalance current I_UNB is synchronized by using the phase current I_A as a reference.

$$\angle \overline{I_{unb}} = \angle \overline{I\_UNB} - \angle \overline{I\_A}$$

(Equation 147)

In a three-phase star-connected capacitor bank circuit, there may be some amount of natural unbalance current flowing through the neutral, which is primarily due to capacitor manufacturing tolerances. The natural unbalance current must be compensated for before using the measured unbalance current for the function operation. The natural unbalance current needs to be recorded when there is no fault in the capacitor banks, and it is initiated through the command *Record unbalance*, available under menu path **Control** > **CUBPTOC**. By selecting *Record unbalance* with value "Record", the measured unbalance current $\overline{I}_{Unb}$ is considered as the natural unbalance current $\overline{I}_{NatUnb}$ and is stored as a reference. The amplitude and angle of the recorded natural unbalance current I_AMPL_NAT and I_ANGL_NAT are available in the monitored data view.

Once the natural unbalance current is recorded during further executions of the function, the natural unbalance current is subtracted from the measured unbalance current $\overline{I}_{Unb}$ to obtain the compensated unbalance current $\overline{I}_{CompUnb}$ as shown in *Figure 413*.

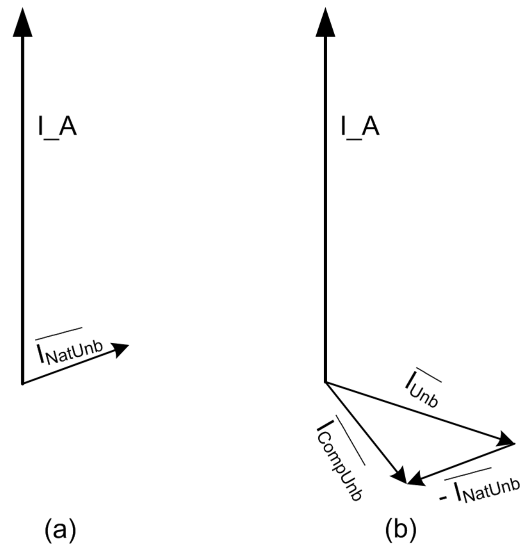


Figure 413: Natural unbalance compensation. (a) Healthy condition when the natural unbalance is recorded (b) Unbalance compensation during faulty conditions

The natural unbalance current compensation is enabled using the setting *Natural Comp Enable*. If *Natural Comp Enable* is set to “FALSE”, the unbalance current is not compensated. If *Natural Comp Enable* is set to “TRUE”, the compensated unbalance current is calculated based on the equation.

$$\overline{I}_{CompUnb} = \overline{I}_{Unb} - \overline{I}_{NatUnb}$$

(Equation 148)

The amplitude I_AMPL_COMP and the angle I_ANGL_COMP of the compensated unbalance current $\overline{I}_{CompUnb}$ are available in the monitored data view.

Level detector 1

The calculated compensated unbalance current I_AMPL_COMP is compared to the set *Start value*. If I_AMPL_COMP exceeds the set *Start value*, the Level detector 1 sends an enabling signal to the Timer 1 module.

Timer 1

Once activated, the Timer 1 module 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* and *Curve parameter E*.

In a drop-off situation, that is when a fault suddenly disappears before the operate delay is exceeded, the Timer 1 reset state is activated. The functionality of the Timer 1 in the reset state depends on the combination of the Operating curve type 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, an immediate reset occurs. The START output is deactivated when the reset timer has elapsed.

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.

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.

The Timer 1 module calculates the start duration value START_DUR, which indicates the percentile ratio of the start situation and the set operation time. The value is available in the monitored data view.

In a typical double-Y-connected configuration (*Figure 412*), there are two branches in every phase and hence six individual counters COUNT_BR1_A, COUNT_BR2_A, COUNT_BR1_B, COUNT_BR2_B, COUNT_BR1_C and COUNT_BR2_C are maintained. Based on the phase angle of the compensated unbalance current I_ANGL_COMP, the phase and the branch of the element failure location is detected. However, the element failure location also depends on the type of capacitor banks, that is, whether internal or external fuses are used. The setting *Fuse location* is used to set the capacitor bank type as “External” or “Internal”.

For an external fuse capacitor bank, the element failure location and corresponding counters to be incremented are determined based on the phase angle of the compensated unbalance current.

Table 749: Element failure location and counters to be incremented for external fuse case

Phase angle of the compensated unbalance current (degrees)	Phase and branch of the element failure	Counters to be incremented
-15...+15	Phase-A branch 1	COUNT_BR1_A
-15...-45	Phase-A branch 1 Phase-C branch 2	COUNT_BR1_A COUNT_BR2_C
-45...-75	Phase-C branch 2	COUNT_BR2_C
-75...-105	Phase-B branch 1 Phase-C branch 2	COUNT_BR1_B COUNT_BR2_C
-105...-135	Phase-B branch 1	COUNT_BR1_B
-135...-165	Phase-B branch 1 Phase-A branch 2	COUNT_BR1_B COUNT_BR2_A
-165...-180	Phase-A branch 2	COUNT_BR2_A
+165...+180	Phase-A branch2	COUNT_BR2_A
+135...+165	Phase-C branch 1 Phase-A branch 2	COUNT_BR1_C COUNT_BR2_A
+105...+135	Phase-C branch 1	COUNT_BR1_C

Table continues on the next page

Phase angle of the compensated unbalance current (degrees)	Phase and branch of the element failure	Counters to be incremented
+75...+105	Phase-C branch1 Phase-B branch2	COUNT_BR1_C COUNT_BR2_B
+45...+75	Phase-B branch2	COUNT_BR2_B
+15...+45	Phase-A branch1 Phase-B branch2	COUNT_BR1_A COUNT_BR2_B

If the capacitor bank is fuseless, then the setting *Fuse location* should be set to “External” and *Table 749* can be used to determine the element failure location.

If the compensated unbalance current I_AMPL_COMP is greater than three times the set *Alarm value*, it is considered to be a case of blown external fuse. For the internal fuse and blown fuse cases, the element failure location and corresponding counters to be incremented are determined based on the phase angle of the compensated unbalance current.

Table 750: Element failure location and counters to be incremented for internal fuse and blown fuse case

Phase angle of the compensated unbalance current (degrees)	Phase and branch of the element failure	Counters to be incremented
-15...+15	Phase-A branch 2	COUNT_BR2_A
-15... -45	Phase-A branch 2 Phase-C branch 1	COUNT_BR2_A COUNT_BR1_C
-45...-75	Phase-C branch 1	COUNT_BR1_C
-75...-105	Phase-B branch 2 Phase-C branch 1	COUNT_BR2_B COUNT_BR1_C
-105...-135	Phase-B branch 2	COUNT_BR2_B
-135...-165	Phase-B branch 2 Phase-A branch 1	COUNT_BR2_B COUNT_BR1_A
-165...-180	Phase-A branch 1	COUNT_BR1_A
+165...+180	Phase-A branch 1	COUNT_BR1_A
+135...+165	Phase-C branch 2 Phase-A branch 1	COUNT_BR2_C COUNT_BR1_A
+105...+135	Phase-C branch 2	COUNT_BR2_C
+75...+105	Phase-C branch 2 Phase-B branch 1	COUNT_BR2_C COUNT_BR1_B
+45...+75	Phase-B branch 1	COUNT_BR1_B
+15...+45	Phase-A branch 2	COUNT_BR2_A

Phase angle of the compensated unbalance current (degrees)	Phase and branch of the element failure	Counters to be incremented
	Phase-B branch 1	COUNT_BR1_B

After *Alarm delay time* has elapsed, the corresponding counter value is incremented based on the magnitude of the unbalance current. If I_AMPL_COMP is less than 1.5 times the set *Alarm value*, the counter is incremented by one. Furthermore, if I_AMPL_COMP is between 1.5 and 2.5 times the set *Alarm value*, the counter is incremented by two and so on.

Normally, the setting *Alarm value* is about 0.1 percent lower than the value of the unbalance current which is caused by one faulty element. This setting value has to be chosen carefully because a slightly lower value may lead to a situation where the counters show more failures than the actual. Too high setting leads to a situation where a fault is not detected.

The counter values COUNT_BR1_A, COUNT_BR2_A, COUNT_BR1_B, COUNT_BR2_B, COUNT_BR1_C and COUNT_BR2_C are available in the monitoring data view. The total number of element failures in double-Y-connected capacitor banks, FAIL_COUNT, is available in the monitored data view.

The ALARM output is activated, when the value of FAIL_COUNT exceeds the setting *Element failure limit*.

The counter values can be reset via *CUBPTOC counters* which is located under the Clear menu.

Level detector 2

The calculated compensated unbalance current I_AMPL_COMP is compared to the set *Alarm start value*. If the I_AMPL_COMP exceeds the set *Alarm value* the Level detector 2 sends enabling signal to the Alarm control module.

Alarm control

Depending on the *Alarm mode* setting, the alarm stage operation is according to “Normal mode” or “Element counter mode”.

In the “Normal mode” the time characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time*, the ALARM output is activated. If the fault disappears before the alarm activates, the alarm timer is reset immediately.

The “Element counter mode” is used to detect faulty elements of the capacitor bank and count the number of element failures in each branch and line. On activation, this module increments the corresponding element failure counters after the set *Alarm delay time* has elapsed.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode**, which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, CUBPTOC operates normally but the `OPERATE` output is not activated.

4.12.2.5 Application

CUBPTOC is designed for the protection against internal faults in double-Y-connected capacitor banks. This unbalance protection detects an asymmetry in the capacitor bank caused by blown fuses or short circuits across bushings or between capacitor units and the racks in which they are mounted.

Normally, the capacitor units are designed to withstand 110 percent of the nominal voltage continuously. When an element inside a capacitor bank fails, the remaining healthier elements experience an increase in voltage across them. If the voltage exceeds the 110 percent value of the nominal voltage, it can lead to a failure of the healthier elements of the bank and in turn fail the entire capacitor bank. Since the capacitor unbalance current is directly proportional to the element failures, unbalance protection is an effective way of detecting capacitor element failures. The current unbalance protection function is usually used with the three-phase capacitor bank overload protection function to increase the sensitivity of protection for capacitor banks.

Due to the two-stage (operation and alarm stage) unbalance protection and the natural unbalance compensation facility, the protection of capacitor banks with internal fuses can be implemented with a very high degree of sensitivity. Furthermore, CUBPTOC provides a sophisticated method of detecting the number of faulty elements in each phase by calculating the differential unbalance current.

The unbalance protection function can be used for internally fused, externally fused and fuseless shunt capacitor banks. Since a fuseless capacitor bank lacks the individual capacitor unit fuses, current unbalance protection becomes even more critical for fuseless applications.

When an individual element fails, it causes unbalance current. With an increasing number of element failures, the unbalance current increases and CUBPTOC gives an alarm. The alarm level is normally set to 50 percent of the maximum permitted level. The capacitor bank needs to be taken out of service to replace the faulty units. If this is not done, the capacitor bank is tripped when the maximum allowed unbalance current level is exceeded.

If two simultaneous faults occur in the same phase but in different branches, there is no change in the unbalance current and CUBPTOC does not detect this type of faults.

If two simultaneous faults occur in the same branch but in different phases, it may cause a phase angle equal to a situation where there is only one fault in the branch. Therefore, the element failure counters show only one fault instead of two.

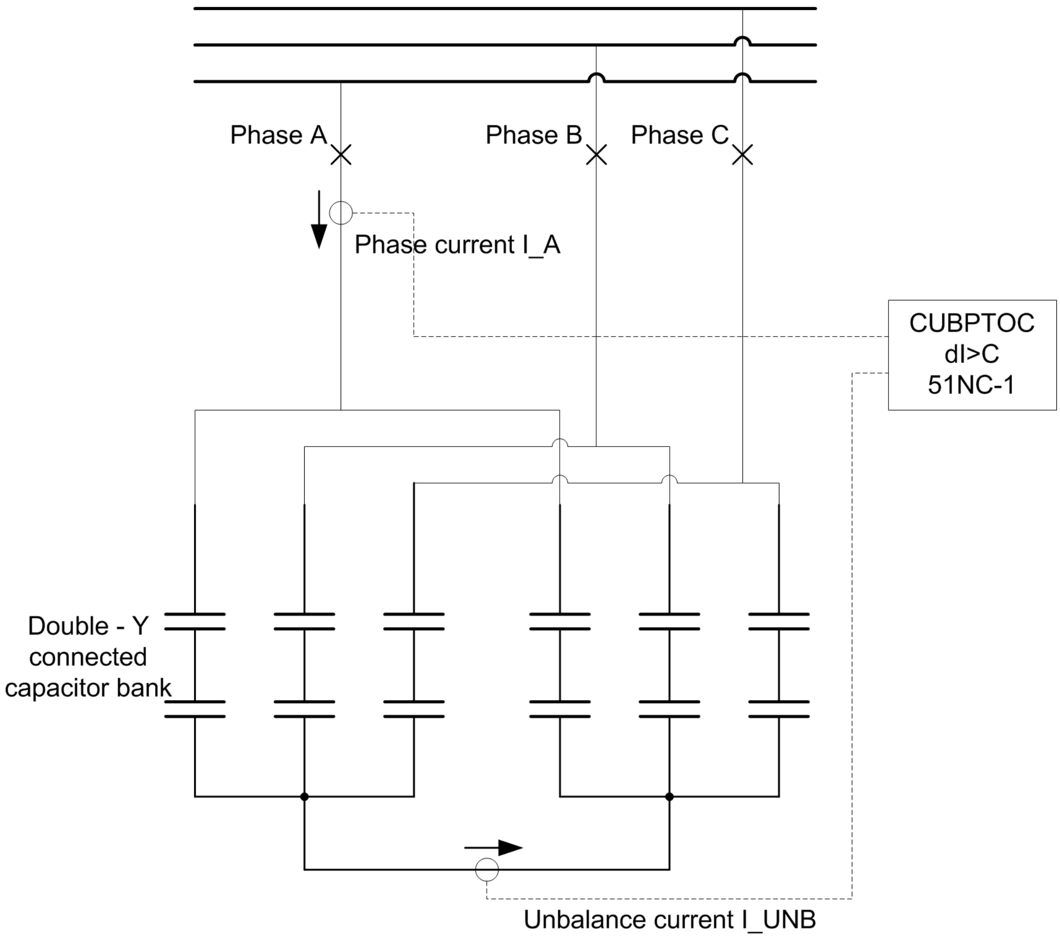


Figure 414: Example of double-Y-connected shunt capacitor bank unbalance protection

Connect the phase current analog input `I_A` and unbalance current `I_UNB` to the IED for the CUBPTOC function to start working.

Steps to measure natural unbalance current

1. The setting *Natural Comp Enable* must be set to “TRUE”.
2. The capacitor bank must be energized.
3. The capacitor bank compensated unbalance current `I_COM_AMPL` is observed from Monitored data.
4. The command *Record unbalance* must be activated by selecting the value “Record” which stores the unbalance reference for future unbalance calculations.
5. The compensated unbalance current (`I_COM_AMPL`) is re-checked to be approximately zero.

The natural unbalance recording should be made only during the steady-state condition and when all the capacitor bank elements are assumed to be in service.

4.12.2.6 Signals

Table 751: CUBPTOC Input signals

Name	Type	Default	Description
I_UNB	REAL	0.0	Capacitor bank unbalance current
I_A	REAL	0.0	Phase A current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 752: CUBPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Alarm

4.12.2.7 Settings

Table 753: CUBPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm mode	1=Normal 2=Element counter			1=Normal	Mode of operation for Alarm stage
Start value	0.01...1.00	xIn	0.01	0.10	Start value
Alarm start value	0.01...1.00	xIn	0.01	0.05	Alarm start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operate delay time	50...200000	ms	10	5000	Operate delay time
Alarm delay time	50...200000	ms	10	200000	Alarm delay time

Table 754: CUBPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Fuse location	1=Internal 2=External			1=Internal	Location of capacitor fuse
Element fail limit	1...100		1	3	Element failure limit above which alarm is active
Natural Comp enable	0=False 1=True			0=False	Enable natural unbalance compensation

Table 755: CUBPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.00860...120.00000		1	28.20000	Parameter A for customer programmable curve
Curve parameter B	0.00000...0.71200		1	0.12170	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		1	2.00	Parameter C for customer programmable curve
Curve parameter E	0.0...1.0		1	1.0	Parameter E for customer programmable curve

Table 756: CUBPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves

4.12.2.8 Monitored data

Table 757: CUBPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
I_NAT_AMPL	FLOAT32	0.00...5.00	xIn	Recorded natural unbalance current amplitude

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
I_NAT_ANGL	FLOAT32	-179.00...179.00	deg	Recorded natural unbalance current angle
I_COM_AMPL	FLOAT32	0.00...5.00	xIn	Compensated unbalance current amplitude
I_COM_ANGL	FLOAT32	-179.00...179.00	deg	Compensated unbalance current angle
COUNT_BR1_A	INT32	0...2147483647		Number of element failures in branch1 phase-A
COUNT_BR2_A	INT32	0...2147483647		Number of element failures in branch2 phase-A
COUNT_BR1_B	INT32	0...2147483647		Number of element failures in branch1 phase-B
COUNT_BR2_B	INT32	0...2147483647		Number of element failures in branch2 phase-B
COUNT_BR1_C	INT32	0...2147483647		Number of element failures in branch1 phase-C
COUNT_BR2_C	INT32	0...2147483647		Number of element failures in branch2 phase-C
FAIL_COUNT	INT32	0...2147483647		Total number of element failures
CUBPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
I-unb	FLOAT32	0.00...5.00	xIn	Measured neutral unbalance current amplitude

4.12.2.9 Technical data

Table 758: CUBPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	1.5 % of the set value or 0.002 × I_n
Start time [1, 2]	Typically 26 ms
Reset time	Typically 40 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	1 % of the theoretical value or ±20 ms
Operate time accuracy in inverse definite minimum time mode	5 % of the theoretical value or ±20 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2,3,4,5,..

4.12.2.10 Technical revision history

Table 759: CUBPTOC Technical revision history

Technical revision	Change
B	Selection name for Recorded unbalance changed.

4.12.3 Shunt capacitor bank switching resonance protection, current based SRCPTOC

4.12.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Shunt capacitor bank switching resonance protection, current based	SRCPTOC	TD>	55TD

1 Fundamental frequency current = 1.0 × I_n, current before fault = 0.0 × I_n, fault current = 2.0 × *Start value*, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact

4.12.3.2 Function block

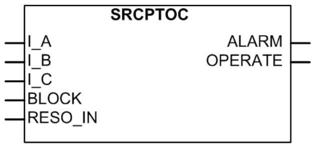


Figure 415: Function block symbol

4.12.3.3 Functionality

The shunt capacitor bank switching resonance protection, current based, function SRCPTOC is used for detecting three-phase resonance caused by capacitor switching or topology changes in the network. The operating characteristic is a definite time (DT).

SRCPTOC contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.12.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”.

The operation of SRCPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

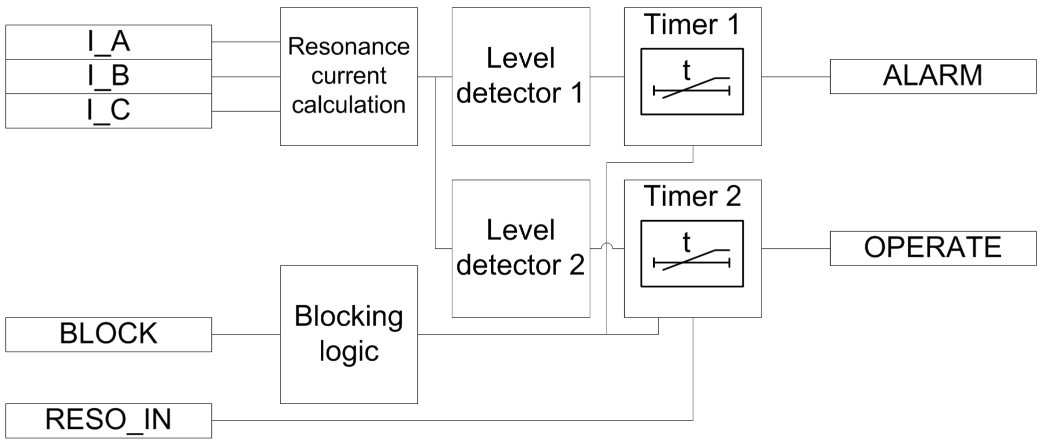


Figure 416: Functional module diagram

Resonance current calculation

This module calculates the resonance current per phase set as per setting *Tuning harmonic Num*. The resonance current for phase A is calculated with the equation.

$$I\_RESO\_A = \sqrt{I_{RMS\_A}^2 - I_{1\_A}^2 - I_{DC\_A}^2 - I_{K\_A}^2}$$

(Equation 149)

I_{RMS_A}	RMS value of current in phase A (contains up to 11 th harmonic)
I_{DC_A}	DC-component in phase A current
I_A	Fundamental component in phase A current
I_{K_A}	K th harmonic component in phase A current, K is defined by setting *Tuning harmonic Num*
I_RESO_A	Calculated resonance current for phase A

The resonance current is calculated through the filter implementation. The DC and fundamental components are removed by passing the total RMS current through the High pass filter. The K th harmonic component is removed by passing the High pass filter output through the K th harmonic Band stop filter. The magnitude response of the High pass filter and all the harmonic Band stop filters are shown in *Figure 417*.

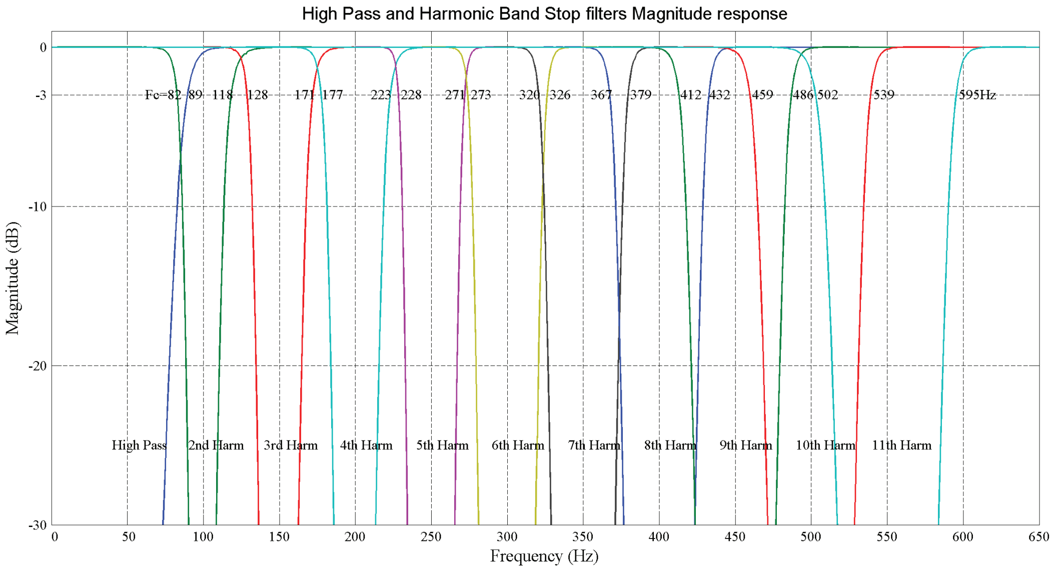


Figure 417: Magnitude response of High pass and all the harmonic Band stop filters

Similarly resonance current is calculated in the same way for phase B and phase C. Resonance currents I_RESO_A, I_RESO_B and I_RESO_C are available in the monitored data view.

The maximum of the three calculated resonance currents is further considered for calculation.

$$I\_RESONANCE = Max(I\_RESO\_A, I\_RESO\_B, I\_RESO\_C)$$

(Equation 150)

If a capacitor bank is used only for reactive power compensation and there is no series reactor in a filter branch, the resonance protection is very important. In this case, the setting *Tuning harmonic Num* should be set to 1 because the capacitor branch is not tuned for a special frequency as in tuned filter applications. Even though *Tuning harmonic Num* is set to 1, the fundamental component is subtracted only once from I_{RMS}.

Level detector 1

The maximum calculated resonance current is compared to the set *Alarm start value*. If the calculated I_RESONANCE exceeds the set *Alarm start value*, the module sends the enabling signal to the Timer 1 module.

Level detector 2

The maximum calculated resonance current is compared to the set *Start value*. If the calculated I_RESONANCE exceeds the set *Start value*, this module sends the enabling signal to the Timer 2 module.

Timer 1

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*, the ALARM output is activated.

If the fault disappears before the alarm activates, the alarm timer is reset immediately.

Timer 2

Once activated, the timer activates the operation timer. 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 operate activates, the operation timer is reset immediately.

If the input RESO_IN becomes active, the OPERATE output is activated immediately. If the resonance protection at a higher-order filter branch has already operated, the function in lower-order filter branches can be tripped immediately using this feature.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, SRCPTOC operates normally but the OPERATE output is not activated.

4.12.3.5 Application

Switched shunt capacitor banks are widely used by utilities and customers in industrial distribution systems to provide voltage support and to improve the power factor of a load. Capacitor steps may be switched in and out of circuits routinely as the demand for capacitive VAR compensation of a load fluctuates. Normally, automatic power factor controllers are employed which automatically switch on or off the capacitors of the capacitor bank, depending upon the prevalent reactive power requirement in the system.

One potential problem for the application of automatic power factor controllers is that it may cause harmonic resonance under certain system conditions. Capacitor switching changes the parameters of the system, which may cause the resonance frequency of the circuit to be equal to one of the frequencies of the harmonic sources prevalent in the system. Harmonic resonance, when it occurs, may result in severe voltage and current distortions, which increases losses and causes overheating of other equipment in the circuit.

A traditional way of solving the problem is to conduct a detailed system study for each individual installation and use the results to properly size the capacitors and determine the right operating range of capacitors to avoid harmonic resonance with other system components. However, this method is not economical but more time-consuming.

The capacitor switching-resonance protection function can be used as a solution to the above mentioned problem. The basis for the harmonic resonance protection is the detection of a current harmonic resonance condition caused by capacitor switching. A prolonged increase of the harmonic distortion level after a switching operation is a clear indication of such condition. When a resonant condition caused by capacitor switching occurs in a circuit, SRCPTOC detunes the circuit by taking the reverse action, that is, switching the capacitor bank off if switching it on causes resonance. If the resonance situation has been detected and SRCPTOC has switched off a capacitor bank, power factor controller should not try to switch on the capacitor bank until the switching resonance function reset.

The capacitor switching-resonance protection function can also be used to protect harmonic filters. In harmonic filter bank applications, the SRCPTOC function can be tuned to harmonic frequency for which the harmonic filter is designed to ensure that the function does not include thr tuned harmonic frequency current into the calculation of the resonance current. If there is more than one harmonic filter bank involved, each SRCPTOC tunes to the harmonic frequency of its corresponding filter bank. The interlinking between the functions can be done in such a way that if resonance occurs in a higher harmonic frequency filter bank, all the lower harmonic frequency filter banks can be tripped immediately by activating the function input `RESO_IN`.

The settings *Alarm start value* and *Start value* determine the portion of the total harmonic current (excluding the harmonic defined by the setting *Tuning harmonic Num*) in relation to the CT nominal value required for SRCPTOC to give alarm and operate respectively.

For power factor correction application

- *Tuning harmonic Num* must be set to 1.
- *Alarm start value* and *Start value* must be set according to the standard IEEE519 -1992.

For harmonic filter application

- *Tuning harmonic Num* must be set to the filter design tuning frequency.
- *Alarm start value* and *Start value* must be set according to the standard IEEE519 -1992.

Settings *Alarm start value* and *Start value* should be selected as such that in normal operation SRCPTOC should not operate.

4.12.3.6 Signals

Table 760: SRCPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RESO_IN	BOOLEAN	0=False	Input signal from higher frequency resonance branch

Table 761: SRCPTOC Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm
OPERATE	BOOLEAN	Operate signal

4.12.3.7 Settings

Table 762: SRCPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm start value	0.03...0.50	xIn	0.01	0.03	Alarm limit for filtered harmonic currents
Start value	0.03...0.50	xIn	0.01	0.03	Tripping limit for filtered harmonic currents indicating resonance condition
Tuning harmonic Num	1...11		1	11	Tuning frequency harmonic number of the filter branch
Operate delay time	120...360000	ms	1	200	Operate delay time for resonance
Alarm delay time	120...360000	ms	1	200	Alarm delay time for resonance alarm

Table 763: SRCPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

4.12.3.8 Monitored data

Table 764: SRCPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
I_RESO_A	FLOAT32	0.00...40.00	xIn	Resonance current for phase A
I_RESO_B	FLOAT32	0.00...40.00	xIn	Resonance current for phase B
I_RESO_C	FLOAT32	0.00...40.00	xIn	Resonance current for phase C
SRCPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.12.3.9 Technical data

Table 765: SRCPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Operate value accuracy: ±3 % of the set value or ±0.002 × I_n (for 2nd order Harmonics) ±1.5 % of the set value or ±0.002 × I_n (for 3rd order < Harmonics < 10th order) ±6 % of the set value or ±0.004 × I_n (for Harmonics >= 10th order)
Reset time	Typically 45 ms or maximum 50 ms
Retardation time	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	-50 dB at $f = f_n$

4.12.3.10 Technical revision history

Table 766: SRCPTOC Technical revision history

Technical revision	Change
B	Internal Improvement.

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

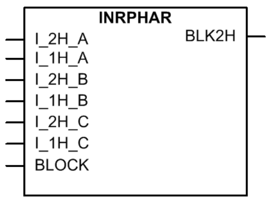


Figure 418: Function block

5.1.3 Functionality

The three-phase inrush detector function 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 INRPHAR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

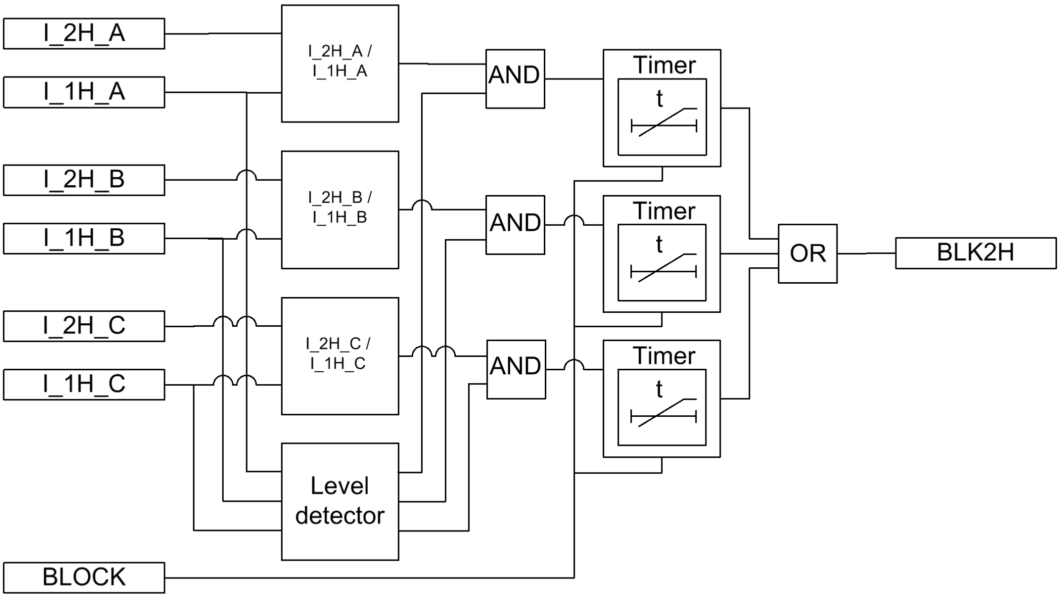


Figure 419: Functional module diagram

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 BLOCK input can be controlled with a binary input, a horizontal communication input or an internal signal of the relay program. The activation of the BLOCK input prevents the BLK2H output from being activated.

It is recommended to use the second harmonic and the waveform based inrush blocking from the TR2PTDF function, if available.

5.1.5 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.

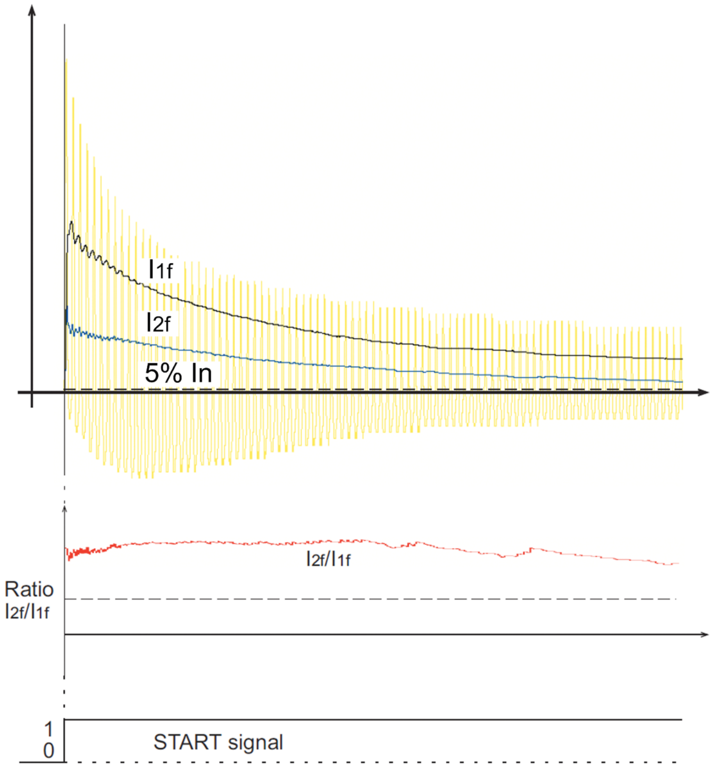


Figure 420: Inrush current in transformer

It is recommended to use the second harmonic and the waveform based inrush blocking from the transformer differential protection function TR2PTDF, if available.

5.1.6 Signals

Table 767: INRPHAR Input signals

Name	Type	Default	Description
I_2H_A	SIGNAL	0	Second harmonic phase A current
I_1H_A	SIGNAL	0	Fundamental frequency phase A current
I_2H_B	SIGNAL	0	Second harmonic phase B current
I_1H_B	SIGNAL	0	Fundamental frequency phase B current
I_2H_C	SIGNAL	0	Second harmonic phase C current
I_1H_C	SIGNAL	0	Fundamental frequency phase C current
BLOCK	BOOLEAN	0=False	Block input status

Table 768: INRPHAR Output signals

Name	Type	Description
BLK2H	BOOLEAN	Second harmonic based block

5.1.7 Settings

Table 769: INRPHAR Group settings (Basic)

Parameter	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	20...60000	ms	1	20	Operate delay time

Table 770: INRPHAR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 771: INRPHAR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

5.1.8 Monitored data

Table 772: INRPHAR Monitored data

Name	Type	Values (Range)	Unit	Description
INRPHAR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.1.9 Technical data

Table 773: 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	+35 ms / -0 ms

5.1.10 Technical revision history

Table 774: INRPHAR Technical revision history

Technical revision	Change
B	Internal improvement
C	Internal improvement

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>/Io>BF	51BF/51NBF

5.2.2 Function block

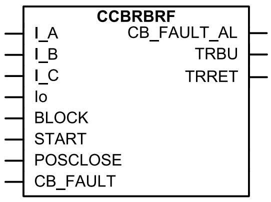


Figure 421: Function block

5.2.3 Functionality

The circuit breaker failure protection 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 retrip function, and also a three-phase conditional back-up trip function.

CCBRBRF uses the same levels of current detection for both retrip 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 retrip 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.

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 CCBRBRF can be described using a module diagram. All the modules in the diagram are explained in the next sections. Also further information on the retrip and backup trip logics is given in sub-module diagrams.

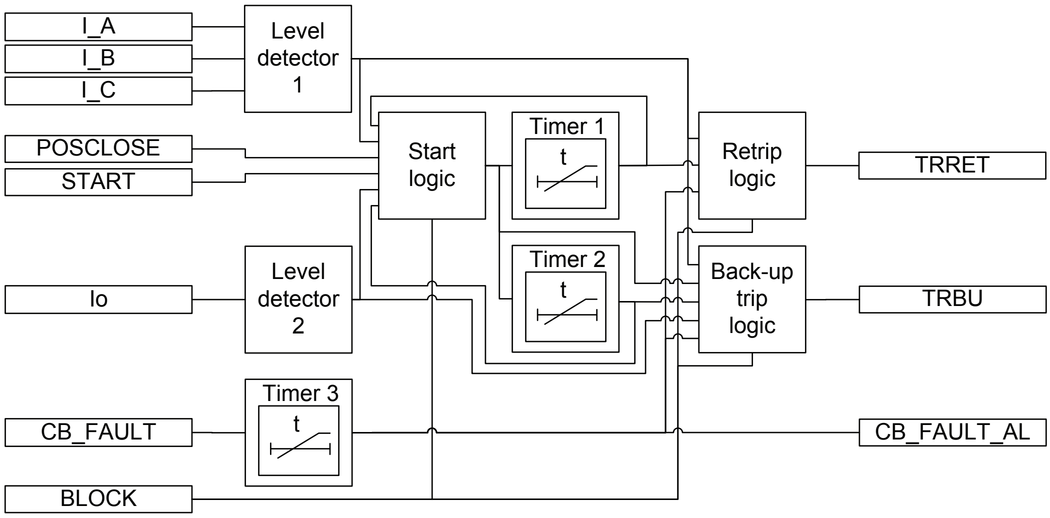


Figure 422: Functional module diagram

Level detector 1

The measured phase currents are compared phasewise 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 breaker failure situations with small fault current or 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 the timer 1 and timer 2. It also resets the function after the circuit breaker failure is handled. On the rising edge of the `START` input, the enabling signal is send to the timer 1 and timer 2.

Function resetting is prevented during the next 150 ms. The 150 ms time elapse is provided to prevent malfunctioning due to oscillation in the starting signal.

In case the setting *Start latching mode* is set to "Level sensitive", the CCBRBRF is reset immediately after the `START` signal is deactivated. The recommended setting value is "Rising edge".

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 the values of the phase currents and the residual current drops below the *Current value* and *Current value Res* setting respectively.
- 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 the "Breaker status" mode, the resetting logic requires that the circuit breaker is in the open condition.
• If the *CB failure mode* setting is set to "Both", the resetting logic requires that the circuit breaker is in the open condition and the values of the phase currents and the residual current drops below the *Current value* and *Current value Res* setting respectively.

The activation of the BLOCK input resets the function.

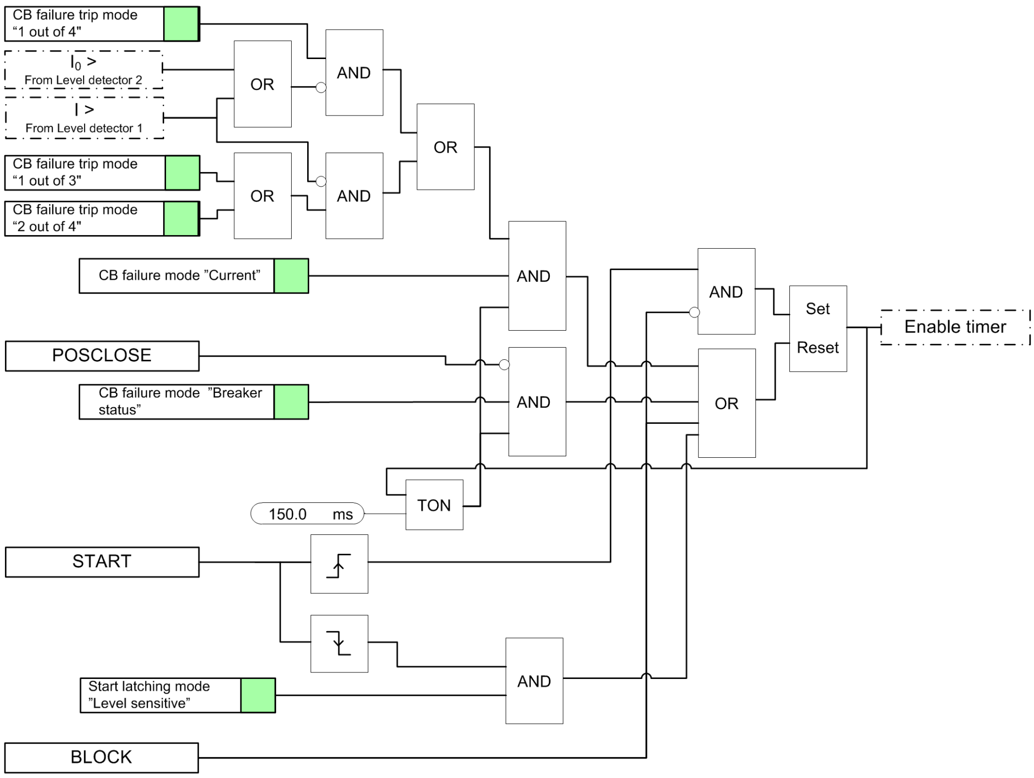


Figure 423: Start logic

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.

Timer 2

Once activated, the timer runs until the set *CB failure delay* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the set maximum time value *CB failure delay*, the backup trip logic is activated. 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 also dependent on the retrip timer.

The minimum time delay for the CB failure delay can be estimated as:

$$CBfailuredelay \geq Retriptime + t_{cbopen} + t_{BFP\_reset} + t_{margin}$$

(Equation 151)

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

It is often required that the total fault clearance time is less than the given critical time. This time often depends on the ability to maintain transient stability in case of a fault close to a power plant.

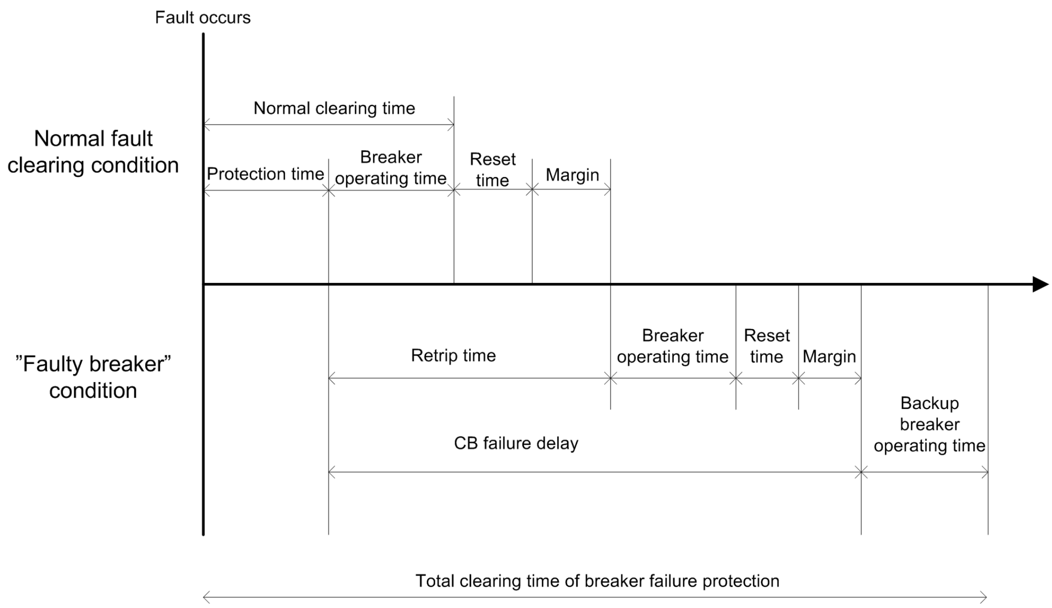


Figure 424: Timeline of the breaker failure protection

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.

- 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 time* setting.

The activation of the BLOCK input or the CB_FAULT_AL output deactivates the TRRET output.

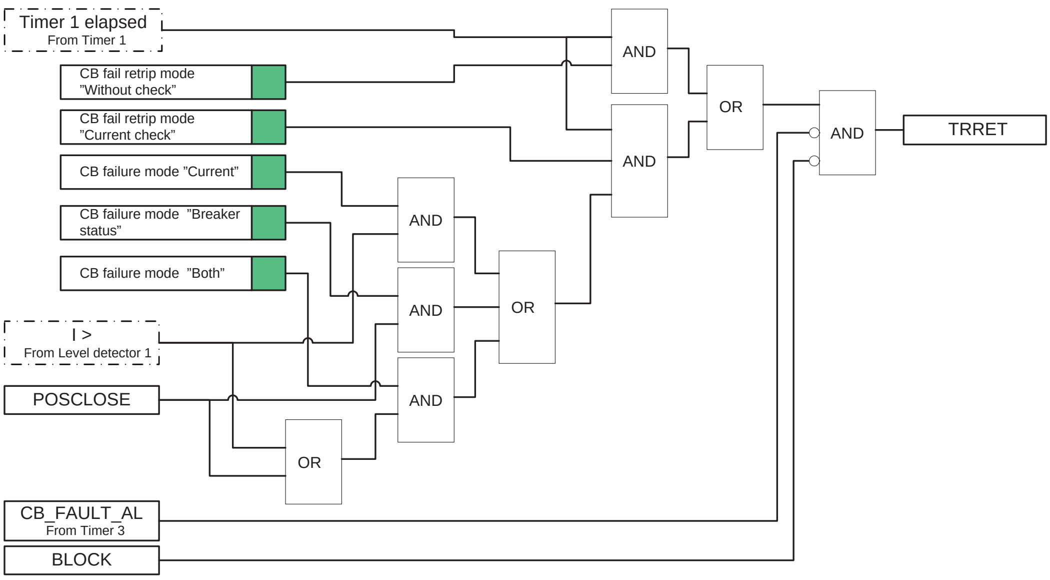


Figure 425: Retrip logic

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 the 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 takes 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 respectively. 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 respectively, whichever takes longer.
- If *CB failure trip mode* is set to "2 out of 4", the failure detection requires that a phase current and a residual current both exceed the *Current value* and *Current value Res* setting respectively or two phase currents exceeding the *Current 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 drop below the *Current value*, whichever takes 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.

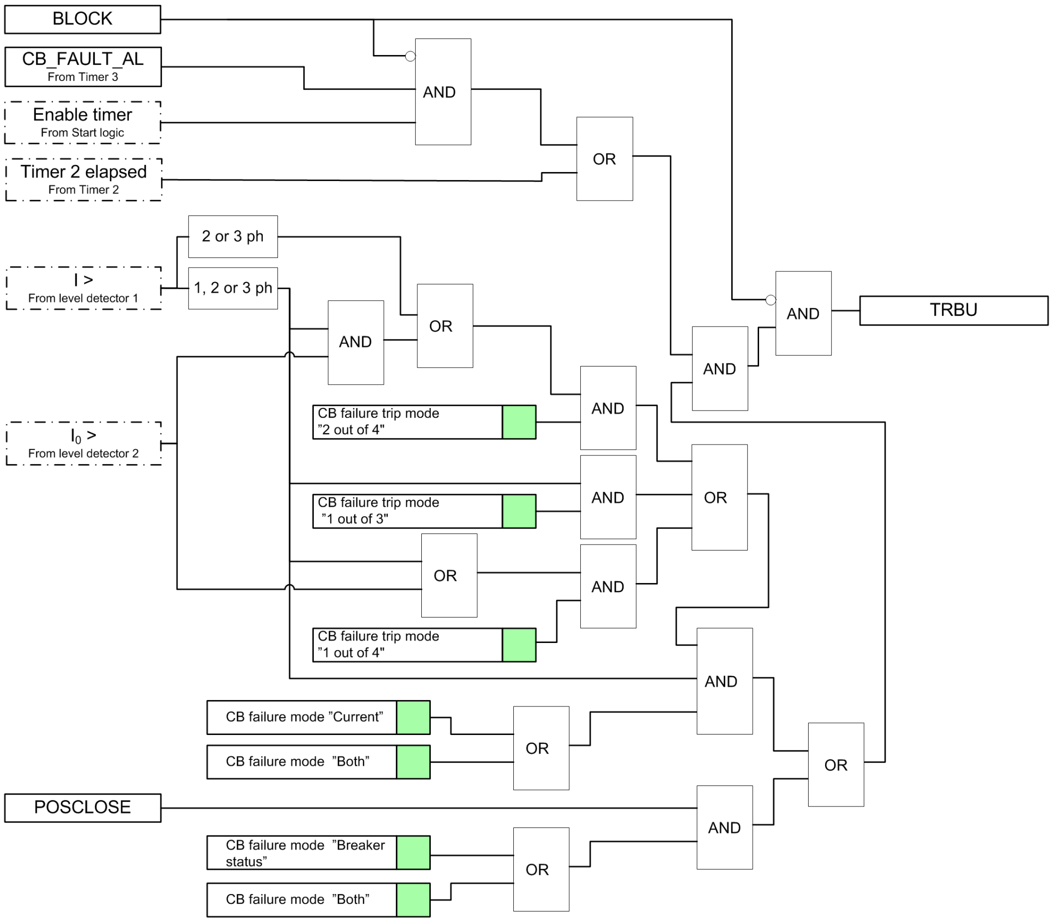


Figure 426: Backup trip logic

5.2.5 Application

The n-1 criterion is often 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 up-stream 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 protection relay maintenance and tests.

CCBRBRF is initiated by operating different protection functions or digital logics inside the protection relay. 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.

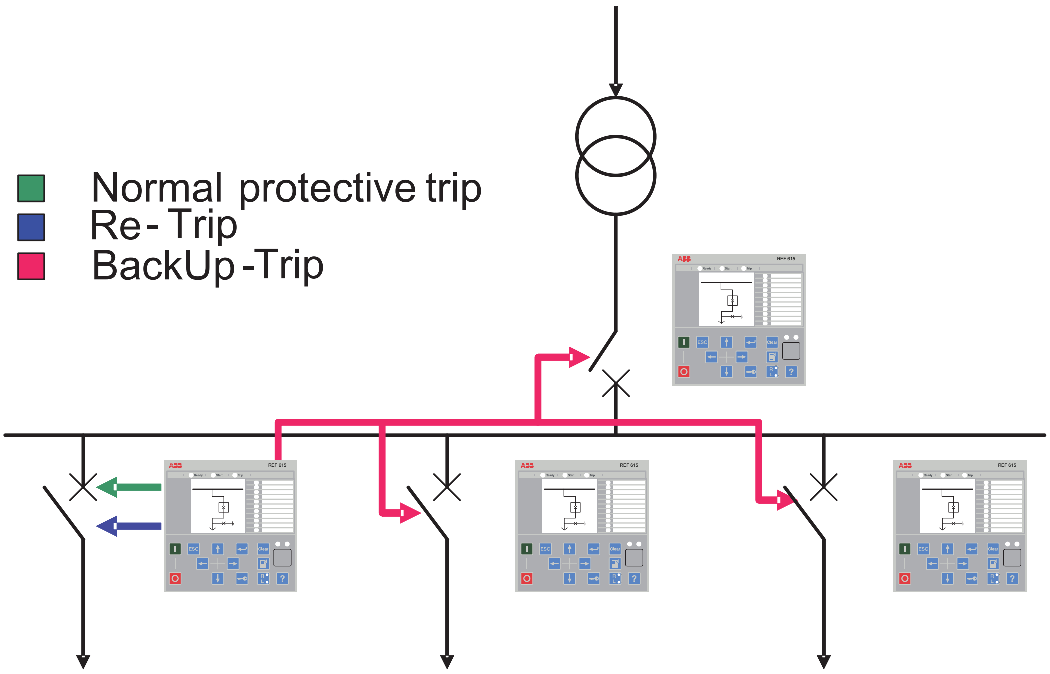


Figure 427: Typical breaker failure protection scheme in distribution substations

5.2.6 Signals

Table 775: CCBRBRF Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current

Table continues on the next page

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block CBFP operation
START	BOOLEAN	0=False	CBFP start command
POSCLOSE	BOOLEAN	0=False	CB in closed position
CB_FAULT	BOOLEAN	0=False	CB faulty and unable to trip

Table 776: CCBRBRF Output signals

Name	Type	Description
CB_FAULT_AL	BOOLEAN	Delayed CB failure alarm
TRBU	BOOLEAN	Backup trip
TRRET	BOOLEAN	Retrip

5.2.7 Settings

Table 777: CCBRBRF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Current value	0.05...2.00	xIn	0.05	0.30	Operating phase current
Current value Res	0.05...2.00	xIn	0.05	0.30	Operating residual current
CB failure trip mode	1=2 out of 4 2=1 out of 3 3=1 out of 4			2=1 out of 3	Backup trip current check mode
CB failure mode	1=Current 2=Breaker status 3=Both			1=Current	Operating mode of function
CB fail retrip mode	1=Off 2=Without Check 3=Current check			1=Off	Operating mode of retrip logic
Retrip time	0...60000	ms	10	120	Delay timer for retrip
CB failure delay	0...60000	ms	10	240	Delay timer for backup trip

Table 778: CCBRBRF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
CB fault delay	0...60000	ms	10	5000	Circuit breaker faulty delay
Measurement mode	2=DFT 3=Peak-to-Peak			3=Peak-to-Peak	Phase current measurement mode of function

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Trip pulse time	0...60000	ms	10	200	Pulse length of retrip and backup trip outputs
Start latching mode	1=Rising edge 2=Level sensitive			1=Rising edge	Start reset delayed or immediately

5.2.8 Monitored data

Table 779: CCBRBRF Monitored data

Name	Type	Values (Range)	Unit	Description
CCBRBRF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.2.9 Technical data

Table 780: CCBRBRF Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5 % of the set value or ±0.002 × I_n
Operate time accuracy	±1.0 % of the set value or ±20 ms
Reset time [1]	Typically 40 ms
Retardation time	<20 ms

5.2.10 Technical revision history

Table 781: CCBRBRF Technical revision history

Technical revision	Change
B	Default trip pulse time changed to 150 ms
C	Added new setting parameter *Start latching mode*. Maximum value changed to 2.00 xIn for the *Current value* setting.
D	Internal improvement.
E	Maximum value for *Current value* and *Current value Res* changed from “1.00 x In” to “2.00 x In”.
F	Step for *Current value* and *Current value Res* changed from "0.05" to "0.01".

1 Trip pulse time defines the minimum pulse length

5.3 Master trip TRPPTRC

5.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Master trip	TRPPTRC	Master Trip	94/86

5.3.2 Function block

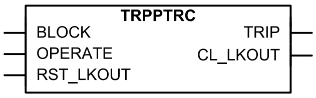


Figure 428: Function block

5.3.3 Functionality

The master trip 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 minimum trip pulse length can be set when the non-latched mode is selected. It is also possible to select the latched or lockout mode for the trip signal.

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 TRPPTRC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

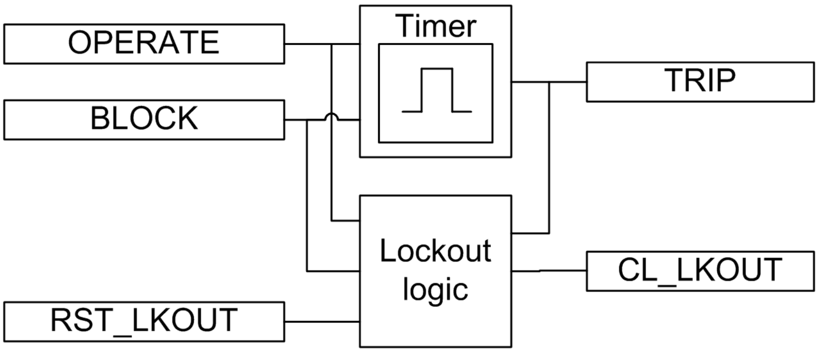


Figure 429: Functional module diagram

Timer

The duration of the TRIP output signal from TRPPTRC can be adjusted with the *Trip pulse time* setting when the "Non-latched" operation mode is used. 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 protection relay, or from external protection functions via one or more of the protection relay's binary inputs. The function has a single trip output TRIP for connecting the function to one or more of the protection relay's binary outputs, and also to other functions within the protection relay requiring this signal.

The BLOCK input blocks the TRIP output and resets the timer.

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 "Latched" mode, the resetting of the TRIP output can be done similarly as when using the "Lockout" mode. It is also possible to reset the "Latched" mode remotely through a separate communication parameter.

The minimum pulse trip function is not active when using the "Lockout" or "Latched" modes but only when the "Non-latched" mode is selected.

The CL_LKOUT and TRIP outputs can be blocked with the BLOCK input.

Table 782: Operation modes for the TRPPTRC trip output

Mode	Operation
Non-latched	The *Trip pulse length* parameter gives the minimum pulse length for TRIP
Latched	TRIP is latched ; both local and remote clear-ing is possible.
Lockout	TRIP is locked and can be cleared only locally via menu or the RST_LKOUT input.

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, TRPPTRC can block the CBXCBR closing.

TRPPTRC 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 two instances of the PTRC function are identical, only the names of the functions, TRPPTRC1 and TRPPTRC2, are different. Therefore, even if all references are made only to TRPPTRC1, they also apply to TRPPTRC2.

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. This signal can also be used for other purposes within the protection relay, for example when starting the breaker failure protection.

TRPPTRC is used for simple three-phase tripping applications.

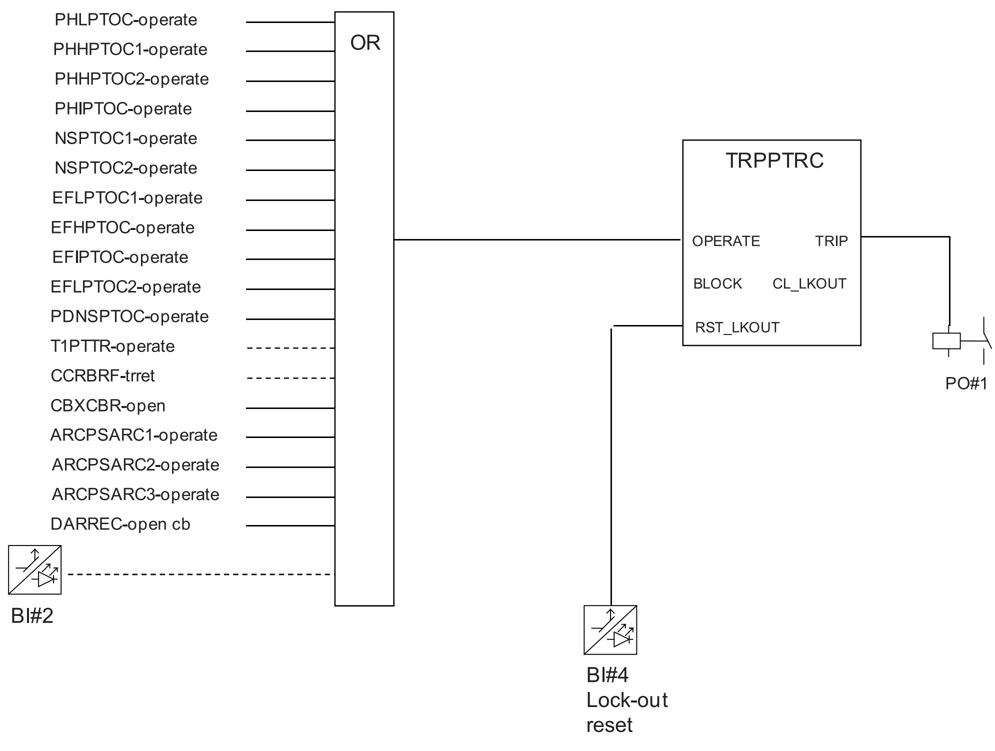


Figure 430: Typical TRPPTRC connection

5.3.6 Signals

Table 783: TRPPTRC Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block of function
OPERATE	BOOLEAN	0=False	Operate
RST_LKOUT	BOOLEAN	0=False	Input for resetting the circuit breaker lockout function

Table 784: 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 785: TRPPTRC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Trip pulse time	20...60000	ms	1	250	Minimum duration of trip output signal
Trip output mode	1=Non-latched 2=Latched 3=Lockout			1=Non-latched	Select the operation mode for trip output

5.3.8 Monitored data

Table 786: TRPPTRC Monitored data

Name	Type	Values (Range)	Unit	Description
TRPPTRC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.3.9 Technical revision history

Table 787: TRPPTRC Technical revision history

Technical revision	Change
B	-
C	-
D	Internal improvement.
E	Setting *Trip output mode* default setting is changed to "Latched".
F	Internal improvement.

5.4 High-impedance fault detection PHIZ

5.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance fault detection	PHIZ	HIF	HIZ

5.4.2 Function block

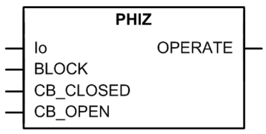


Figure 431: Function block

5.4.3 Functionality

A small percentage of earth faults have a very large impedance. They are comparable to load impedance and consequently have very little fault current. These high-impedance faults do not pose imminent danger to power system equipment. However, they are a substantial threat to humans and properties; people can touch or get close to conductors carrying large amounts of energy.

ABB has developed a patented technology (US Patent 7,069,116 B2 June 27, 2006, US Patent 7,085,659 B2 August 1, 2006) to detect a high-impedance fault.

The high-impedance fault detection function PHIZ also contains a blocking functionality. It is possible to block function outputs, if desired.

PHIZ is limited to be used in 60 Hz electrical networks with efficiently grounded or isolated neutral.

5.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

PHIZ uses a multi-algorithm approach. Each algorithm uses various features of earth currents to detect a high-impedance fault.

Although the PHIZ algorithm is very sophisticated, the setting required to operate the function is simple. The *Security Level* setting, with the setting range of 1 to 10, is set to strike a balance between the extremes of security and dependability which together constitute the reliability of any system. The setting value “10” is more secure than “1”.

The higher the *Security Level* setting, the lower the probability of false detection, but the system might miss out some genuine fault. On the other hand, a lower setting would make the system operate more dependably for high-impedance faults in the line, but the operation is more likely for other transients in the system. There are events in electrical networks which can cause similar current waveforms like high-impedance faults. These events could then be detected by the PHIZ algorithm causing unnecessary detections. Normally, electrical network operator does not know the existence of these events well and those can also be happening very randomly. The effect is also always dependent on event location compared to protection relay measurement location. All these facts make the PHIZ algorithm operation in certain electrical networks quite hard to measure and forecast beforehand. There is not any direct formula which can calculate the exact right setting based on known electrical network parameters.

It is hence recommended to set the value midway to “5” initially. Based on experience and confidence gained in a particular application, the setting can be moved either side. In many cases, it would be a good practice to use PHIZ as an indicative function during a piloting phase, until enough experience has been gathered and a suitable setting found.

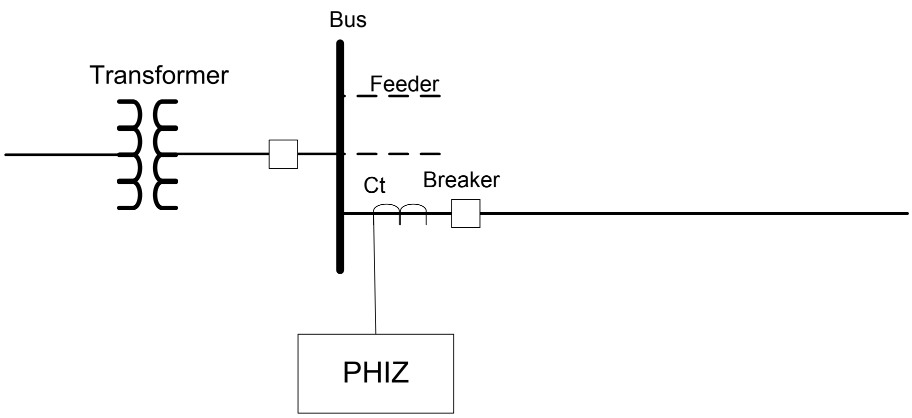


Figure 432: Electrical power system equipped with PHIZ

Power system signals are acquired, filtered and then processed by individual high-impedance fault detection algorithm. The results of these individual algorithms are further processed by a decision logic to provide the detection decision. The decision logic can be modified depending on the application requirement.

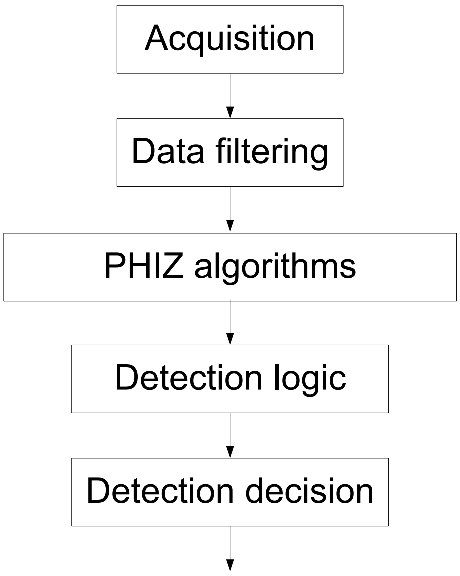


Figure 433: Block diagram of PHIZ

PHIZ is based on algorithms that use earth current signatures which are considered non-stationary, temporally volatile and of various burst duration. All harmonic and non-harmonic components within the available data window can play a vital role in the high-impedance fault detection. A major challenge is to develop a data model that acknowledges that high-impedance faults could take place at any time within the observation window of the signal and could be delayed randomly and attenuated substantially. The model is motivated by extensive research, actual experimental observations in the laboratory, field testing and what traditionally represents an accurate depiction of a non-stationary signal with a time-dependent spectrum.

Figure 434: Validation of PHIZ on gravel

Figure 435: Validation of PHIZ on concrete

Figure 436: Validation of PHIZ on sand

Figure 437: Validation of PHIZ on grass

5.4.5 Application

PHIZ is used to detect a downed conductor dropping to a very resistive ground, causing an earth fault which is very difficult to detect by a conventional protection relay functionality. PHIZ is then targeted to be used with overhead lines. PHIZ is limited to be used in 60 Hz electrical networks with efficiently grounded or isolated neutral.

Electric power lines experience faults for many reasons. In most cases, electrical faults manifest in mechanical damage, which must be repaired before returning the line to service.

Most of the electrical network faults are earth faults. Conventional protection systems based on overcurrent, impedance or other principles are suitable for detecting relatively low-impedance faults which have a relatively large fault current.

However, a small percentage of the earth faults have a very large impedance. They are comparable to load impedance and consequently have very little fault current. These high-impedance faults do not pose imminent danger to power system equipment. However, they are a considerable threat to people and property. The IEEE Power System Relay Committee working group on High Impedance Fault Detection Technology defines High Impedance Faults as those that 'do not produce enough fault current to be detectable by conventional overcurrent relays or fuses.

PHIZ always needs sensitive Io measurement.

High-impedance fault (PHIZ) detection requires a different approach than that for conventional low-impedance faults. Reliable detection of PHIZ provides safety to humans and animals. PHIZ detection can also prevent fire and minimize property damage. ABB has developed innovative technology for high-impedance fault detection with over ten years of research resulting in many successful field tests.

5.4.6 Signals

Table 788: PHIZ Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Earth current measured using SEF CT
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
CB_CLOSED	BOOLEAN	0=False	Circuit Breaker Closed input
CB_OPEN	BOOLEAN	0=False	Circuit Breaker Open input

Table 789: PHIZ Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate

5.4.7 Settings

Table 790: PHIZ Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Security Level	1...10		1	5	Security Level

Table 791: PHIZ Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
System type	1=Grounded 2=Ungrounded			1=Grounded	System Type

5.4.8 Monitored data

Table 792: PHIZ Monitored data

Name	Type	Values (Range)	Unit	Description
Position	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Position
PHIZ	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.4.9 Technical revision history

Table 793: PHIZ Technical revision history

Technical revision	Change
B	Internal improvement
C	Added inputs for Circuit Breaker Closed and Circuit Breaker Open

5.5 Emergency start-up ESMGAPC

5.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Emergency start-up	ESMGAPC	ESTART	ESTART

5.5.2 Function block

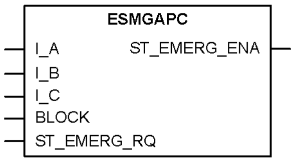


Figure 438: Function block

5.5.3 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 that can damage the motor. The emergency start-up function ESMGAPC allows motor start-ups during such emergency conditions. ESMGAPC is only to force the protection relay to allow the restarting of the motor. After the emergency start input is activated, the motor can be started normally. ESMGAPC itself does not actually restart the motor.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

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 ESMGAPC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

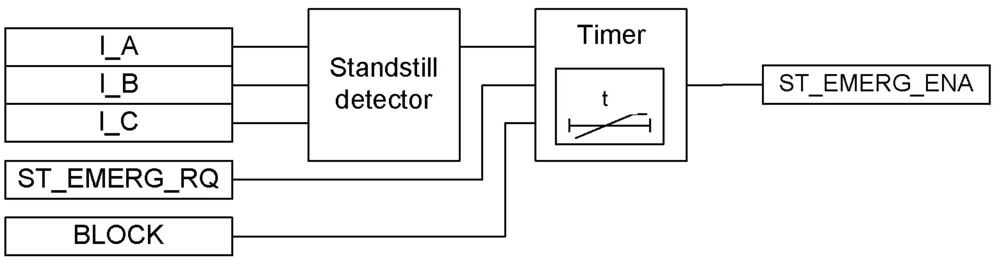


Figure 439: Functional module diagram

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 activated and motor standstill condition is fulfilled. Thus, 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 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.

5.5.5 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 start-up time counter exceeds the restart inhibit level, the value is set slightly below the restart disable value to allow at least one motor start-up.

The activation of the ST_EMERG_RQ digital input allows to perform emergency start. The protection relay is forced to a state which allows the restart of motor, and the operator can now restart the motor. 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.

5.5.6 Signals

Table 794: ESMGAPC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ST_EMERG_RQ	BOOLEAN	0=False	Emergency start input

Table 795: ESMGAPC Output signals

Name	Type	Description
ST_EMERG_ENA	BOOLEAN	Emergency start

5.5.7 Settings

Table 796: ESMGAPC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Motor standstill A	0.05...0.20	xIn	0.01	0.12	Current limit to check for motor standstill condition

Table 797: ESMGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

5.5.8 Monitored data

Table 798: ESMGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
T_ST_EMERG	Timestamp			Emergency start activation time-stamp
ESMGAPC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.5.9 Technical data

Table 799: ESMGAPC Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5 % of the set value or ±0.002 × U_n

5.5.10 Technical revision history

Table 800: ESMGAPC Technical revision history

Technical revision	Change
B	Internal improvement
C	Internal improvement

5.6 Automatic switch-onto-fault logic CVPSOF

5.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Automatic switch-onto-fault logic (SOF)	CVPSOF	CVPSOF	SOFT/21/50

5.6.2 Function block

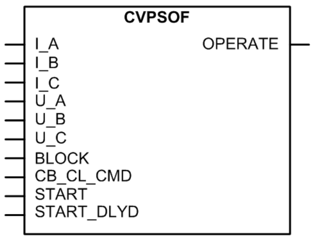


Figure 440: Function block

5.6.3 Functionality

The automatic switch-onto-fault function CVPSOF is a complementary function, especially to the distance protection function (DSTPDIS), but it can also be used to complement the non-directional or directional overcurrent protection functions (PHxPTOC, DPHxPDOC).

CVPSOF accelerates the operation of the protection ensuring a fast trip when the breaker is closed onto faulted feeder or bus. Without CVPSOF 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.

5.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of CVPSOF can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

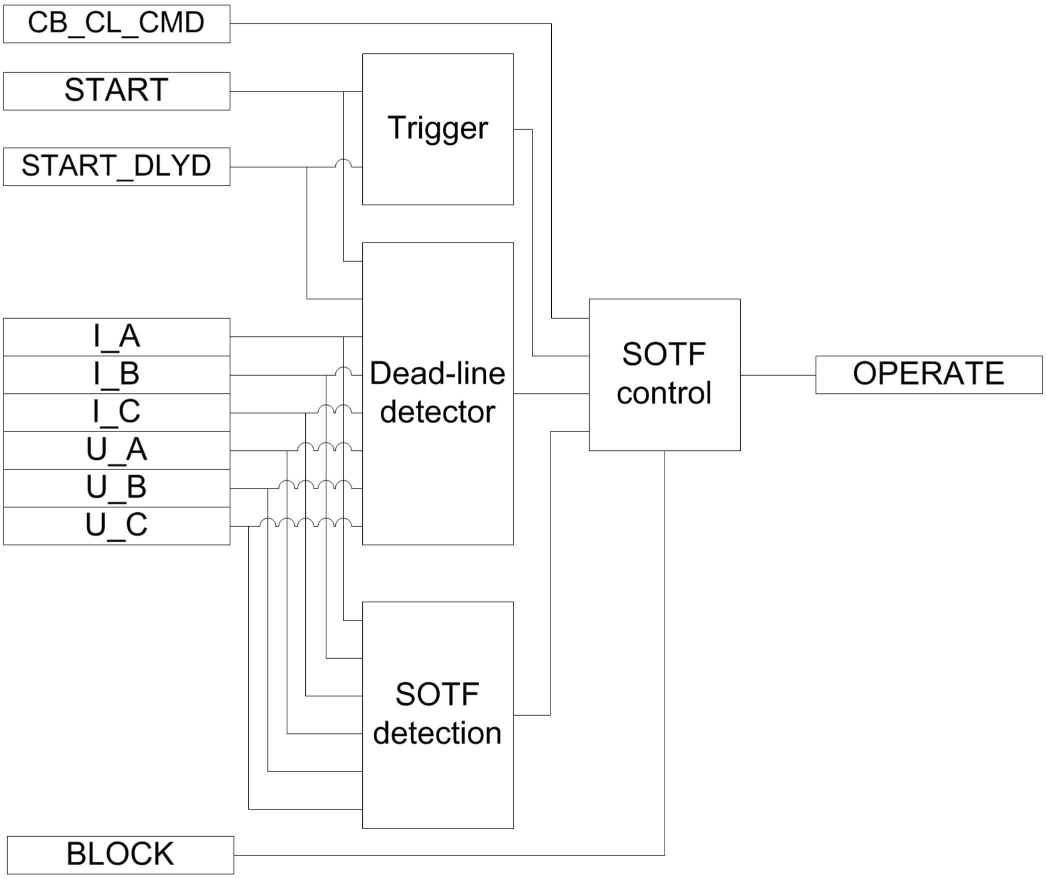


Figure 441: Functional module diagram

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.

- `START` input has no delay. Thus, a switch-onto-fault situation is immediately signalled to SOTF control.
- `START_DLYD` input 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 detector

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 801: Options for dead line detection

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.

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, on the measured internal voltage and current levels, or on both.

Table 802: Options for SOTF detection

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 & Voltage	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.

5.6.5 Application

The operation of CVPSOF 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 CVPSOF 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 CVPSOF to increase the dependability of the scheme. The other main advantage of using CVPSOF is that it typically accelerates the tripping in case of energizing a feeder onto a fault. Without CVPSOF, this tripping is normally performed by the normal time-graded protection or alternatively by the time-delayed local backup protection, for which operating times are considerably longer than with CVPSOF 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 CVPSOF 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...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. This 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 CVPSOF by the dead line detection function when the high-speed autoreclosing 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.

5.6.6 Signals

Table 803: CVPSOF Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
U_A	SIGNAL	0	Phase A voltage
U_B	SIGNAL	0	Phase B voltage
U_C	SIGNAL	0	Phase C voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
CB_CL_CMD	BOOLEAN	0=False	External enabling of SOTF by CB close command
START	BOOLEAN	0=False	Start from function to be accelerated by SOTF
START_DLYD	BOOLEAN	0=False	Start from function to be accelerated with delay by SOTF

Table 804: CVPSOF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate

5.6.7 Settings

Table 805: CVPSOF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 806: CVPSOF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	1=Start 2=Current&voltage 3=Both			3=Both	Mode of operation of SOTF Function
Automatic SOTF Ini	1=DLD disabled 2=Voltage 3=Current 4=Current&voltage			2=Voltage	Automatic switch onto fault initialization
Current dead Lin Val	0.01...1.00	xIn	0.01	0.20	Dead line value, current. Used also in auto activation logic
Voltage dead Lin Val	0.01...0.58	xUn	0.01	0.40	Dead line value, voltage. Used also in auto activation logic
Cur voltage Det time	0...60000	ms	10	20	Time delay for voltage and current based detection
Operate time delay	0...120000	ms	10	20	Delay for the delayed start input
SOTF reset time	0...60000	ms	10	1000	SOTF detection period after initialization
Dead line time	0...60000	ms	10	200	Delay time for activation of dead line detection

5.6.8 Monitored data

Table 807: CVPSOF Monitored data

Name	Type	Values (Range)	Unit	Description
CVPSOF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.6.9 Technical data

Table 808: CVPSOF Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2Hz
	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 ±20 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

5.7 Fault locator SCEFRFLO

5.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fault locator	SCEFRFLO	FLOC	21FL

5.7.2 Function block

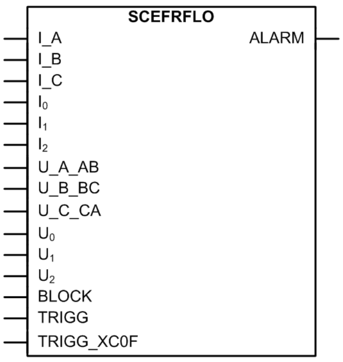


Figure 442: Function block

5.7.3 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 all kinds of distribution networks. Earth faults can be located in effectively earthed and in low-resistance or low-reactance earthed networks. Under certain limitations, SCEFRFLO can also be applied for an 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 phase currents and phase-to-earth voltages are measured.

The fault distance estimate is obtained when the function is externally or internally triggered.

5.7.4 Operation principle

The fault distance calculation is done in two steps. First, the fault type is determined with the inbuilt Phase Selection Logic (PSL). Second, based on the selected impedance measuring element (fault loop) the fault distance from the measuring point to the fault location is calculated.

As a fundamental operation criterion, the phase current and voltage magnitudes must exceed the threshold values of 2% xIn and 3% xUn, respectively.

The function can be enabled or disabled with the *Operation* setting. The corresponding parameter values are “On" and "Off".

The operation of SCEFRFLO can be described with a module diagram. All the modules in the diagram are explained in the next sections.

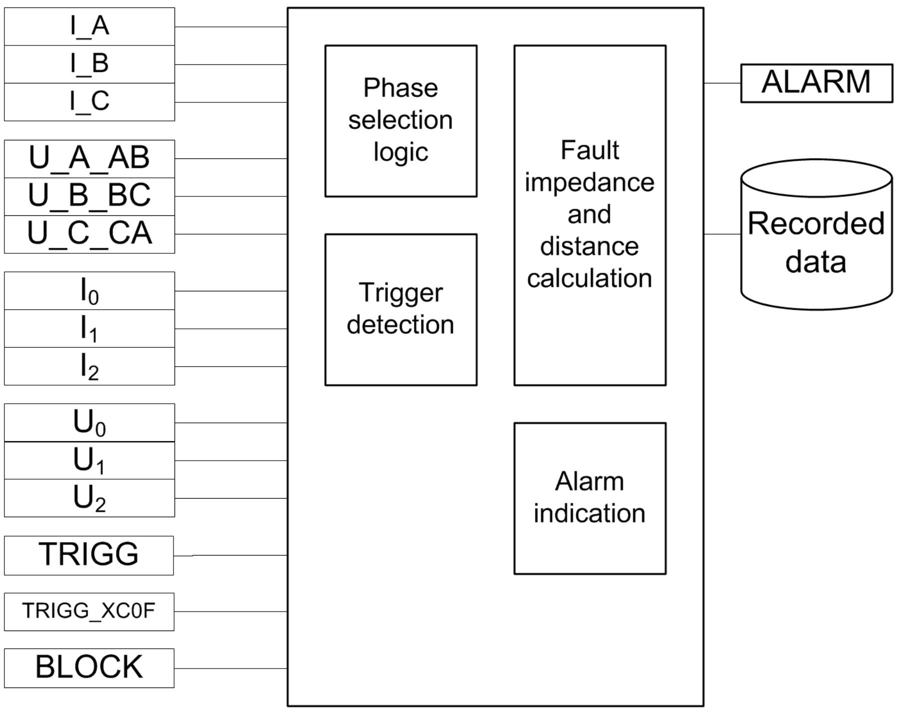


Figure 443: Functional module diagram

5.7.4.1 Phase selection logic

Identification of the faulty phases is provided by the built-in Phase Selection Logic based on combined impedance and current criterion. Phase selection logic 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 setting *Z Max phase load* can be calculated using the equation.

$$Z\ Max\ phase\ load = 0.8 \cdot \frac{U_{xy}^2}{S_{max}}$$

(Equation 152)

U_{xy}	Nominal phase-to-phase voltage
S_{max}	Maximum three-phase load

For example, if U_{xy} = 20 kV and S_{max} = 1 MVA, then *Z Max phase load* = 320.0 Ω.

The identification of the faulty phases is compulsory for the correct operation of SCEFRFLO. This is because only one of the impedance-measuring elements (fault loops) provides the correct result for a specific fault type. A three-phase fault is an exception and theoretically it can be calculated with any of the fault loops. The fault loop used in the fault distance calculation is indicated in the recorded data Flt loop as specified in *Table 809*.

Table 809: Fault types and corresponding fault loops

Fault type	Description	Flt loop
-	No fault	No fault
A-E	Phase A-to-earth fault	AG Fault
B-E	Phase B-to-earth fault	BG Fault
C-E	Phase C-to-earth fault	CG Fault
A-B	Phase A-to-B short circuit fault	AB Fault
B-C	Phase B-to-C short circuit fault	BC Fault
C-A	Phase C-to-A short circuit fault	AC Fault
A-B-C-(E)	Three-phase short circuit	ABC Fault

In case of two-phase-to-earth faults (A-B-E, B-C-E or C-A-E), 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 (either “AB Fault” or “BC Fault” or “CA Fault”) is used for calculation. When the faults are located at different feeders, the phase-to-earth loop (either “AG Fault” or “BG Fault” or “CG Fault”) corresponding to the faulty phase at the protected feeder is used for calculation.

5.7.4.2 Fault impedance and distance calculation

As soon as a fault condition is recognized by the phase selection logic, the fault distance calculation is started with one of the seven impedance-measuring elements, that is, the fault loops. SCEFRFLO employs independent algorithms for each fault type to achieve optimal performance.

The inherent result from the fault distance calculation is the ohmic fault loop impedance value.

Table 810: The calculated impedance values available in the recorded data

Impedance valule	Description
Flt phase reactance	Estimated positive sequence reactance from the substation to the fault location in primary ohms.
Flt point resistance	Fault resistance value in the fault spot in primary ohms. The composition of this term depends on the fault loop as described in the following subsections.
Flt loop resistance	The total fault loop resistance from the substation to the fault location in primary ohms. Fault point resistance is included in this value. The composition of this term is different for short-circuit and earth-fault loops as described in the following subsections.
Flt loop reactance	The total fault loop reactance from the substation to the fault location in primary ohms. The composition of this term is different for short-circuit and earth-faults loops as described in the following subsections.

These impedance values can be utilized as such or they can be further processed in system level fault location applications, such as distribution management system (DMS).

Fault loops “AG Fault” or “BG Fault” or “CG Fault”

Fault loops “AG Fault”, “BG Fault” or “CG Fault” are used for single-phase-to-earth faults. When the individual earth faults are located at different feeders, they are also applied in the case of two-phase-to-earth fault. In this case, the phase-to-earth loop (either “AG Fault” or “BG Fault” or “CG Fault”) corresponding to the faulty phase at the protected feeder, is used for calculation. *Figure 444* shows the phase-to-earth fault loop model. The following impedances are measured and stored in the recorded data of SCEFRFLO.

$$Flt\ point\ resistance = R_{fault}$$

(Equation 153)

$$Flt\ loop\ resistance = R_1 + R_N + R_{fault}$$

(Equation 154)

$$Flt\ loop\ reactance = X_1 + X_N$$

(Equation 155)

$$Flt\ phase\ reactance = X_1$$

(Equation 156)

R_1	Estimated positive-sequence resistance from the substation to the fault location
X_1	Estimated positive-sequence reactance from the substation to the fault location
R_0	Estimated zero-sequence resistance from the substation to the fault location
X_0	Estimated zero-sequence reactance from the substation to the fault location
R_N	Estimated the earth return path resistance (= (R0 – R1)/3) from the substation to the fault location
X_N	Estimated is the earth return path reactance (= (X0 – X1)/3) from the substation to the fault
R_{fault}	Estimated fault resistance at the fault location

The recorded data Flt phase reactance provides the estimated positive-sequence reactance from the substation to the fault location.

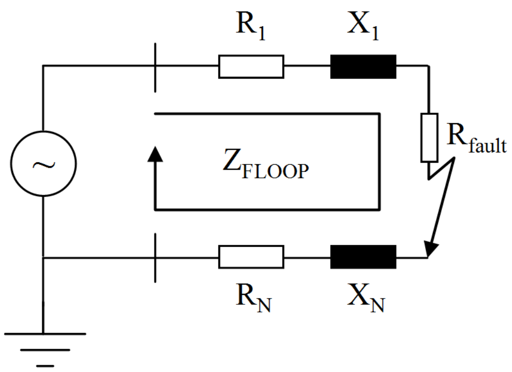


Figure 444: Fault loop impedance for phase-to-earth fault loops “AG Fault”, “BG Fault” or “CG Fault”

The earth-fault distance calculation algorithm is selected with setting *EF algorithm Sel*. Options for the selection are “Load compensation” and “Load modelling”. For the correct operation of both algorithms there should not be any zero-sequence current sources, for example, earthing transformers, in front of the protection relay location.

The “Load compensation” algorithm utilizes symmetrical components to compensate for the effect of load on the measured voltages and currents. In case of radial feeders, this algorithm should be selected with low-impedance/effectively earthed systems where the fault current is fed from one side only and there are no in-feeds along the protected line.

The “Load modelling” algorithm takes into account the effect of the load in the measured currents and voltages by considering it in the fault loop model. In case of radial feeders, this algorithm can be applied with low-impedance/effectively earthed systems where the fault current is fed from one side only. The “Load modelling” algorithm has been especially designed for unearthed systems.

The “Load modelling” algorithm requires the *Equivalent load Dis* setting, that is, an equivalent load distance, as an additional parameter. The derivation and meaning of this parameter is illustrated in *Figure 445*, where the load is assumed to be evenly distributed along the feeder, resulting in the actual voltage drop curve as seen in the middle part of *Figure 445*.

In case of evenly distributed load, *Equivalent load Dis* ~ 0.5. When the load is tapped at the end of the feeder, *Equivalent load Dis* = 1.0. If the load distribution is unknown, a default value of 0.5 can be used for *Equivalent load Dis*.

The maximum value of the voltage drop, denoted as U_{drop}(real), appears at the end of the feeder. 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.

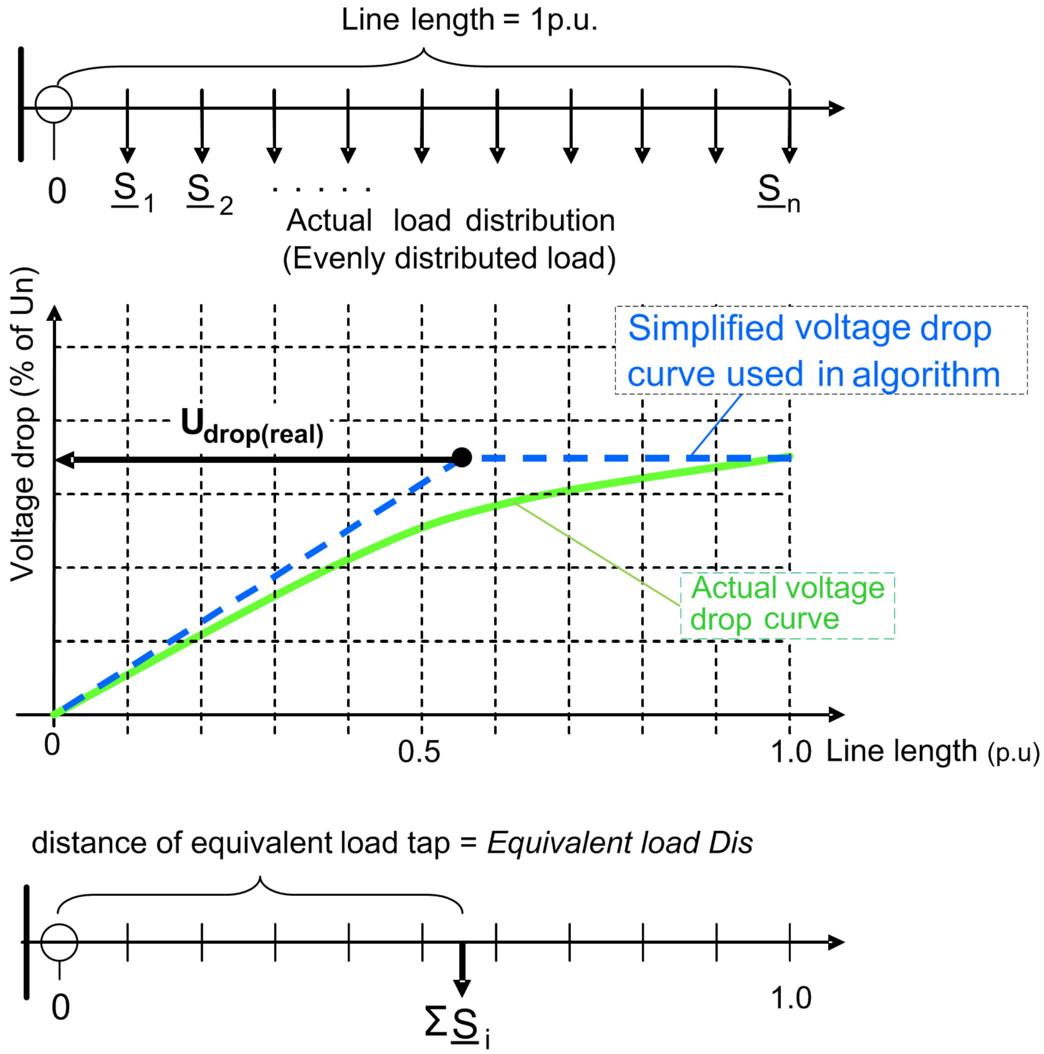


Figure 445: Description of the equivalent load distance

The exact value for *Equivalent load Dis* can be calculated based on the load flow and voltage drop calculations using data from DMS-system and the following equation.

$$\text{Equivalent load Dis} = \frac{U_{d(real)}}{U_{d(tap,d=1)}}$$

(Equation 157)

$U_{d(real)}$	The actual maximum voltage drop of the feeder
$U_{d(tap,d=1)}$	The fictional voltage drop, if the entire load would be tapped at the end (d=1) of the feeder (not drawn in *Figure 445*). The calculation of this value requires data from the DMS system.

Alternatively, the setting *Equivalent load Dis* can be determined by conducting a single-phase earth-fault test (R_{fault} = 0 Ω) 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. As a result, the calculated value is stored in the recorded data Equivalent load Dis.

In addition, when the setting *EF algorithm Sel* is equal to “Load modelling”, the *EF algorithm Cur Sel* setting determines whether zero-sequence “Io based” or negative-sequence “I2 based” current based algorithm is used. The difference between “Io based” and “I2 based” methods is that “I2 based” does not require the *Ph capacitive React* and *Ph leakage Ris* settings. In case of “Io based”, these settings are needed to compensate for the influence of the line-charging capacitances of the protected feeder. This improves the accuracy of the fault location estimate when fault resistance is involved in the fault.

Under certain restrictions, the “Load modelling” algorithm can also be applied to unearthed networks. In this case the *EF algorithm Cur Sel* setting should be set to “Io based” and thus *Ph capacitive React* and *Ph leakage Ris* settings must be determined.

The prerequisite for the operation of SCEFRFLO in earth faults in unearthed networks is that the earth-fault current of the network corresponding to a solid fault exceeds the pre-fault load current; that is the *Equation 158* is valid.

$$Flt\ to\ Lod\ Cur\ ratio = \frac{\left|I_{ef(Rfault=0)}\right|}{\left|I_{Load}\right|} \geq 1$$

(Equation 158)

This ratio is estimated by SCEFRFLO and stored in the recorded data Flt to Lod Cur ratio together with the fault distance estimate.

In case of unearthed network, sufficient fault current magnitude resulting in Flt to Lod Cur ratio >1 can be achieved, for example, with proper switching operations in the background network, if possible, which increase the fault current. If the faulty feeder is re-energized after the switching operation, a new estimate for the fault distance can be obtained. Fault resistance decreases the fault location accuracy and the resistance should not be too high, the maximum is a few hundred ohms. Also low value of Flt to Lod Cur ratio causes inaccuracy and affects the quality of fault distance estimate. Considered inaccuracies affecting the calculated fault distance estimate are reported in the recorded result quality indicator value Flt Dist quality in *Table 811*.

Fault loops “AB Fault”, “BC Fault” or “CA Fault”

Fault loops “AB Fault”, “BC Fault” or “CA Fault” are used for phase-to-phase short circuit faults as well as in the case of a two-phase-to-earth fault if the individual earth faults are located at the same feeder. *Figure 446* shows the phase-to-phase fault loop model. The following impedances are measured and stored in the recorded data of SCEFRFLO.

$$Flt\ point\ resistance = \frac{R_{fault}}{2}$$

(Equation 159)

$$Flt\ loop\ resistance = R_1 + \frac{R_{fault}}{2}$$

(Equation 160)

$$Flt\ loop\ reactance = Flt\ phase\ reactance = X_1$$

(Equation 161)

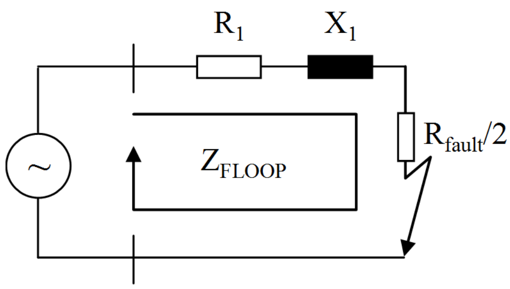


Figure 446: Fault loop impedance for phase-to-phase fault loops (either “AB Fault”, “BC Fault” or “CA Fault”)

The fault distance calculation algorithm for the phase-to-phase fault loops is defined by using settings *Load Com PP loops* and *Enable simple model*. Options for the selection are "Disabled" or "Enabled".

Load compensation can be enabled or disabled with setting *Load Com PP loops*. 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 from each shot of an autoreclosing sequence.

The fault distance calculation is most accurate when calculated with the fault loop model. This model requires positive sequence impedances of the protected feeder to be given as settings. If these settings are not available, valid impedance values can be calculated also without the fault loop model with setting *Enable simple model* = “TRUE”. However, valid distance estimate, that is, the conversion of measured impedance (“electrical fault distance”) into a physical fault distance requires accurate positive sequence impedance settings.

Fault loop “ABC Fault”

Fault loop “ABC Fault” is used exclusively for the three-phase short circuit fault. *Figure 447* shows the three-phase fault loop model. The following impedances are measured and stored in the recorded data of SCEFRFLO.

$$Flt\ point\ resistance = R_{fault}$$

(Equation 162)

$$Flt\ loop\ resistance = R_1 + R_{fault}$$

(Equation 163)

$$Flt\ loop\ reactance = Flt\ phase\ reactance = X_1$$

(Equation 164)

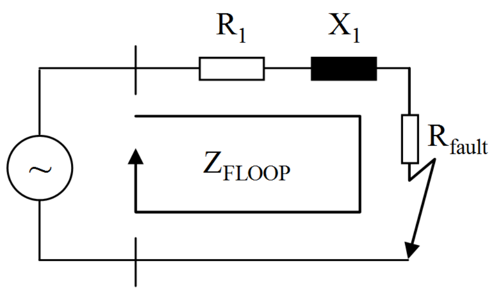


Figure 447: Fault loop impedance for a three-phase fault loop ("ABC Fault")

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 influence of line parameter asymmetry is reduced. If the line is non-transposed, all the phase-to-phase loops have different fault loop reactances. The use of positive-sequence quantities results in the average value of phase-to-phase loop reactances, that is, the most representative estimate in case of three-phase faults.

The fault distance calculation algorithm for the three-phase fault loop is defined by using settings *Load Com PP loops* and *Enable simple model*. Options for the selection are "Disabled" or "Enabled".

Load compensation can be enabled or disabled with setting *Load Com PP loops*. 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 from each shot of an autoreclosing sequence.

The fault distance calculation is most accurate when the calculation is made with the fault loop model. This model requires positive sequence impedances of the protected feeder to be given as settings. If these settings are not available, valid impedance values can be calculated also without the fault loop model with setting *Enable simple model* = "TRUE". However, valid distance estimate, that is, the conversion of measured impedance (''electrical fault distance'') into a physical fault distance requires accurate positive sequence impedance settings.

Estimation of fault resistance in different fault loops

The fault point resistance value provided by the impedance calculation is available in recorded data Flt point resistance and it depends on the applied fault loop as shown in *Figure 448*. In case of earth faults, the estimated fault point resistance includes the total fault point resistance between the faulted phase and earth, for example, the arc and earthing resistances. In case of phase-to-phase faults, the estimated fault point resistance is half of the total fault point resistance between the phases. In case of a three-phase fault, the estimated fault point resistance equals the total fault point resistance as per phase value, for example, the arc resistance per phase.

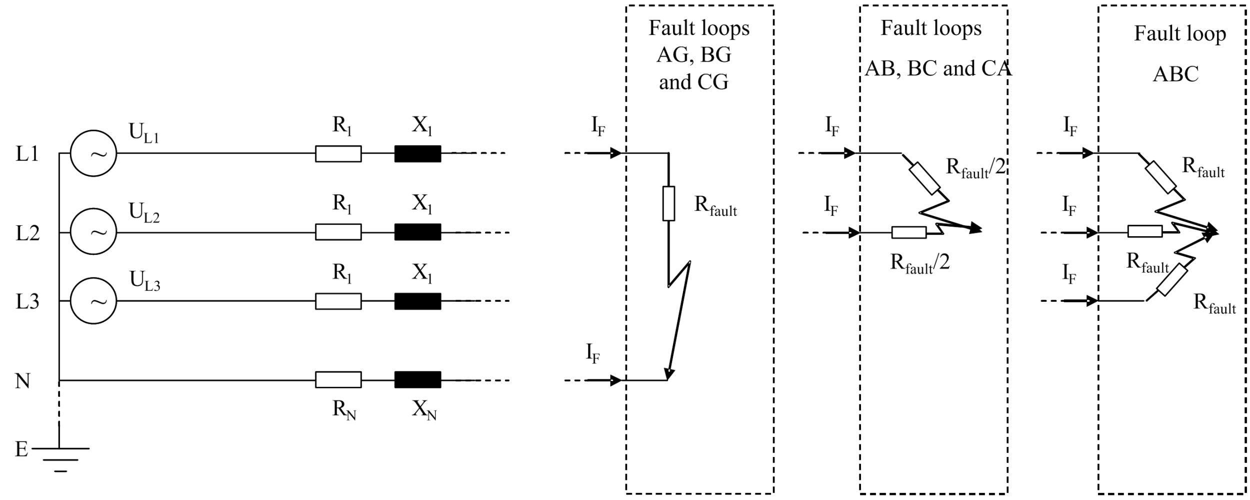


Figure 448: Definition of a physical fault point resistance in different fault loops

Steady-state asymmetry and load compensation

In reality, power systems are never perfectly symmetrical. The asymmetry produces steady-state quantities in the form of zero-sequence and negative-sequence voltages and currents. If not compensated, these are error sources for fault distance calculation especially in case of earth faults. All earth-fault distance calculation algorithms of SCEFRFLO utilize the delta-quantities which mitigate the effects of the steady-state asymmetry.

Load current is another error source for fault distance calculation. Its influence increases with higher fault resistance values. SCEFRFLO employs independent load compensation methods for each fault type to achieve optimal performance. The purpose of load compensation is to improve the accuracy of the fault distance calculation models by estimating the actual fault current in the fault location. Delta-quantities are used for this to mitigate the effect of load current on fault distance estimation. For earth faults, the load compensation is done automatically inside the fault distance calculation algorithm. For short circuit faults, load compensation is enabled with setting *Load Com PP loops*. The default value is “Enabled”. The parameter should be set to “Disabled” only if the ratio between the expected fault current and load current is large or when the fault distance estimate for short circuit fault is required for each shot of an autoreclosing sequence.

The delta-quantity describes the change in measured signal due to the fault.

$$\Delta x = x_{fault} + x_{pre\text{-}fault}$$

(Equation 165)

x_{fault}	Corresponds to the signal value during fault
$x_{pre\text{-}fault}$	Corresponds to the signal value during healthy state just before fault

Result quality indicator

The quality of the estimated fault distance is judged and reported in recorded data as the Flt Dist quality together with the fault distance estimate. The Flt Dist quality is a bit vector indicating detected sources of inaccuracy in the fault distance estimate. In case Flt Dist quality equals 1, the result is not affected by error sources. This results in good quality for fault distance estimate. If factors affecting negatively to fault distance estimation are detected, the Flt Dist quality is according to *Table 811*. In this case estimated fault distance, Flt distance value is given in HMI in parenthesis.

Table 811: Fault distance quality indicator Flt Dist quality

Value	Corresponding inaccuracy description
2	Estimation stability criterion has not been reached
4	Fault point resistance exceeds 500 Ω
8	Fault point resistance exceeds 5 × X_{loop}
16	Fault point resistance exceeds 20 × X_{loop}[1]
32	Flt to Lod Cur ratio is below 1.00
64	Fault distance estimate outside tolerances (<-0.1 pu or >1.1 pu)
128	Distance estimate calculation is not done due to too low magnitudes of I or U
256	Distance estimate calculation cannot be performed (for example avoiding internal division by zero)

For example, if fault point resistance exceeds 500 Ω and Flt to Lod Cur ratio is below 1.0, Flt Dist quality is “36”. As another example, if no error sources are found, but stability criterion is not met, the value of Flt Dist quality is “2”.

Impedance settings

The fault distance calculation in SCEFRFLO is based on the fault loop impedance modeling. The fault loop is parametrized with the impedance settings and these can be set at maximum for three line sections (A, B and C). Each section is enabled by entering a section length, which differs from zero to settings *Line Len section A*, *Line Len section B* or *Line Len section C* in the order section A-> section B-> section C.

The earth-fault loops require both positive-sequence and zero-sequence impedances, for example, *R1 line section A* and *X1 line section A*, *R0 line section A* and *X0 line section A*. For the short circuit loops, only positive-sequence impedances are needed. Even these can be omitted in the short circuit loops, if the setting *Enable simple model* equals "TRUE".

If the impedance settings are in use, it is important that the settings closely match the impedances of used conductor types. The impedance settings are given in primary ohms [ohm/pu] and the line section lengths in per unit [pu]. Thus, impedances can be either given in ohm/km and section length in km, or ohm/mile and section length in miles. The resulting Flt distance matches the units entered for the line section lengths.

Positive-sequence impedance values

Fault location requires accurate setting values for line impedances. Positive-sequence impedances are required both for location of short circuits and earth

[1] Xloop is the total loop reactance according to settings

faults. As data sheet impedance per unit values are generally valid only for a certain tower configuration, the values should be adjusted according to the actual installation configuration. This minimizes the fault location errors caused by inaccurate settings.

The positive-sequence reactance per unit and per phase can be calculated with a following approximation equation which applies to symmetrically transposed three-phase aluminium overhead lines without ground wires.

$$X_1 \approx \omega_n \cdot 10^{-4} \left(2 \cdot \ln \frac{a_{en}}{r} + 0.5 \right) [\Omega / km]$$

(Equation 166)

ω_n	$2 \times \pi \times f_n$, where f_n = fundamental frequency [Hz]
a_{en}	$\sqrt[3]{(a_{12} \cdot a_{23} \cdot a_{31})}$ the geometric average of phase distances [m]
a_{xy}	distance [m] between phases x and y
r	radius [m] for single conductor

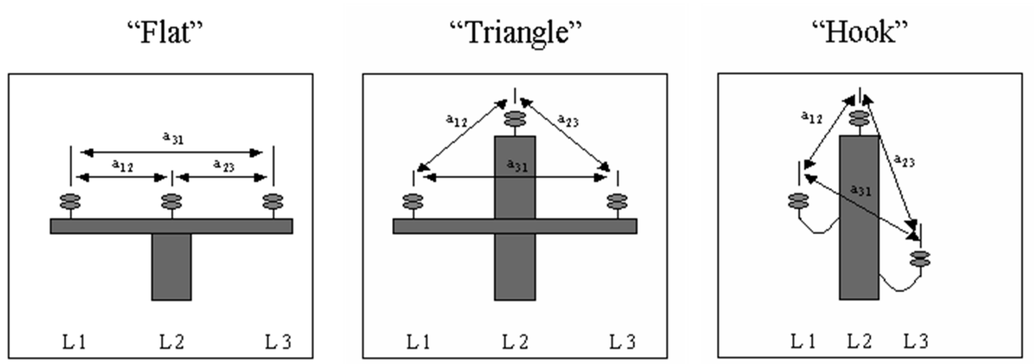


Figure 449: Typical distribution line tower configurations

Example values of positive-sequence impedances for typical medium voltage overhead-lines are given in the following tables.

Table 812: 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 813: 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 814: 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

Zero-sequence impedance values

Location of earth faults requires both positive-sequence and zero-sequence impedances. For short circuit faults, zero-sequence impedances are not required.

The positive-sequence impedance per unit values for the lines are typically known or can easily be obtained from data sheets. The zero-sequence values are generally not as easy to obtain as they depend on the actual installation conditions and configurations. Sufficient accuracy can, however, be obtained with rather simple calculations using the following equations, which apply per phase for symmetrically transposed three-phase aluminium overhead lines without ground wires.

$$R_0[50Hz] \approx R1 + 0.14804[\Omega / km]$$

(Equation 167)

$$R_0[60Hz] \approx R1 + 0.17765[\Omega / km]$$

(Equation 168)

$$X_0 \approx 2 \cdot \omega_n \cdot 10^{-4} \left(3 \cdot \ln \frac{w}{r_{en}} + 0.25 \right) [\Omega / km]$$

(Equation 169)

R_1	conductor AC resistance [Ω/km]
W	$658\sqrt{\frac{\rho_{earth}}{f_n}}$
	the equivalent depth [m] of the earth return path
ρ_{earth}	earth resistivity [Ωm]
r_{en}	$\sqrt[3]{r \cdot \sqrt[3]{a_{12}^2 \cdot a_{23}^2 \cdot a_{31}^2}}$
	the equivalent radius [m] for conductor bundle
r	radius [m] for single conductor
a_{xy}	distance [m] between phases x and y

Ph leakage Ris and *Ph capacitive React* settings

The *Ph leakage Ris* and *Ph capacitive React* settings are used for improving fault distance estimation accuracy for earth faults. They are critical for an accurate fault location in unearthed networks. In other types of networks they are less critical. The *Ph leakage Ris* setting represents the leakage losses 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 *Ph leakage Ris* should be about 20…40 × *Ph capacitive React*.

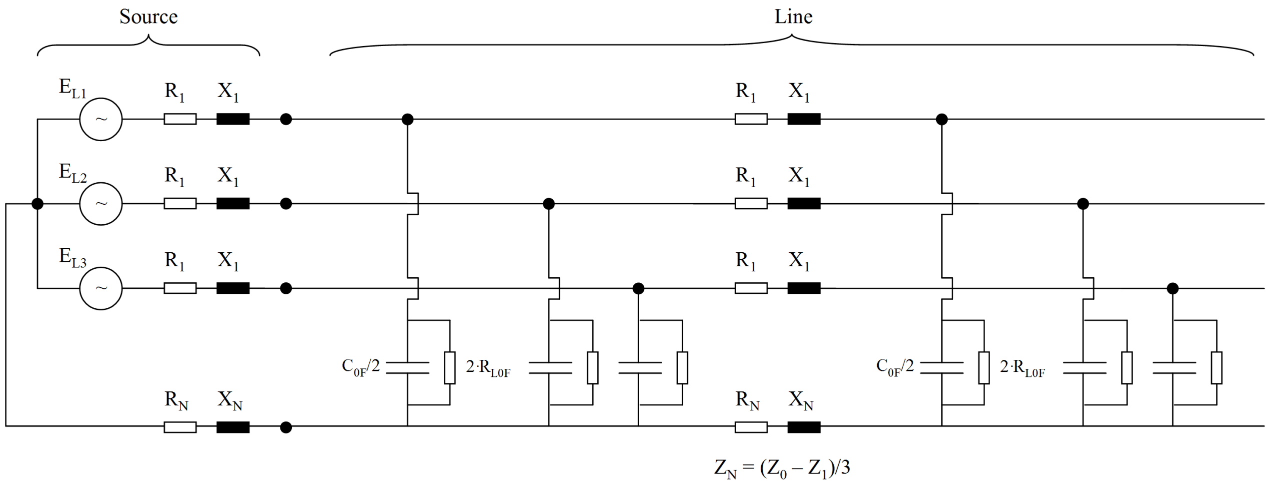


Figure 450: Equivalent diagram of the protected feeder. R L0F = Ph leakage Ris.

The determination 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, the setting value can be calculated.

$$Ph\ capacitive\ React = \frac{1}{(\omega_n \cdot C_{0F})}$$

(Equation 170)

In case of unearthed network, if the earth-fault current produced by the protected feeder I_{ef} is known, the setting value can be calculated.

$$Ph\ capacitive\ React = \frac{\sqrt{3} \cdot U_{xy}}{I_{ef}}$$

(Equation 171)

U_{xy} Phase-to-earth voltage

SCEFRFLO can also determine the value for the *Ph capacitive React* setting by measurements. The calculation of *Ph capacitive React* is triggered by the binary signal connected to the TRIGG_XC0F input when an earth-fault test is conducted outside the protected feeder during commissioning, for example, at the substation busbar. The *Calculation Trg mode* has to be “External”. After the activation of the TRIGG_XC0F triggering input, the calculated value for setting *Ph capacitive React* is obtained from recorded data as parameter *XC0F Calc*. This value has to be manually entered for the *Ph capacitive React* setting. The calculated value matches the current switching state of the feeder and thus, if the switching state of the protected feeder changes, the value should be updated.

Figure 451 shows an example configuration, which enables the measurement of setting *Ph capacitive React*.

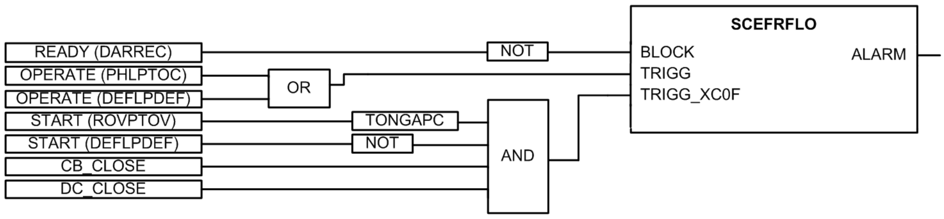


Figure 451: An example configuration, which enables the measurement of setting Ph capacitive React

If the earth fault is detected by the residual overvoltage function (START of ROVPTOV), but not seen by the forward-looking earth-fault protection function (START of DEFLPDEF), the fault is located outside the protected feeder. This is mandatory for valid measurement of setting *Ph capacitive React*. After a set delay (TONGAPC), the input TRIGG_XC0F is activated and the parameter *XC0F Calc* in the recorded data is updated. The delay (TONGAPC) must be set longer than the start delay of the directional earth-fault function DEFLPDEF, but shorter than the minimum operating time of the directional earth-fault functions in any of the feeders. For example, if the start delay is 100 ms and the shortest operating time 300 ms, a value of 300 ms can be used. Circuit breaker and disconnector status is used to verify that the entire feeder is measured.

Modeling a non-homogeneous line

A typical distribution feeder is built with several different types of overhead lines and cables. This means that the feeder is electrically non-homogeneous. SCEFRFLO allows the modeling of the line impedance variation in protection relay with three line sections with independent impedance settings. This improves the accuracy of physical fault distance conversion done in the protection relay, especially in cases where the line impedance non-homogeneity is severe. Each section is enabled by entering a section length, which differs from zero, to settings *Line Len section A*, *Line Len section B* or *Line Len section C* in the order section A-> section B-> section C.

Impedance model with one line section is enabled by setting *Line Len section A* to differ from zero. In this case the impedance settings *R1 line section A*, *X1 line section A*, *R0 line section A* and *X0 line section A* are used for the fault distance calculation and for conversion from reactance to physical fault distance. This option should be used only in the case of a homogeneous line, that is, when the protected feeder consists of only one conductor type.

Impedance model with two line sections is enabled by setting both *Line Len section A* and *Line Len section B* to differ from zero. In this case the 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* and *X0 line section B* are used for the fault distance calculation and for conversion from reactance to physical fault distance. This option should be used in the case of a non-homogeneous line when the protected feeder consists of two types of conductors.

Impedance model with three line sections is enabled by setting *Line Len section A*, *Line Len section B* and *Line Len section C* all differ from zero. In this case the 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* and *X0 line section C* are used for the fault distance calculation and for conversion from reactance to physical fault distance. This option should be used in the case of a non-homogeneous line when the protected feeder consists of more than two types of conductors.

The effect of line impedance non-homogeneity in the conversion of fault loop reactance into physical fault distance is demonstrated in example shown in *Figure 452* with 10 kilometer long feeder with three line types. The total line impedance for the 10 km line is R1 = 6.602 Ω (0.660 Ω/km) and X1 = 3.405 Ω (0.341 Ω/km), consisting of the following sections and impedance values.

- 4 km of PAS 150 (R1 = 0.236 Ω/km, X1 = 0.276 Ω/km)
- 3 km of Al/Fe 54/9 Raven (R1 = 0.536 Ω/km, X1 = 0.369 Ω/km)
- 3 km of Al/Fe 21/4 Swan (R1 = 1.350 Ω/km, X1 = 0.398 Ω/km)

The non-homogeneity of feeder impedance can be illustrated by drawing the protected feeder in RX-diagram (in the impedance plane), as shown in *Figure 452*.

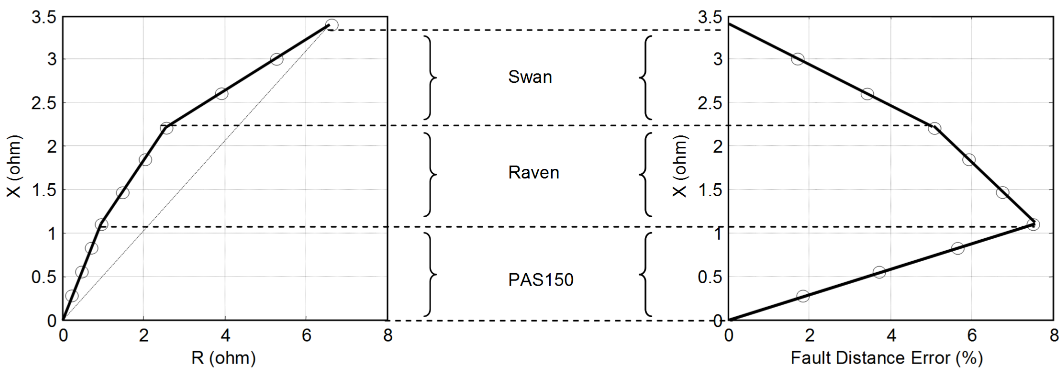


Figure 452: Example impedance diagram of an electrically non-homogeneous feeder (left), and the resulting error in fault distance if the measured fault loop reactance is converted into physical fault distance by using only one line section parameters (right).

In *Figure 452* the feeder is modelled either with one or three line sections with parameters given in *Table 815*.

Table 815: Impedance settings

Parameter	Impedance model with one section	Impedance model with three sections
R1 line section A	0.660 Ω/pu	0.236 Ω/pu
X1 line section A	0.341 Ω/pu	0.276 Ω/pu
Line Len section A	10000 pu	4000 pu
R1 line section B	N/A	0.536 Ω/pu
X1 line section B	N/A	0.369 Ω/pu
Line Len section B	0.000 pu	3000 pu
R1 line section C	N/A	1.350 Ω/pu
X1 line section C	N/A	0.398 Ω/pu
Line Len section C	0.000 pu	3000 pu

Figure 452 illustrates the conversion error from measured fault loop reactance into physical fault distance. The fault location is varied from 1 km to 10 km in 1 km steps (marked with circles). An error of nearly eight per cent at maximum is created by the conversion procedure when modeling a non-homogenous line with only one section. By using impedance model with three line sections, there is no error in the conversion.

The previous example assumed a short circuit fault and thus, 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 corresponds to several physical fault locations (For example, A or B in *Figure 453*). The actual fault location must be identified using additional information, for example, short circuit current indicators placed on tapping points.

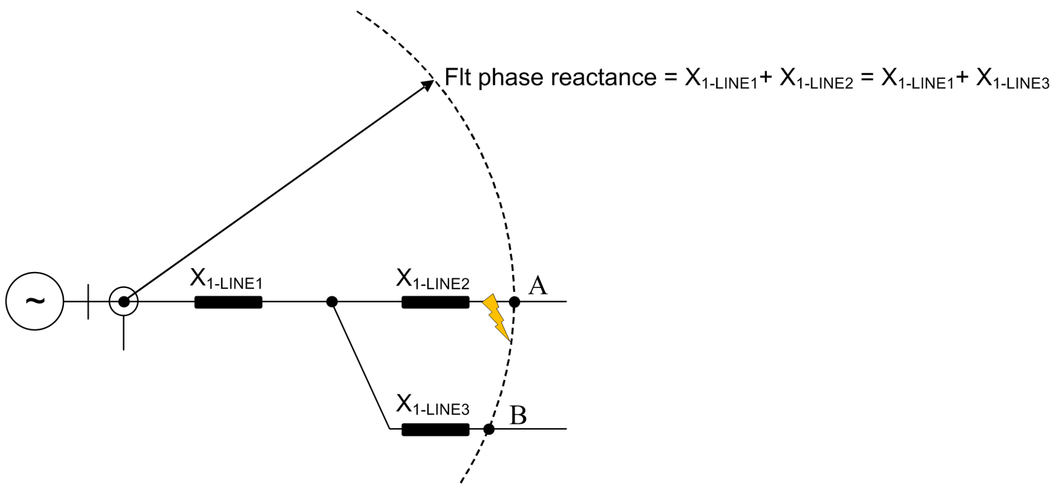


Figure 453: Fault on a distribution line with spurs

5.7.4.3 Trigger detection

The fault distance estimate is obtained when SCEFRFLO is triggered. The triggering method is defined with setting *Calculation Trg mode*. The options for selection are: "External" or "Internal", where the default value is "External". The TRIGG_OUT event indicates fault distance value recording moment. The fault distance estimate, Flt distance, together with the timestamp of actual triggering are saved in the recorded data of SCEFRFLO.

- In case of external triggering, an external trigger signal should be connected to the TRIGG input. The triggering signal is typically a trip signal from a protective function. At triggering moment the fault distance is stored into recorded data. It is important that triggering is timed suitably to provide sufficient distance estimation calculation time before tripping of the feeder circuit breaker.
- In case of internal triggering, the TRIGG input is not used for triggering. Instead, the trigger signal is created internally so that the estimation is started when phase selection logic detects a fault and the estimate is triggered when its value has stabilized sufficiently. This is judged by maximum variation in fault distance estimate and defined with setting *Distance estimate Va* (in the same unit as the fault distance estimate). When successive estimates during one fundamental cycle are within "final value ± *Distance estimate Va*", the fault distance estimate (mean of successive estimates) is recorded. In case stabilization criterion has not been fulfilled, the fault distance estimate is given just before the phase currents are interrupted. The phase selection logic is a non-directional function, and thus internal triggering should not be used when directionality is required.

Generally, SCEFRFLO requires a minimum of two fundamental cycles of measuring time after the fault occurrence. *Figure 454* illustrates typical behavior of fault distance estimate of SCEFRFLO as a function of time.

- Immediately after the fault occurrence, the estimate is affected by initial fault transients in voltages and currents.
- Approximately one fundamental cycle after the fault occurrence, the fault distance estimate starts to approach the final value.
- Approximately two fundamental cycles after the fault occurrence, the stability criterion for fault distance estimate is fulfilled and the TRIGG_OUT event is sent. The recorded data values are stored at this moment.

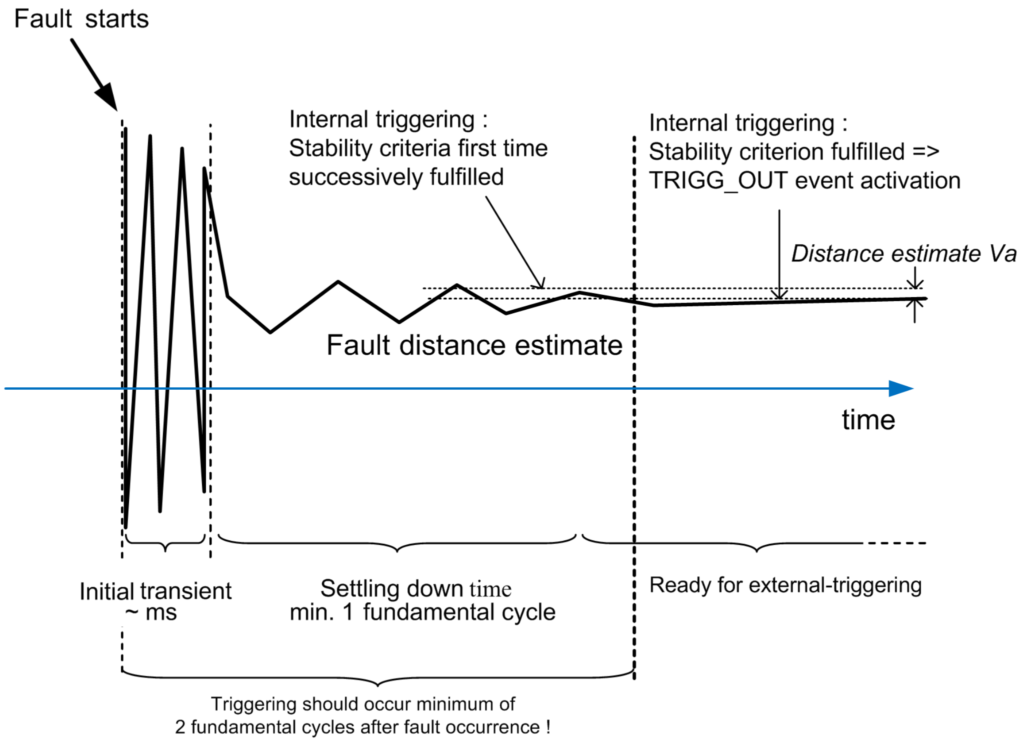


Figure 454: The behavior of fault distance estimate in time

5.7.4.4 Alarm indication

SCEFRFLO contains an alarm output for the calculated fault distance. If the calculated fault distance FLT_DISTANCE is between the settings *Low alarm Dis limit* and *High alarm Dis limit*, the ALARM output is activated.

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.

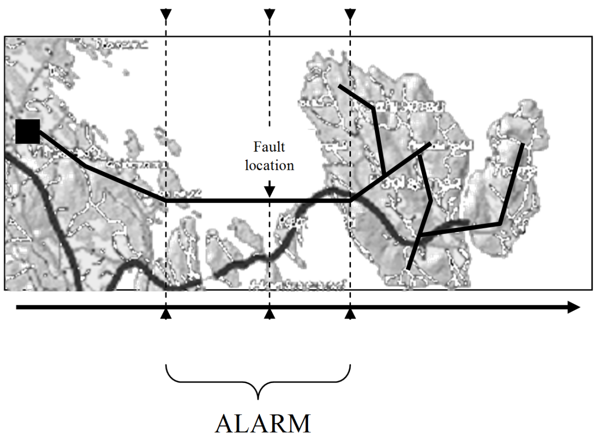


Figure 455: An example of the ALARM output use

5.7.4.5 Recorded data

All the information required for a later fault analysis is recorded to SCEFRFLO recorded data. In the protection relay, recorded data is found in **Monitoring** > **Recorded data** > **Other protection** > **SCEFRFLO**.

The function has also monitored data values which are used for the read-out of continuous calculation values. The cross reference table shows which of the recorded data values are available as continuous monitoring values during a fault.

Table 816: Cross reference table for recorded and monitored data values

Recorded data	Monitored data
Flt loop	FAULT_LOOP
Flt distance	FLT_DISTANCE
Flt Dist quality	FLT_DIST_Q
Flt loop resistance	RFLOOP
Flt loop reactance	XFLOOP
Flt phase reactance	XFPHASE
Flt point resistance	RF
Flt to Lod Cur ratio	IFLT_PER_ILD
Equivalent load Dis	S_CALC
XC0F Calc	XC0F_CALC

5.7.4.6 Measurement modes

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 (*VT connection* is set to “Wye”). Another alternative is to measure phase-to-phase voltages (*VT connection* is set to “Delta”) 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 "Ph-to-ph without Uo" and only phase-to-phase voltages are available (but not Uo), only short-circuit measuring loops (fault loops “AB Fault”, “BC Fault” or “CA Fault” or “ABC Fault”) can be measured accurately. In this case, the earth-fault loops (fault loops either “AG Fault”, “BG Fault” or “CG Fault”) cannot provide correct fault distance estimates and the triggering of the function in case of earth fault is automatically disabled.

5.7.5 Application

The main objective of the feeder terminals is a fast, selective and reliable operation in faults inside the protected feeder. In addition, information on the distance to the fault point is very important for those involved in operation and maintenance. Reliable information on the fault location greatly decreases the downtime of the protected feeders and increases the total availability of a power system.

SCEFRFLO provides impedance-based fault location. It is designed for radially operated distribution systems and is applicable for locating short circuits in all kinds of distribution networks. Earth faults can be located in effectively earthed and low resistance/low-reactance earthed networks. Under certain limitations, SCEFRFLO can also be applied for earth-fault location in unearthed distribution networks.

Configuration example

A typical configuration example for SCEFRFLO triggering is illustrated in *Figure 451* where external triggering is applied, that is, *Calculation Trg mode* is set to "External". The OPERATE signal from 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 the 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 can be decreased due to inaccurate load compensation. During the dead time of an autoreclosing sequence, the load condition of the feeder is uncertain.

The triggering of SCEFRFLO can also be inhibited during the autoreclosing sequence. This is achieved by connecting the inverted READY signal from the autoreclosing function DARREC, which indicates that the autoreclosing sequence is in progress, to the BLOCK input of SCEFRFLO. Blocking of the 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 when *Load Com PP loops* is set to "Enabled" or, for earth faults, when *EF algorithm Sel* is set to "Load compensation" or "Load modelling".

5.7.6 Signals

Table 817: SCEFRFLO Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
Io	SIGNAL	0	Residual current
I_1	SIGNAL	0	Positive sequence current
I_2	SIGNAL	0	Negative sequence current
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC

Table continues on the next page

Name	Type	Default	Description
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
Uo	SIGNAL	0	Residual voltage
U_1	SIGNAL	0	Positive phase sequence voltage
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
TRIGG	BOOLEAN	0=False	Distance calculation triggering signal
TRIGG_XC0F	BOOLEAN	0=False	XC0F calculation triggering signal

Table 818: SCEFRFLO Output signals

Name	Type	Description
ALARM	BOOLEAN	Fault location alarm signal

5.7.7 Settings

Table 819: SCEFRFLO Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Z Max phase load	1.0...10000.0	ohm	0.1	80.0	Impedance per phase of max. load, overcurr./under-imp., PSL
Ph leakage Ris	20...1000000	ohm	1	210000	Line PhE leakage resistance in primary ohms
Ph capacitive React	10...1000000	ohm	1	7000	Line PhE capacitive reactance in primary ohms
R1 line section A	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line resistance, line section A
X1 line section A	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line reactance, line section A
R0 line section A	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line resistance, line section A
X0 line section A	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line reactance, line section A
Line Len section A	0.000...1000.000	pu	0.001	0.000	Line length, section A

Table 820: SCEFRFLO Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
High alarm Dis limit	0.000...1.000	pu	0.001	0.000	High alarm limit for calculated distance
Low alarm Dis limit	0.000...1.000	pu	0.001	0.000	Low alarm limit for calculated distance
Equivalent load Dis	0.00...1.00		0.01	0.50	Equivalent load distance when EF algorithm equals to load modelling
R1 line section B	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line resistance, line section B
X1 line section B	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line reactance, line section B
R0 line section B	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line resistance, line section B
X0 line section B	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line reactance, line section B
Line Len section B	0.000...1000.000	pu	0.001	0.000	Line length, section B
R1 line section C	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line resistance, line section C
X1 line section C	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line reactance, line section C
R0 line section C	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line resistance, line section C
X0 line section C	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line reactance, line section C
Line Len section C	0.000...1000.000	pu	0.001	0.000	Line length, section C

Table 821: SCEFRFLO Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Phase voltage Meas	1=Accurate 2=Ph-to-ph without Uo			1=Accurate	Phase voltage measurement principle
Calculation Trg mode	1=Internal 2=External			2=External	Trigger mode for distance calculation

Table 822: SCEFRFLO Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
EF algorithm Sel	1=Load compensation 2=Load modelling			1=Load compensation	Selection for PhE-loop calculation algorithm
EF algorithm Cur Sel	1=Io based 2=I2 based			1=Io based	Selection for earth-fault current model

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Load Com PP loops	0=Disabled 1=Enabled			1=Enabled	Enable load compensation for PP/3P-loops
Enable simple model	0=Disabled 1=Enabled			0=Disabled	Enable calc. without impedance settings for PP/3P-loops
Distance estimate Va	0.001...0.300		0.001	0.015	Allowed variation of short circuit distance estimate

5.7.8 Monitored data

Table 823: SCEFRFLO Monitored data

Name	Type	Values (Range)	Unit	Description
RF	FLOAT32	0.0...1000000.0	ohm	Fault point resistance in primary ohms
FAULT_LOOP	Enum	1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault -5=No fault		Fault impedance loop
FLT_DISTANCE	FLOAT32	0.00...3000.00	pu	Fault distance in units selected by the user
FLT_DIST_Q	INT32	0...511		Fault distance quality
RFLOOP	FLOAT32	0.0...1000000.0	ohm	Fault loop resistance in primary ohms
XFLOOP	FLOAT32	0.0...1000000.0	ohm	Fault loop reactance in primary ohms
XFPHASE	FLOAT32	0.0...1000000.0	ohm	Positive sequence fault reactance in primary ohms
IFLT_PER_ILD	FLOAT32	0.00...60000.00		Fault to load current ratio

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
S_CALC	FLOAT32	0.00...1.00		Estimated equivalent load distance
XC0F_CALC	FLOAT32	0.0...1000000.0	ohm	Estimated PhE capacitive reactance of line
SCEFRFLO	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
Triggering time	Timestamp			Estimate triggering time
Flt loop	Enum	1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault -5=No fault		Fault loop
Flt distance	FLOAT32	0.00...3000.00	pu	Fault distance
Flt Dist quality	INT32	0...511		Fault distance quality
Flt loop resistance	FLOAT32	0.0...1000000.0	ohm	Fault loop resistance
Flt loop reactance	FLOAT32	0.0...1000000.0	ohm	Fault loop reactance
Flt phase reactance	FLOAT32	0.0...1000000.0	ohm	Fault phase reactance
Flt point resistance	FLOAT32	0.0...1000000.0	ohm	Fault resistance
Flt to Lod Cur ratio	FLOAT32	0.00...60000.00		Fault to load current ratio
Equivalent load Dis	FLOAT32	0.00...1.00		Estimated equivalent load distance
XC0F Calc	FLOAT32	0.0...1000000.0	ohm	Estimated PhE capacitive reactance of the line
Pre fault time	Timestamp			Pre-fault time

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
A Pre Flt Phs A Magn	FLOAT32	0.00...40.00	xIn	Pre-fault current phase A, magnitude
A Pre Flt Phs A Angl	FLOAT32	-180.00...180.00	deg	Pre-fault current phase A, angle
A Pre Flt Phs B Magn	FLOAT32	0.00...40.00	xIn	Pre-fault current phase B, magnitude
A Pre Flt Phs B Angl	FLOAT32	-180.00...180.00	deg	Pre-fault current phase B, angle
A Pre Flt Phs C Magn	FLOAT32	0.00...40.00	xIn	Pre-fault current phase C, magnitude
A Pre Flt Phs C Angl	FLOAT32	-180.00...180.00	deg	Pre-fault current phase C, angle
V Pre Flt Phs A Magn	FLOAT32	0.00...40.00	xIn	Pre-fault voltage phase A, magnitude
V Pre Flt Phs A Angl	FLOAT32	-180.00...180.00	deg	Pre-fault voltage phase A, angle
V Pre Flt Phs B Magn	FLOAT32	0.00...40.00	xIn	Pre-fault voltage phase B, magnitude
V Pre Flt Phs B Angl	FLOAT32	-180.00...180.00	deg	Pre-fault voltage phase B, angle
V Pre Flt Phs C Magn	FLOAT32	0.00...40.00	xIn	Pre-fault voltage phase C, magnitude
V Pre Flt Phs C Angl	FLOAT32	-180.00...180.00	deg	Pre-fault voltage phase C, angle
A Flt Phs A Magn	FLOAT32	0.00...40.00	xIn	Fault current phase A, magnitude
A Flt Phs A angle	FLOAT32	-180.00...180.00	deg	Fault current phase A, angle
A Flt Phs B Magn	FLOAT32	0.00...40.00	xIn	Fault current phase B, magnitude
A Flt Phs B angle	FLOAT32	-180.00...180.00	deg	Fault current phase B, angle
A Flt Phs C Magn	FLOAT32	0.00...40.00	xIn	Fault current phase C, magnitude
A Flt Phs C angle	FLOAT32	-180.00...180.00	deg	Fault current phase C, angle

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
V Flt Phs A Magn	FLOAT32	0.00...40.00	xIn	Fault voltage phase A, magni-tude
V Flt Phs A angle	FLOAT32	-180.00...180.00	deg	Fault voltage phase A, angle
V Flt Phs B Magn	FLOAT32	0.00...40.00	xIn	Fault voltage phase B, magni-tude
V Flt Phs B angle	FLOAT32	-180.00...180.00	deg	Fault voltage phase B, angle
V Flt Phs C Magn	FLOAT32	0.00...40.00	xIn	Fault voltage phase C, magni-tude
V Flt Phs C angle	FLOAT32	-180.00...180.00	deg	Fault voltage phase C, angle

5.7.9 Technical data

Table 824: SCEFRFLO Technical data

Characteristic	Value
Measurement accuracy	At the frequency f = f_n Impedance: ±2.5 % or ±0.25 Ω Distance: ±2.5 % or ±0.16 km/0.1 mile XC0F_CALC: ±2.5 % or ±50 Ω IFLT_PER_ILD: ±5 % or ±0.05

5.7.10 Technical revision history

Table 825: SCEFRFLO Technical revision history

Technical revision	Change
B	Internal improvement.

5.8 Circuit breaker uncorresponding position start-up UPCALH

5.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit breaker uncorresponding position start-up	UPCALH	CBUPS	CBUPS

5.8.2 Function block

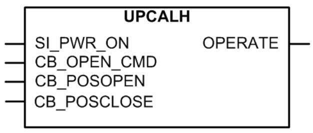


Figure 456: Function block

5.8.3 Functionality

The circuit breaker uncorresponding position start-up function UPCALH detects circuit breaker openings in an unknown situation. An unexpected breaker opening can be caused by, for example, internal mechanical malfunction.

UPCALH can be used independently. The function output is activated when detecting a circuit breaker opening in an unknown situation.

In most cases, the function module is used together with the AR function module. The operate output signal can be one of the start-up signals of the AR function.

5.8.4 Operation principle

The function can be enabled or disabled with the *Operation* setting. The corresponding parameter values are “On" and "Off".

The operation of UPCALH can be described with a module diagram. All the modules in the diagram are explained in the next sections.

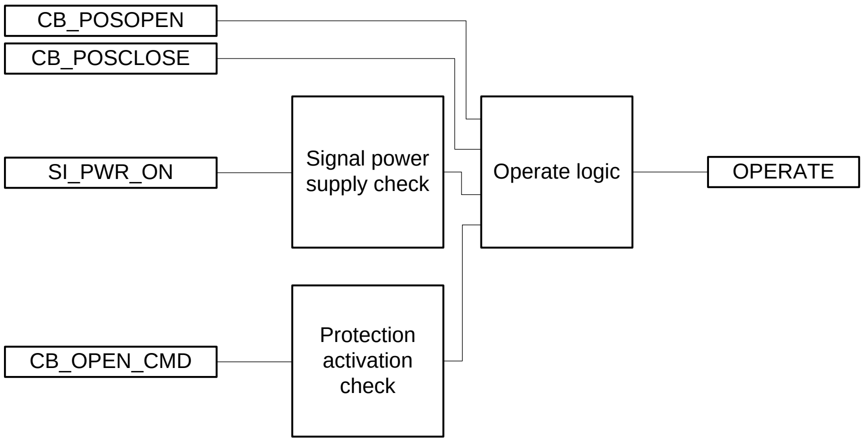


Figure 457: Functional module diagram

Signal power supply check

This module is used for signal power supply supervision. The activation of the SI_PWR_ON input enables the Operate logic module after the value of the *CB power on delay time* setting has elapsed.

Protection activation check

The main purpose of the module is to disable the Operate logic module when the CB open command has been deployed by another function, for example, a protection or control function. The activation of the CB_OPEN_CMD input disables the Operate logic module immediately. The duration of the disabling time can be set with the *CB open hold delay* setting.

Operate logic

The OPERATE output of this module can be used for closing the circuit breaker if it is opened for an unknown reason. The OPERATE output is activated immediately after the CB_POSOPEN input becomes active and CB_POSCLOSE inactive. The pulse length for the OPERATE output signal can be set with the *Operate pulse time* setting.

The module is disabled if the signal power supply is faulty (SI_PWR_ON = FALSE) or the open command is sent to the breaker (CB_OPEN_CMD = TRUE).

5.8.5 Application

The uncorresponding circuit breaker position means that the actual position of the circuit breaker's control switch is unmatched with the real position of the circuit breaker. In a normal situation, the function is used in cooperation with the autoreclosing function DARREC. The operate signal can start the autoreclosing when detecting that the circuit breaker has opened in an unknown situation. If the function is used as a stand-alone function when an unknown circuit breaker open is detected, the function output can be used as an information indication for the supervision station.

5.8.6 Signals

Table 826: UPCALH Input signals

Name	Type	Default	Description
CB_OPEN_CMD	BOOLEAN	0=False	CB open command, common
CB_POSCLOSE	BOOLEAN	0=False	CB position closed
CB_POSOPEN	BOOLEAN	0=False	CB position open
SI_PWR_ON	BOOLEAN	0=False	Signal power on

Table 827: UPCALH Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate

5.8.7 Settings

Table 828: UPCALH Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operate pulse time	100...20000	ms	1	100	Operate pulse time
Signal pwr on delay	300...500	ms	1	300	Signal power on delay time

Table 829: UPCALH Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
CB open hold delay	300...500	ms	1	300	CB open hold delay time

5.8.8 Technical data

Table 830: UPCALH Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

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

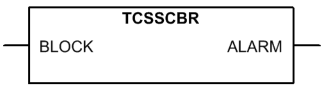


Figure 458: Function block

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 corresponding function block in the relay configuration.

The function starts and operates when TCSSCBR 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. Blocking deactivates the ALARM output and resets the timer.

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 TCSSCBR can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

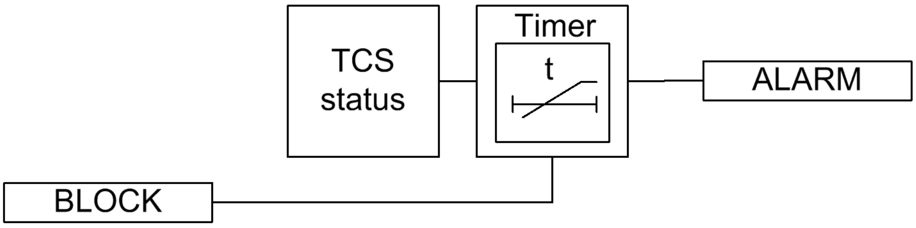


Figure 459: Functional module diagram

TCS status

This module receives the trip circuit status from the hardware. A detected failure in the trip circuit activates the timer.

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 `BLOCK` input can be controlled with a binary input, a horizontal communication input or an internal signal of the relay program. The activation of the `BLOCK` input prevents the `ALARM` output to be activated.

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 supervision is necessary to find out the vitality of the control circuits continuously.

Figure 460 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. 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 resistance remains small, that is, it does not harm or overload the circuit breaker's trip coil.

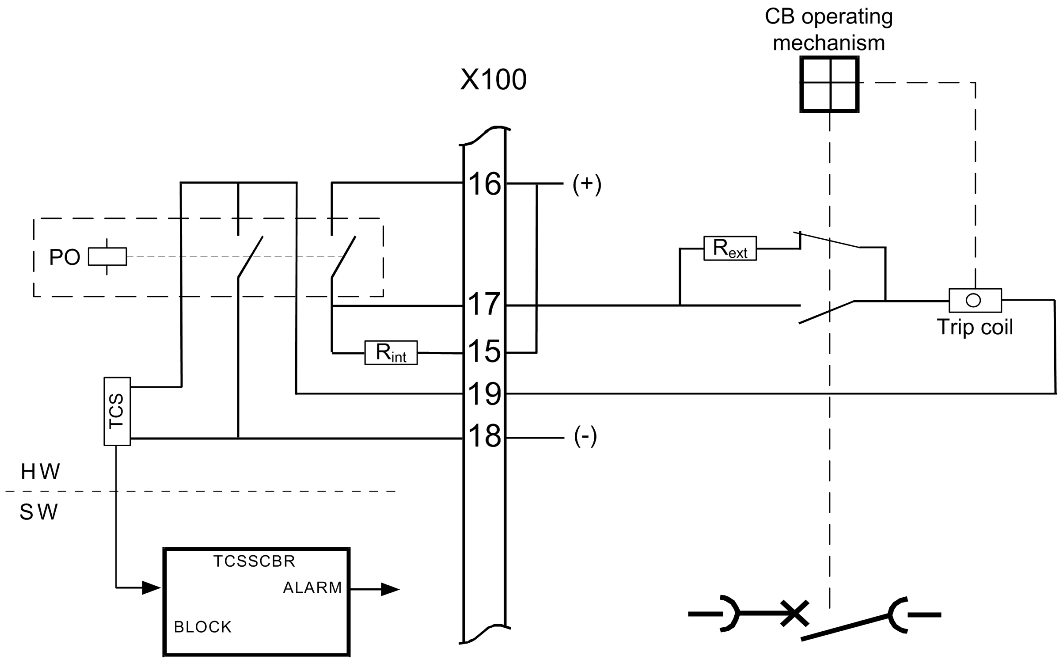


Figure 460: Operating principle of the trip-circuit supervision with an external resistor. The TCSSCBR blocking switch is not required since the external resistor is used.

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.

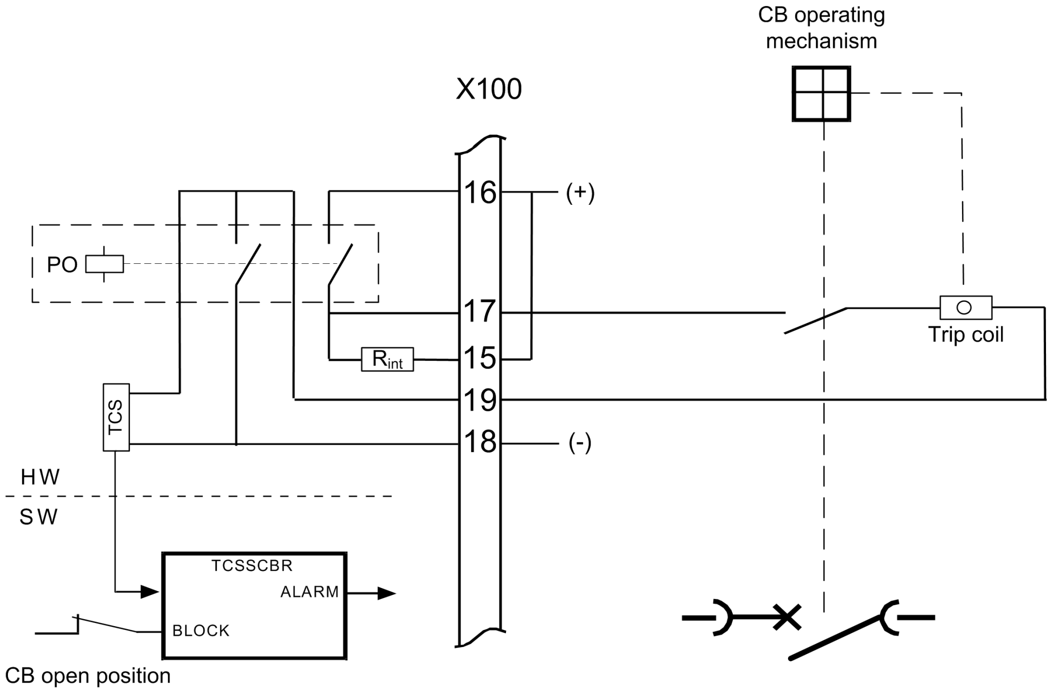


Figure 461: Operating principle of the trip-circuit supervision without an external resistor. The circuit breaker open indication is set to block TCSSCBR when the circuit breaker is open.

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. The supervising current cannot detect if one or all the other contacts connected in parallel are not connected properly.

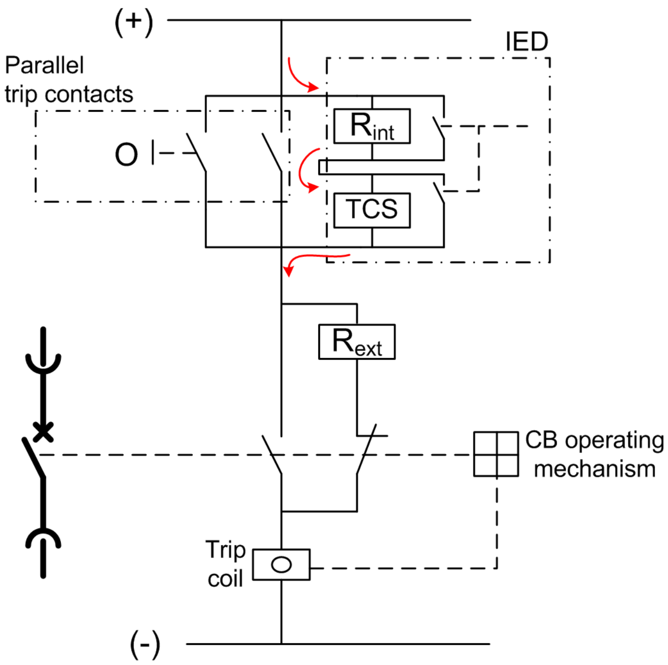


Figure 462: Constant test current flow in parallel trip contacts and trip circuit supervision

In case of parallel trip contacts, the recommended way to do the wiring is that the TCS test current flows through all wires and joints.

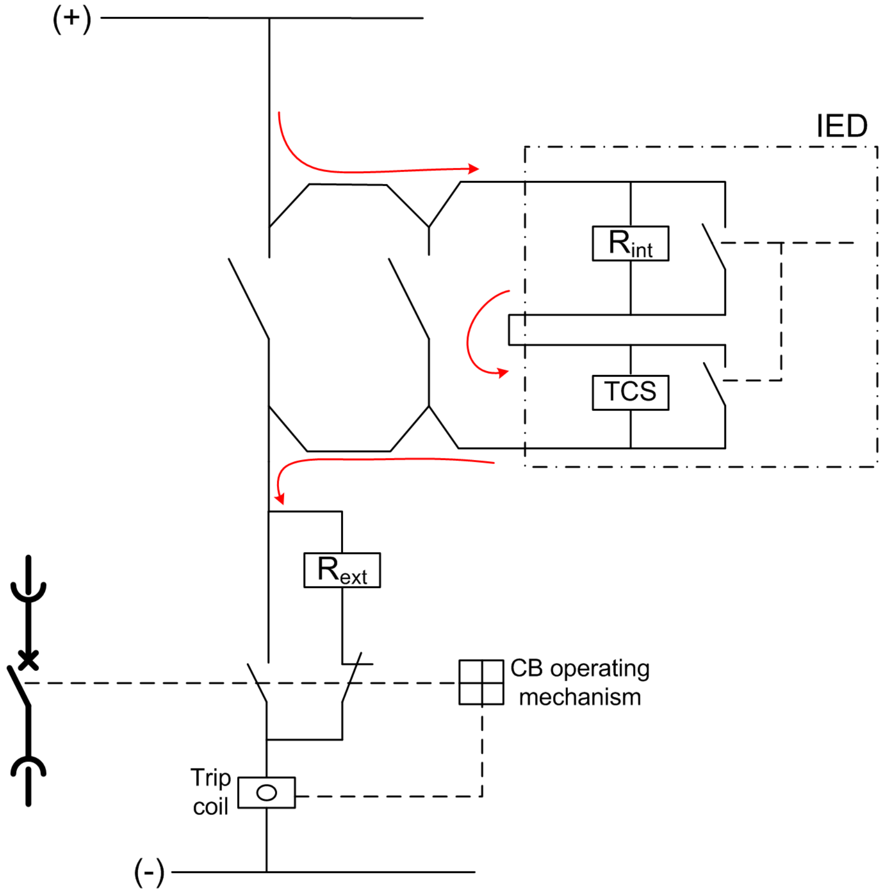


Figure 463: Improved connection for parallel trip contacts where the test current flows through all wires and joints

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 relay not-in-use does not typically 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 relay 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 relay 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 relay trip contact and the circuit breaker coil. This way the breaking capacity question is solved, but the TCS circuit in the protection relay 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 20 V (15...20 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, a fault is detected.

Mathematically, the operation condition can be expressed as:

$$U_C - (R_{ext} + R_{int} + R_s) \times I_c \geq 20V \quad AC/DC$$

(Equation 172)

U_c	Operating voltage over the supervised trip circuit
I_c	Measuring current through the trip circuit, appr. 1.5 mA (0.99...1.72 mA)
R_{ext}	external shunt resistance
R_{int}	internal shunt resistance, 1 kΩ
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 20 V over the internal circuit, while a resistance too low can enable false operations of the trip coil.

Table 831: Values recommended for the external resistor R ext

Operating voltage U_c	Shunt resistor R_{ext}
48 V AC/DC	1.2 kΩ, 5 W
60 V AC/DC	5.6 kΩ, 5 W
110 V AC/DC	22 kΩ, 5 W
220 V AC/DC	33 kΩ, 5 W

Due to the requirement that the voltage over the TCS contact must be 20 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_{int},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.

Using power output contacts without trip circuit supervision

If TCS is not used but the contact information of corresponding power outputs are required, the internal resistor can be by-passed. The output can then be utilized as a normal power output. When bypassing the internal resistor, the wiring between the terminals of the corresponding output X100:16-15(PO3) or X100:21-20(PO4) can be disconnected. The internal resistor is required if the complete TCS circuit is used.

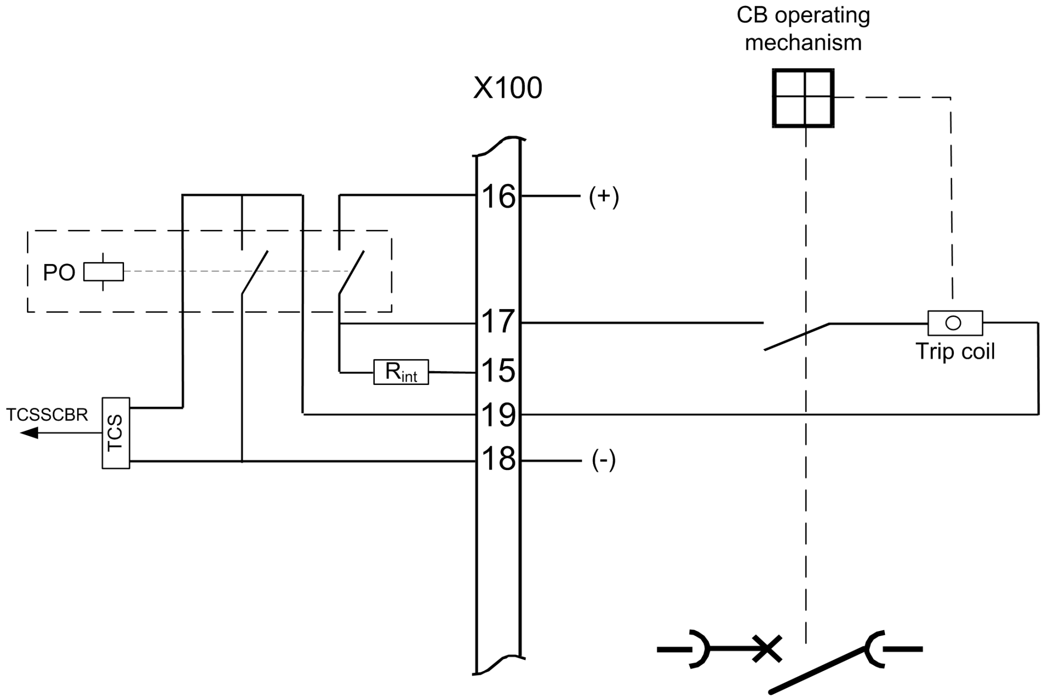


Figure 464: Connection of a power output in a case when TCS is not used and the internal resistor is disconnected

Incorrect connections and use of trip circuit supervision

Although the TCS circuit consists of two separate contacts, it must be noted that those are designed to be used as series connected to guarantee the breaking capacity given in the technical manual of the protection relay. In addition to the weak breaking capacity, the internal resistor is not dimensioned to withstand current without a TCS circuit. As a result, this kind of incorrect connection causes immediate burning of the internal resistor when the circuit breaker is in the close position and the voltage is applied to the trip circuit. The following figure shows incorrect usage of a TCS circuit when only one of the contacts is used.

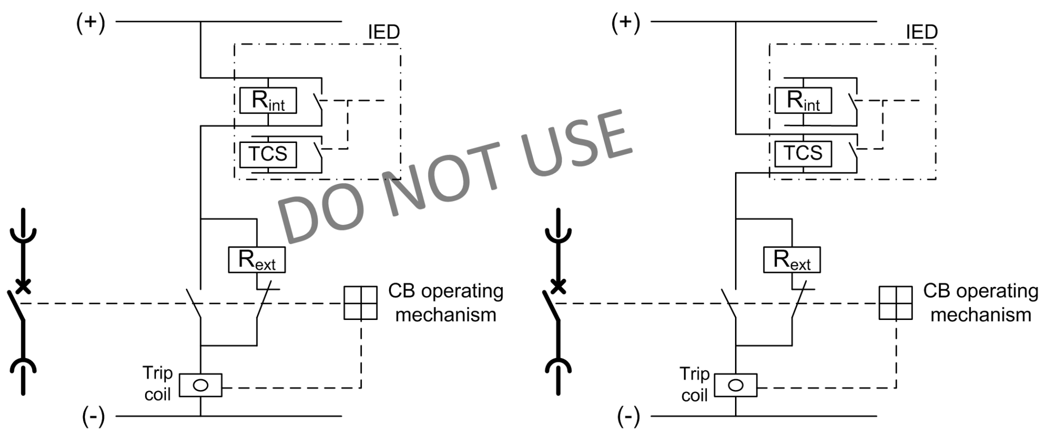


Figure 465: Incorrect connection of trip-circuit supervision

A connection of three protection relays with a double pole trip circuit is shown in the following figure. Only the protection relay R3 has an internal TCS circuit. In order to test the operation of the protection relay R2, but not to trip the circuit breaker, the upper trip contact of the protection relay R2 is disconnected, as shown in the figure, while the lower contact is still connected. When the protection relay R2 operates, the coil current starts to flow through the internal resistor of the protection relay R3 and the resistor burns immediately. As proven with the previous examples, both trip contacts must operate together. Attention should also be paid for correct usage of the trip-circuit supervision while, for example, testing the protection relay.

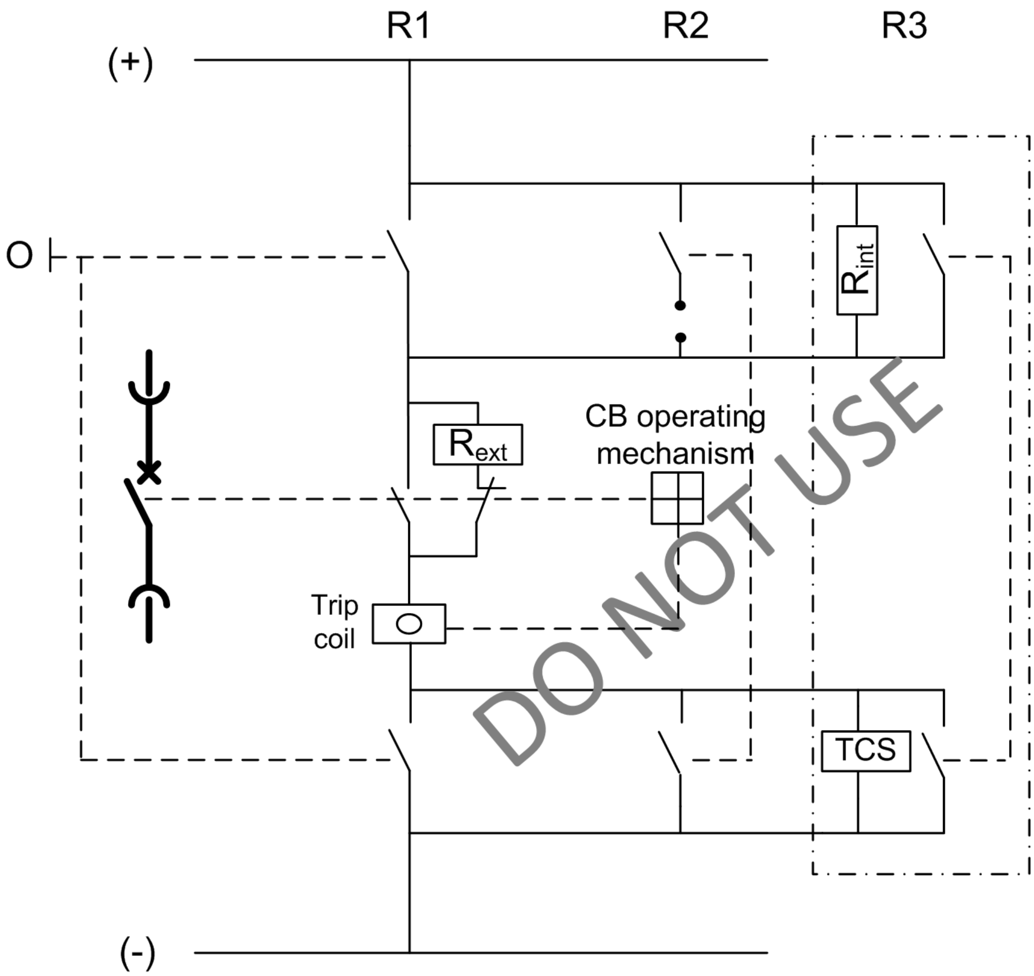


Figure 466: Incorrect testing of protection relays

6.1.6 Signals

Table 832: TCSSCBR Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block input status

Table 833: TCSSCBR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

6.1.7 Settings

Table 834: TCSSCBR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operate delay time	20...300000	ms	1	3000	Operate delay time

Table 835: TCSSCBR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	20...60000	ms	1	1000	Reset delay time

6.1.8 Monitored data

Table 836: TCSSCBR Monitored data

Name	Type	Values (Range)	Unit	Description
TCSSCBR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.1.9 Technical revision history

Table 837: TCSSBR Technical revision history

Technical revision	Change
B	Internal improvement
C	Internal improvement

6.2 Current circuit supervision CCSPVC

6.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current circuit supervision	CCSPVC	MCS 3I	MCS 3I

6.2.2 Function block

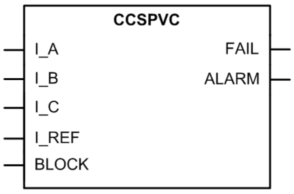


Figure 467: Function block

6.2.3 Functionality

The current circuit supervision function CCSPVC is used for monitoring current transformer secondary circuits.

CCSPVC 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 protection relay.

CCSPVC 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 CCSPVC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

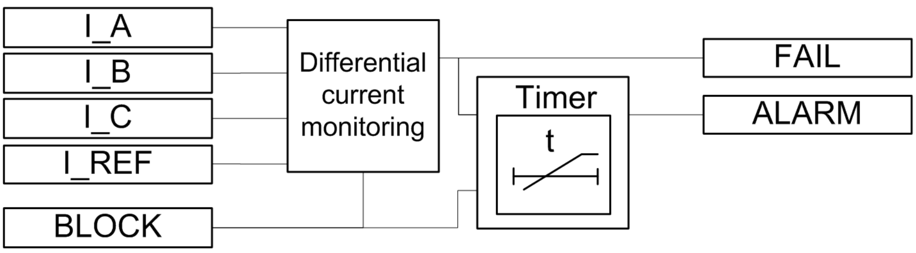


Figure 468: Functional module diagram

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 equation.

$$MAX(I\_A, I\_B, I\_C) \times Start\ value$$

(Equation 173)

The differential current is limited to 1.0 × In.

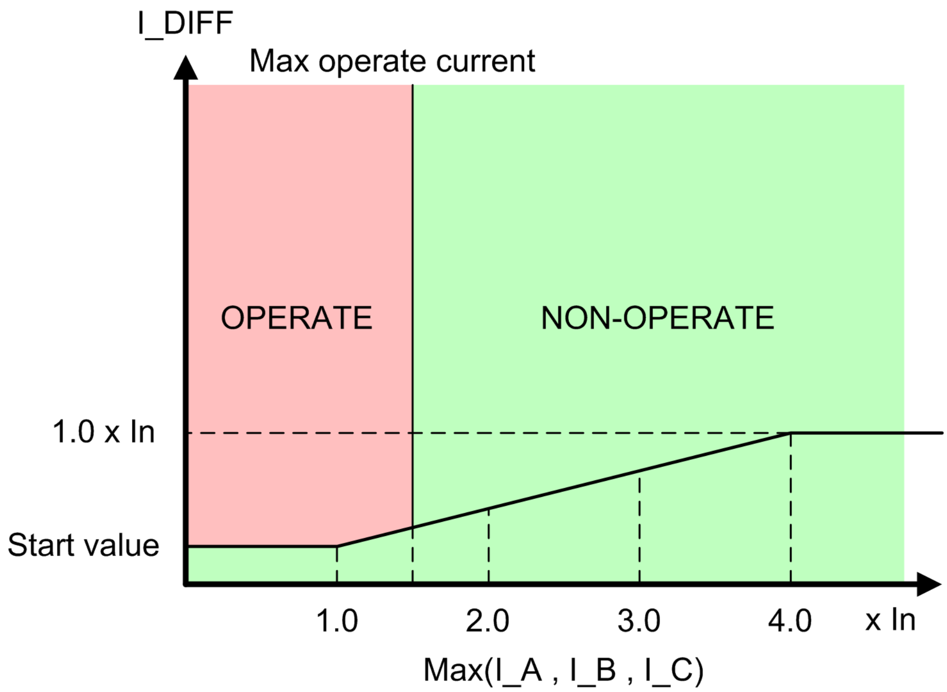


Figure 469: CCSPVC operating characteristics

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 equation.

$$I\_DIFF = \left|\overline{I\_A} + \overline{I\_B} + \overline{I\_C}\right| - \left|\overline{I\_REF}\right|$$

(Equation 174)

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 is deactivated immediately immediately. However, the ALARM output is deactivated immediately after a fixed delay of three seconds.

The function resets when the differential current is below the start value and the highest phase current is more than 5 percent of the nominal current (0.05 × In).

If the current falls to zero when the FAIL or ALARM outputs are active, the deactivation of these outputs is prevented.

The activation of the BLOCK input deactivates the ALARM output.

6.2.5 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 can result in differences in the secondary currents from the two CT cores. An unwanted blocking of protection functions during the transient stage must then be avoided.

The supervision function must be sensitive and have a short operation time 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 protection relay, 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

CCSPVC compares the sum of phase currents to the current measured with the core-balanced CT.

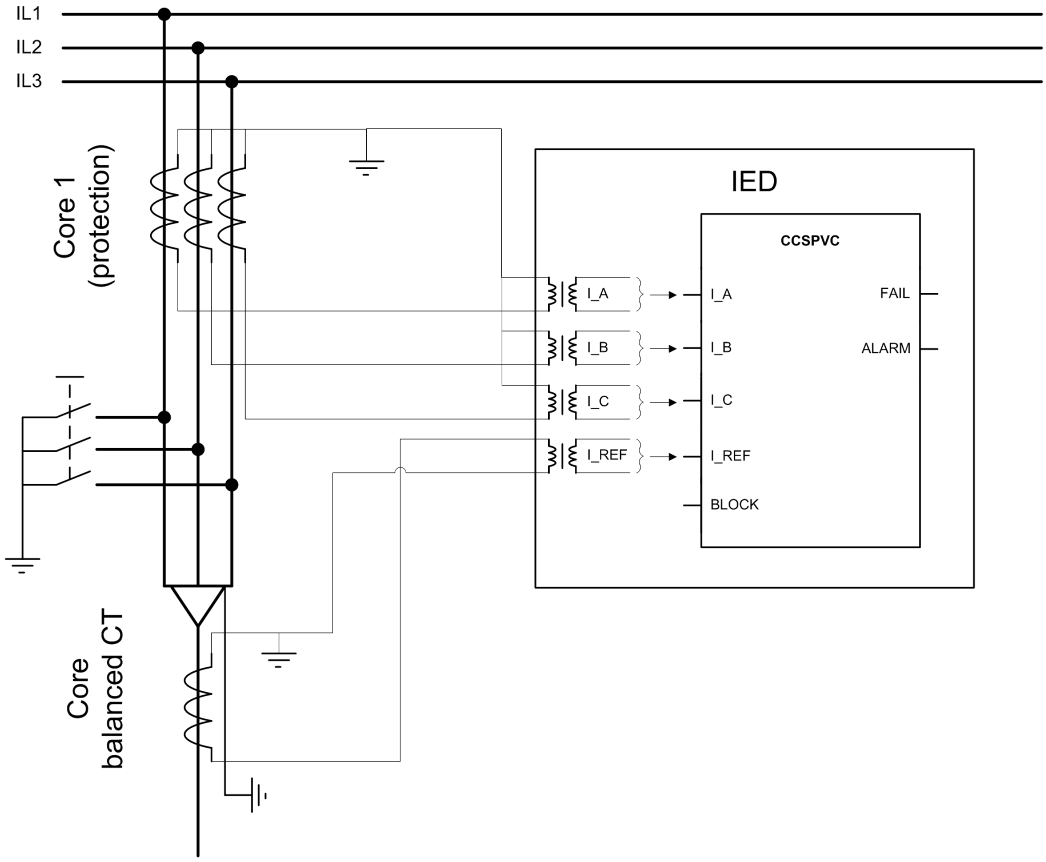


Figure 470: Connection diagram for reference current measurement with core-balanced current transformer

Current measurement with two independent three-phase sets of CT cores

Figure 471 and *Figure 472* show diagrams of connections where the reference current is measured with two independent three-phase sets of CT cores.

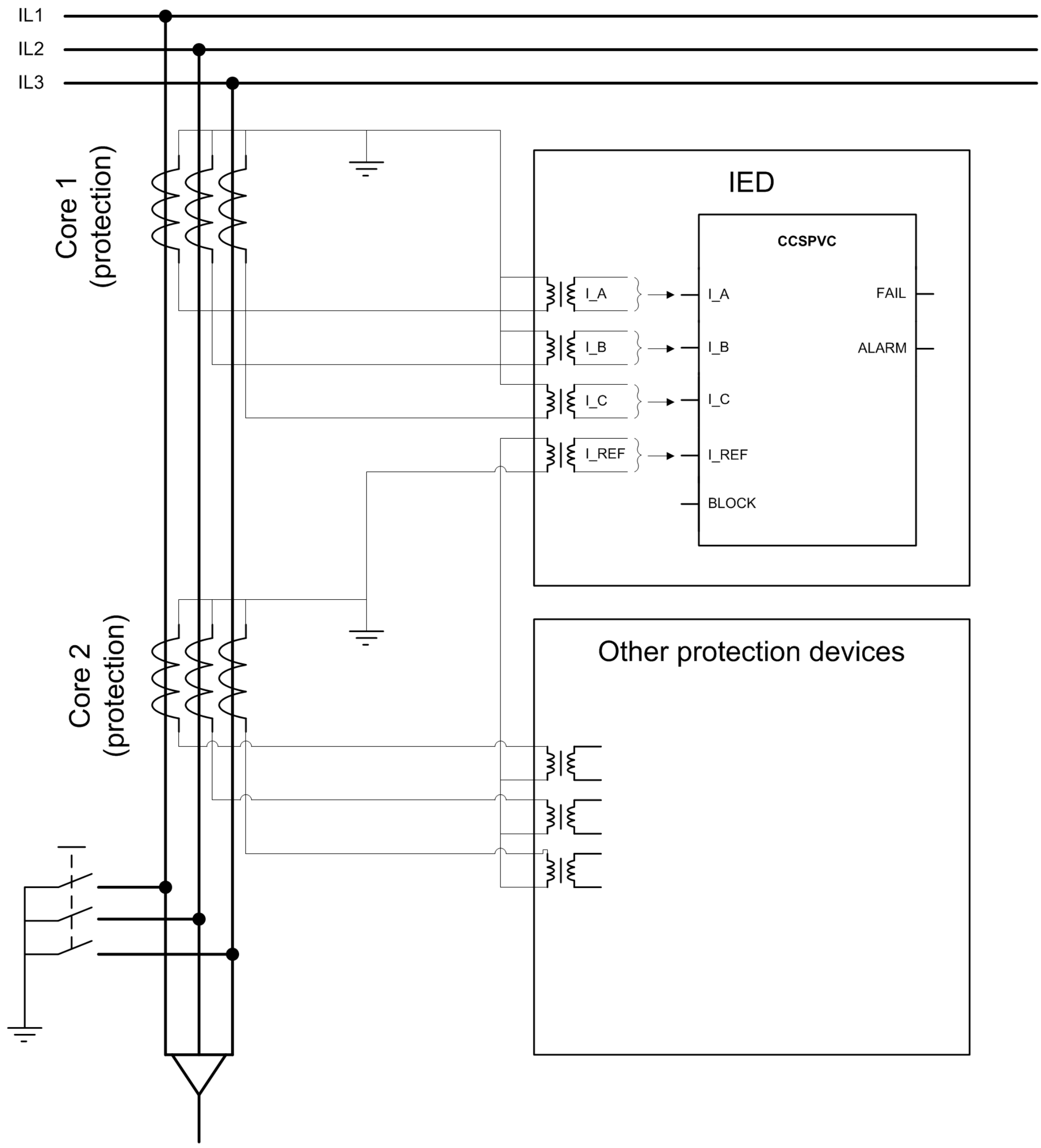


Figure 471: Connection diagram for current circuit supervision with two sets of three-phase current transformer protection cores

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.

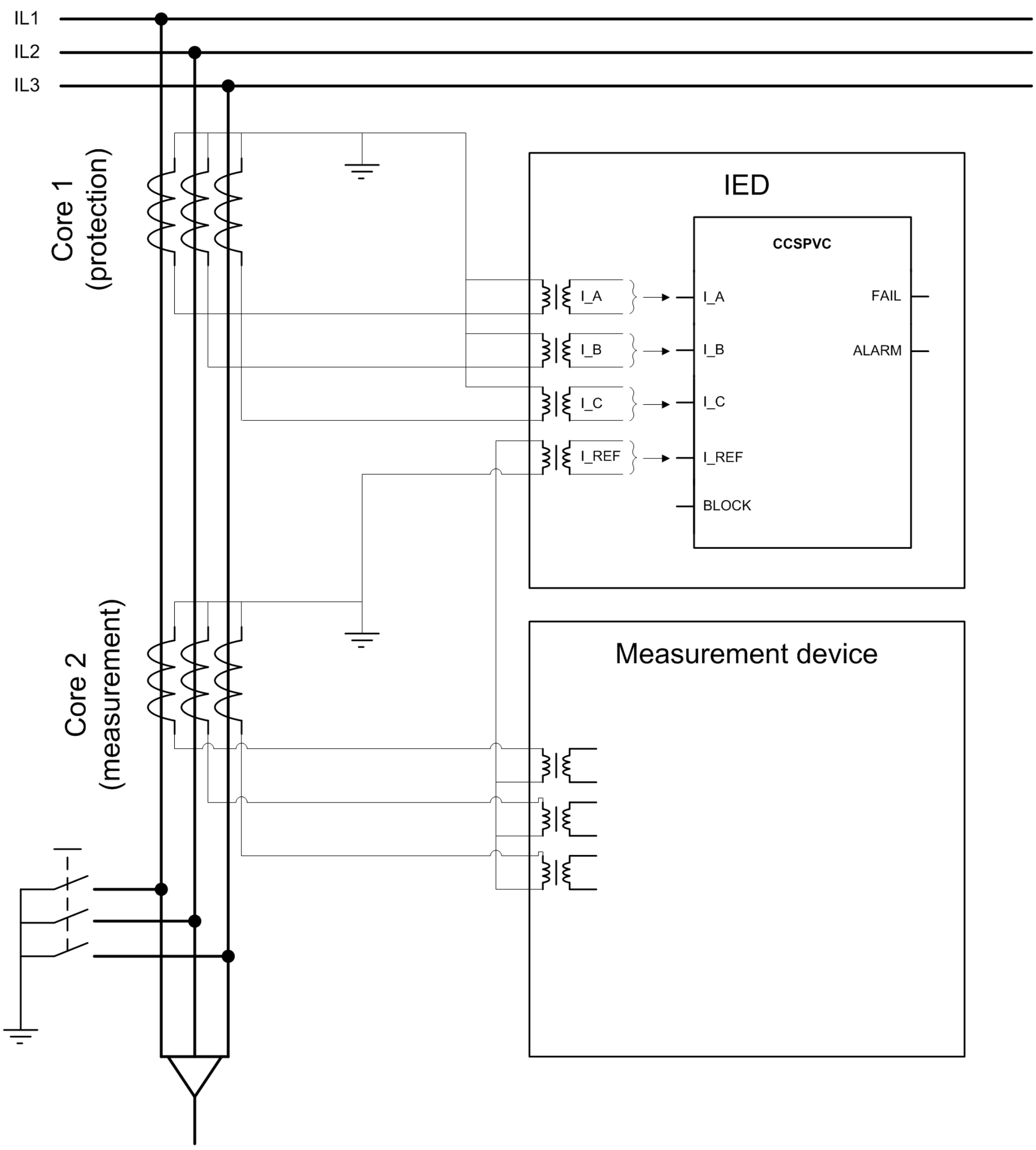


Figure 472: Connection diagram for current circuit supervision with two sets of three-phase current transformer cores (protection and measurement)

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.

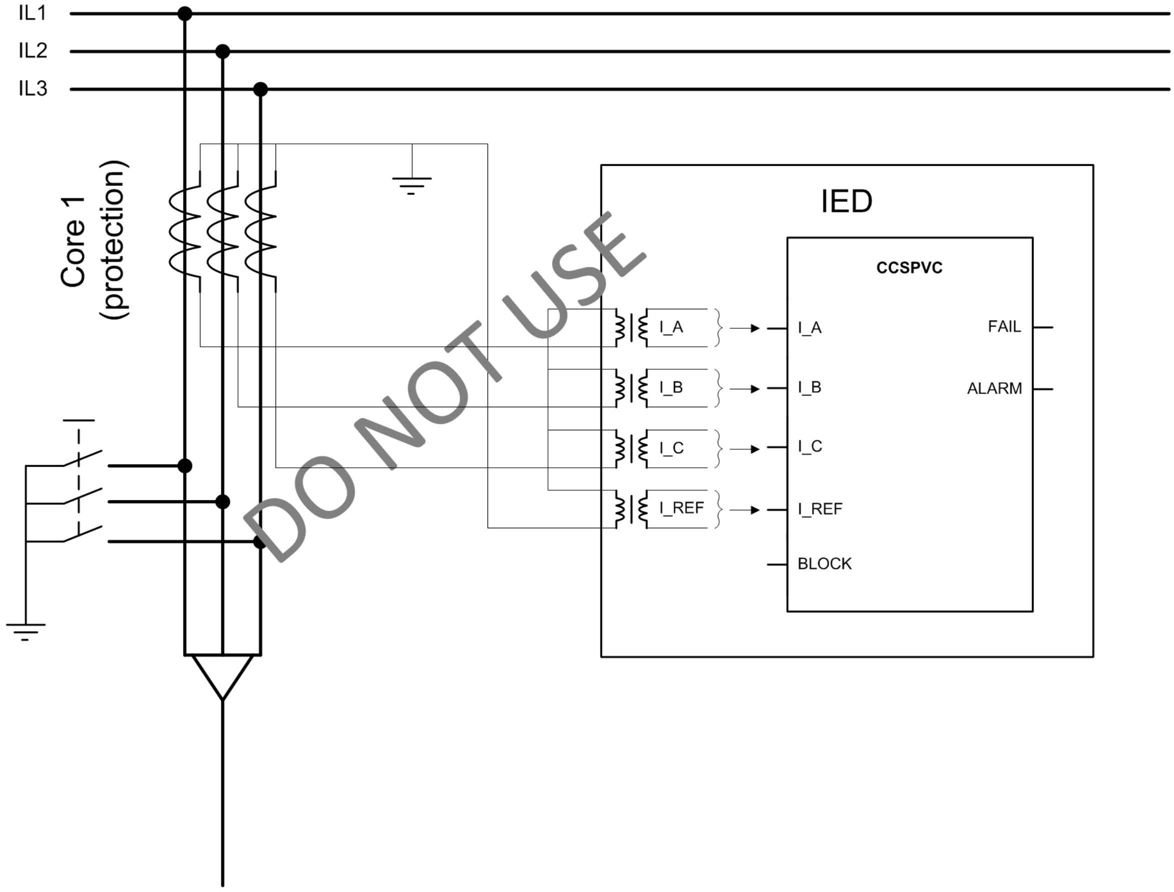


Figure 473: Example of incorrect reference current connection

6.2.6 Signals

Table 838: CCSPVC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_REF	SIGNAL	0	Reference current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 839: CCSPVC Output signals

Name	Type	Description
FAIL	BOOLEAN	Fail output
ALARM	BOOLEAN	Alarm output

6.2.7 Settings

Table 840: CCSPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On / Off
Start value	0.05...0.20	xIn	0.01	0.05	Minimum operate current differential level

Table 841: CCSPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Max operate current	1.00...5.00	xIn	0.01	1.50	Block of the function at high phase current

6.2.8 Monitored data

Table 842: CCSPVC Monitored data

Name	Type	Values (Range)	Unit	Description
IDIFF	FLOAT32	0.00...40.00	xIn	Differential current
CCSPVC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.2.9 Technical data

Table 843: CCSPVC Technical data

Characteristic	Value
Operate time [1]	<30 ms

[1] Including the delay of the output contact

6.2.10 Technical revision history

Table 844: CCSPVC Technical revision history

Technical revision	Change
B	Internal improvement
C	Internal improvement
D	Internal improvement

6.3 Advanced current circuit supervision for transformers CTSRCTF

6.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Advanced current circuit supervision for transformers	CTSRCTF	MCS 3I, I2	MCS 3I, I2

6.3.2 Function block

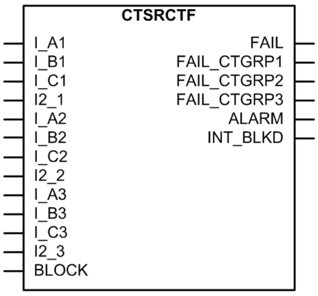


Figure 474: Function block

6.3.3 Functionality

The advanced current circuit supervision for transformers function CTSRCTF is used for monitoring the current transformer secondary circuit where a separate reference current transformer input for comparison is not available or where a separate voltage channel for calculating or measuring the zero-sequence voltage is not available. CTSRCTF can be used for detecting the single-phase failure on the current transformer secondary for protection application involving two or three sets of the three-phase current transformers.

CTSRCTF detects a fault in the measurement circuit and issues an alarm which can be used for blocking the protection functions, for example, differential protection, to avoid unwanted tripping.

CTSRCTF is internally blocked in case of a transformer under no-load condition or if a current in any one phase exceeds the set maximum limit.

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 CTSRCTF can be described with a module diagram. All the modules in the diagram are explained in the next sections.

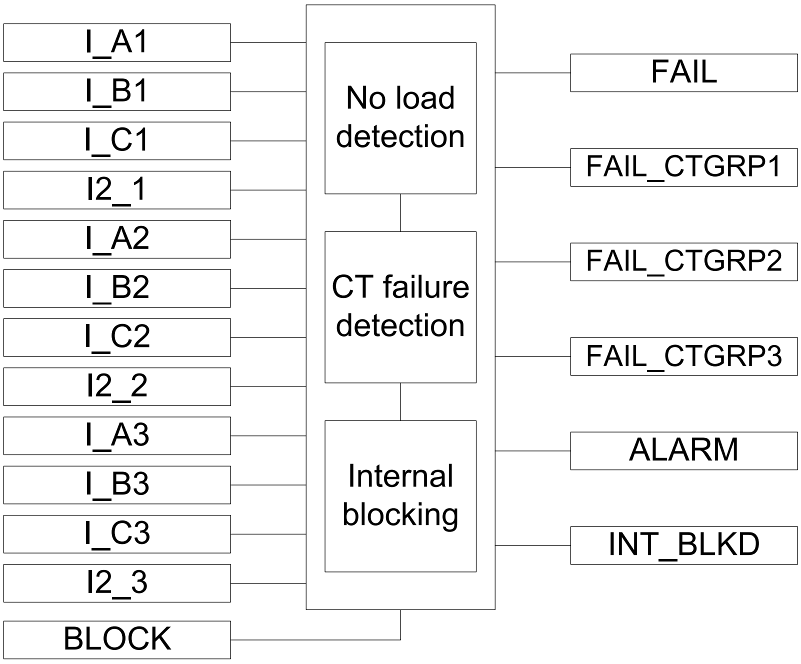


Figure 475: Functional module diagram

No-load detection

No-load detection module detects the loading condition. If all the three-phase currents of any two sets of current transformer are zero, the protected equipment is considered to be in the no-load condition and the function is internally blocked by activating the INT_BLKD output.

To avoid any false operation, the function is also internally blocked if any two-phase currents of any set of current transformers are below *Min operate current*. This activates INT_BLKD. The value of the Min operate current setting depends on the type of equipment to be protected. For example, in case of transformer protection, *Min operate current* depends on the no-load current rating. Typically, it can be set equal to the transformer no-load current rating.

CT failure detection

This module detects the CT secondary failure in any sets of current transformers. The module continuously scans the value of all the three-phase currents in all groups of current transformers to detect any sudden drop in the current value to zero. The detection of a zero current should not be the only criterion for considering a fault in the current transformer secondary. Two other criteria are evaluated to confirm the CT failure:

- A zero current due to the CT failure does not result in a negative-sequence current on healthy CT sets.

  On the detection of a zero current in any phase on either group of CT, the negative-sequence current I_2 is further evaluated. For a genuine CT secondary failure, the magnitude of I_2 changes only on the side where zero current has been detected. The change in the magnitude of I_2 (ΔI_2) on the other sets of the current transformer (other than where zero current is detected) is calculated. If the change is detected on the healthy sets of CT, it is an indication of system failure.
- A zero current due to the CT failure does not result in a phase angle difference between the healthy phases.

  If a system faults happens on the phase A, it results in a change in the phase angle difference between phase B and phase C. This change in the phase angle difference between the healthy phases is evaluated in all three sets of current transformer, and if the change is detected in any set of CT, it is an indication of the system failure.

If both conditions are satisfied at zero current, the FAIL output is activated immediately. The ALARM output is activated after a fixed 200 ms delay. FAIL needs to be active during the delay. The outputs FAIL, CTGRP1, FAIL_CTGRP2 and FAIL_CTGRP3 are activated according to the CT group where the secondary failure is detected.

Activation of the BLOCK input deactivates the FAIL and ALARM outputs.

It is not possible to detect the CT secondary failure happening simultaneously with the system faults or failures or two simultaneous failures in the secondary circuit. The function resets if the zero current does not exist longer than 200 ms.

Internal blocking

This module blocks the function internally under specific condition to avoid any false operation during a system fault situation. When any of the following condition is satisfied, the function is internally blocked and the FAIL output is deactivated immediately.

- Magnitude of any phase current for any group of current transformers exceeds the *Max operate current* setting. The magnitude of phase current is calculated from the peak-to-peak value.
- Magnitude of the negative-sequence current I_2 on the healthy set of current transformer exceeds the *Max Nq Seq current* setting.

The INT_BLKD output is activated when FAIL is deactivated if any of the above conditions is satisfied. The ALARM output is also deactivated after a fixed three-second delay after the FAIL output is deactivated.

6.3.5 Application

Open or short-circuited current transformer secondary can cause unwanted operation in many protection functions, such as earth-fault current and differential. The simplest method for detecting the current transformer secondary failure is by comparing currents from two independent three-phase sets of CTs or the CT cores measuring the same primary currents. Another widely used method is the detection of a zero-sequence current and zero-sequence voltage. The detection of a zero-sequence current in the absence of a zero-sequence voltage is an indication of the current transformer secondary failure. However, both methods have disadvantages as they require an additional set of current transformer, or a voltage channel is needed for detecting a zero-sequence voltage.

The methods may not be applicable where additional current channels or voltage channels are not available. This CT secondary circuit supervision presents an algorithm that can be used as an example for detecting the CT secondary failure used for the unit protection of a two-winding or three-winding transformer. However, the function has a limitation that it cannot detect failure in case of equipment under protection in no-load condition or when two simultaneous secondary CT failures occur.

The detection of a zero current in any one phase is a partial indication of failure in the current transformer secondary. Furthermore, if this current zero is due to the failure in the current transformer secondary, it results in a change in the magnitude of the negative-sequence current in the group only where current zero has been detected. However, changes in the negative-sequence current in other groups of three-phase current transformers at the instance of zero-current detection is an indication of a system problem. Also, it may happen that after the detection of a failure in the current transformer secondary, a fault may occur in the system. During such condition, functions are internally blocked.

Phase discontinuity

A zero current detected due to the phase discontinuity results in an asymmetry in all the sets of the current transformer, which then results in a change in the negative-sequence current (ΔI_2) in the healthy set. This change in the negative-sequence current on the healthy sides, that is, other than where a zero current has been detected, blocks the function.

In case of a lightly loaded transformer (up to 30 %) the change in the negative-sequence current may be very negligible. However, a phase discontinuity results in a change in the phase angle difference between two healthy phases in the set of CTs where a zero current has been detected as well as on the primary side of the transformer. This change in the value of the angle blocks the function internally.

Overload / System short circuit condition

It is required that any overload or short circuit conditions after a CT failure should block the function. During overload or short circuit condition, the phase current increases beyond its rated value; if any phase current on any set of current transformer exceeds the set limit, the function is blocked internally. Also in case of an unsymmetrical fault, the negative-sequence current increases. If the negative-sequence current increases beyond the set limit, the function is blocked internally. The overcurrent and negative-sequence current setting both can be set equal to the overcurrent and negative-sequence protection function start value.

The internal blocking is thus useful for avoiding false operation during a fault situation.

6.3.6 Signals

Table 845: CTSRCTF Input signals

Name	Type	Default	Description
I_A1	SIGNAL	0	Phase A current from set 1
I_B1	SIGNAL	0	Phase B current from set 1
I_C1	SIGNAL	0	Phase C current from set 1
I2_1	SIGNAL	0	Negative-sequence current from set 1
I_A2	SIGNAL	0	Phase A current from set 2
I_B2	SIGNAL	0	Phase B current from set 2
I_C2	SIGNAL	0	Phase C current from set 2
I2_2	SIGNAL	0	Negative-sequence current from set 2
I_A3	SIGNAL	0	Phase A current from set 3
I_B3	SIGNAL	0	Phase B current from set 3
I_C3	SIGNAL	0	Phase C current from set 3
I2_3	SIGNAL	0	Negative-sequence current from set 3
BLOCK	BOOLEAN	0=False	Block signal for acti-vating the blocking mode

Table 846: CTSRCTF Output signals

Name	Type	Description
FAIL	BOOLEAN	CT secondary failure
FAIL_CTGRP1	BOOLEAN	CT secondary failure group 1
FAIL_CTGRP2	BOOLEAN	CT secondary failure group 2
FAIL_CTGRP3	BOOLEAN	CT secondary failure group 3
ALARM	BOOLEAN	Alarm

6.3.7 Settings

Table 847: CTSRCTF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Min operate current	0.01...0.50	xIn	0.01	0.02	Minimum operate current
Max operate current	1.00...5.00	xIn	0.01	1.30	Maximum operate current
Max Ng Seq current	0.01...1.00	xIn	0.01	0.10	Maximum I2 current in healthy set

6.3.8 Monitored data

Table 848: CTSRCTF Monitored data

Name	Type	Values (Range)	Unit	Description
INT_BLKD	BOOLEAN	0=False 1=True		Function blocked internally
CTSRCTF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.3.9 Technical data

Table 849: CTSRCTF Technical data

Characteristic	Value
Operate time [1]	<30 ms

[1] Including the delay of the output contact

6.4 Current transformer supervision for high-impedance protection scheme HZCCxSPVC

6.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current transformer supervision for high-impedance protection scheme for phase A	HZCCASPVC	MCS I_A	MCS I_A
Current transformer supervision for high-impedance protection scheme for phase B	HZCCBSPVC	MCS I_B	MCS I_B
Current transformer supervision for high-impedance protection scheme for phase C	HZCCCSPVC	MCS I_C	MCS I_C

6.4.2 Function block

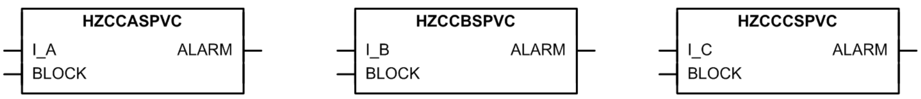


Figure 476: Function block

6.4.3 Functionality

The current transformer supervision for high-impedance protection scheme function HZCCxSPVC is a dedicated phase-segregated supervision function to be used along with the high-impedance differential protection for detecting the broken CT secondary wires. The differential current is taken as an input for the protection relay. During normal CT condition, the value of the differential current is zero. However, when the CT is broken, the secondary differential current starts flowing and it is used for generating alarms.

To avoid faulty operation, HZCCxSPVC should have a sensitive setting, compared to the high-impedance differential protection. The function is likely to start under through-fault conditions. However, by incorporating a high time delay (3 s or more), the downstream protection clears the fault before an alarm is generated.

HZCCxSPVC generates an alarm when the differential current exceeds the set limit. The function operates within the DT characteristic.

The function contains a blocking functionality. It is possible to block the function output, Timer or the whole function.

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 HZCCxSPVC can be generated with a module diagram. All the modules in the diagram are explained in the next sections.

The module diagram illustrates all the phases of the function. However, the functionality is described only for phase A. The functionality for phase B and C is identical.

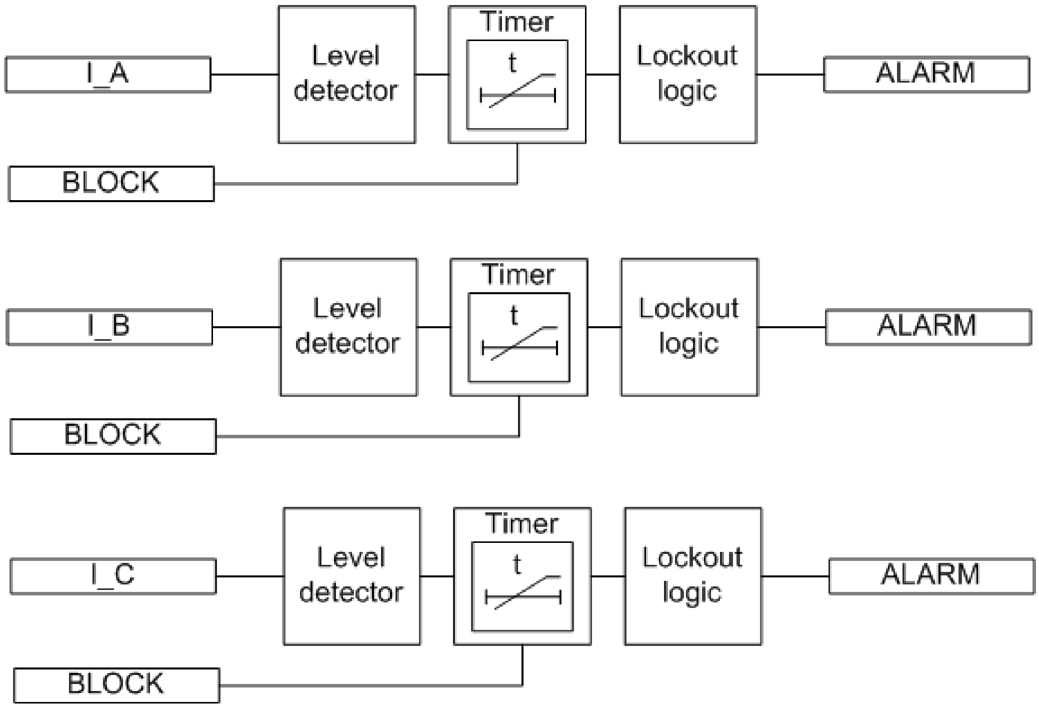


Figure 477: Functional module diagram

Level detector

This module compares the differential current I_A to the set *Start value*. The timer module is activated if the differential current exceeds the value set in the *Start value* setting.

Timer

The time characteristic is according to DT. When the alarm timer reaches the value set by *Alarm delay time*, the ALARM output is activated. If the fault disappears before the module generates an alarm signal, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the alarm timer resets. The activation of the BLOCK signal resets the Timer and deactivates the ALARM output.

Lockout logic

HZCCxSPVC is provided with the possibility to activate a lockout for the ALARM output depending on the *Alarm output mode* setting. In the "Lockout" mode, the ALARM must be reset manually from the LHMI Clear menu after checking the CT secondary circuit. In the "Non-latched" mode, the ALARM output functions normally, that is, it resets as soon as the fault is cleared.

6.4.5 Measuring modes

The function operates on two alternative measurement modes, DFT and Peak-to-Peak. The measurement mode is selected using the *Measurement mode* setting.

6.4.6 Application

HZCCxSPVC is a dedicated phase-segregated supervision function to be used along with the high-impedance differential protection for detecting the broken CT secondary wires. The operation principle of HZCCxSPVC is similar to the high-impedance differential protection function HIxPDIF. However, the current setting of HZCCxSPVC is set to be much more sensitive than HIxPDIF and it operates with a higher time delay. A typical example of the HZCCxSPVC *Start value* setting is 0.1 pu with an *Alarm delay time* of 3 s or more.

As the current setting of HZCCxSPVC is more sensitive than the actual differential stage, it can start internally under the through-fault conditions; however, a sufficient time delay prevents false alarm. If the bus wire is broken, differential current arises depending on the load of the feeder with the broken bus wire.

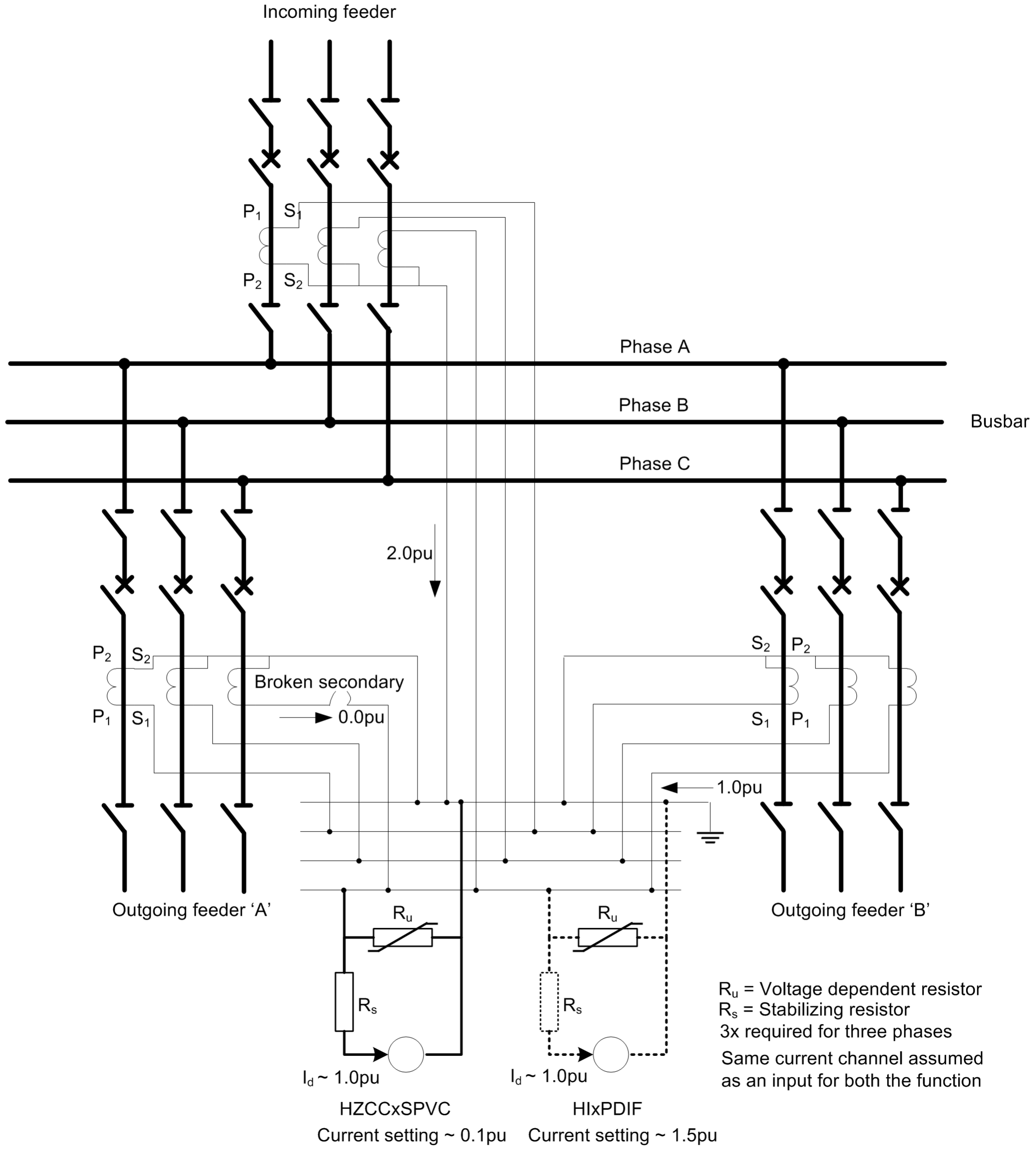


Figure 478: Broken secondary detection by HZCCxSPVC

In the example, the incoming feeder is carrying a load of 2.0 pu and both outgoing feeders carry an equal load of 1.0 pu However, both HIxPDIF and HZCCxSPVC consider the current as an increased differential or unbalance current because of the broken CT wire in phase C. Both HIxPDIF and HZCCxSPVC receive the differential current of approximately 1.0 pu The main differential protection HIxPDIF cannot operate because of the higher current setting.

All CTs must have the same ratio.

The `ALARM` output of the CT supervision function can be used to energize an auxiliary relay which can short-circuit the current CT wires, making the busbar differential protection inoperative. This arrangement does not prevent unwanted operation of HIxPDIF if the start setting is below the rated load. For example, if the start setting for HIxPDIF in the example is set as 0.8 pu HIxPDIF operates before HZCCxSPVC.

6.4.7 Signals

Table 850: HZCCASPVC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
BLOCK	BOOLEAN	0=False	Block signal for activating blocking mode

Table 851: HZCCBSPVC Input signals

Name	Type	Default	Description
I_B	SIGNAL	0	Phase B current
BLOCK	BOOLEAN	0=False	Block signal for activating blocking mode

Table 852: HZCCCSPVC Input signals

Name	Type	Default	Description
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating blocking mode

Table 853: HZCCASPVC Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

Table 854: HZCCBSPVC Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

Table 855: HZCCCSPVC Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

6.4.8 Settings

Table 856: HZCCASPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Start value	1.0...100.0	%In	0.1	10.0	Start value, percentage of the nominal current
Alarm delay time	100...300000	ms	10	3000	Alarm delay time
Alarm output mode	1=Non-latched 3=Lockout			3=Lockout	Select the operation mode for alarm output

Table 857: HZCCASPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time
Measurement mode	2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

Table 858: HZCCBSPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Start value	1.0...100.0	%In	0.1	10.0	Start value, percentage of the nominal current
Alarm delay time	100...300000	ms	10	3000	Alarm delay time
Alarm output mode	1=Non-latched 3=Lockout			3=Lockout	Select the operation mode for alarm output

Table 859: HZCCBSPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time
Measurement mode	2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

Table 860: HZCCCSPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Start value	1.0...100.0	%In	0.1	10.0	Start value, percentage of the nominal current
Alarm delay time	100...300000	ms	10	3000	Alarm delay time
Alarm output mode	1=Non-latched 3=Lockout			3=Lockout	Select the operation mode for alarm output

Table 861: HZCCCSPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time
Measurement mode	2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

6.4.9 Monitored data

Table 862: HZCCASPVC Monitored data

Name	Type	Values (Range)	Unit	Description
HZCCASPVC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 863: HZCCBSPVC Monitored data

Name	Type	Values (Range)	Unit	Description
HZCCBSPVC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 864: HZCCCSPVC Monitored data

Name	Type	Values (Range)	Unit	Description
HZCCCSPVC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.4.10 Technical data

Table 865: HZCCxSPVC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the current measured: f_n ±2 Hz
	±1.5 % of the set value or ±0.002 × I_n
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

6.4.11 Technical revision history

Table 866: HZCCxSPVC Technical revision history

Technical revision	Change
B	Function name changed from HZCCRDIF to HZCCASPVC, HZCCBSPVC, HZCCCSPVC.

6.5 Fuse failure supervision SEQSPVC

6.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fuse failure supervision	SEQSPVC	FUSEF	60

6.5.2 Function block

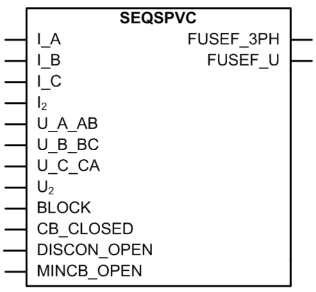


Figure 479: Function block

6.5.3 Functionality

The fuse failure supervision function SEQSPVC is used to block the voltagemeasuring functions when failure occurs in the secondary circuits between the voltage transformer (or combi sensor or voltage sensor) and merging unit to avoid misoperations of the voltage protection functions.

SEQSPVC 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.

6.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of SEQSPVC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

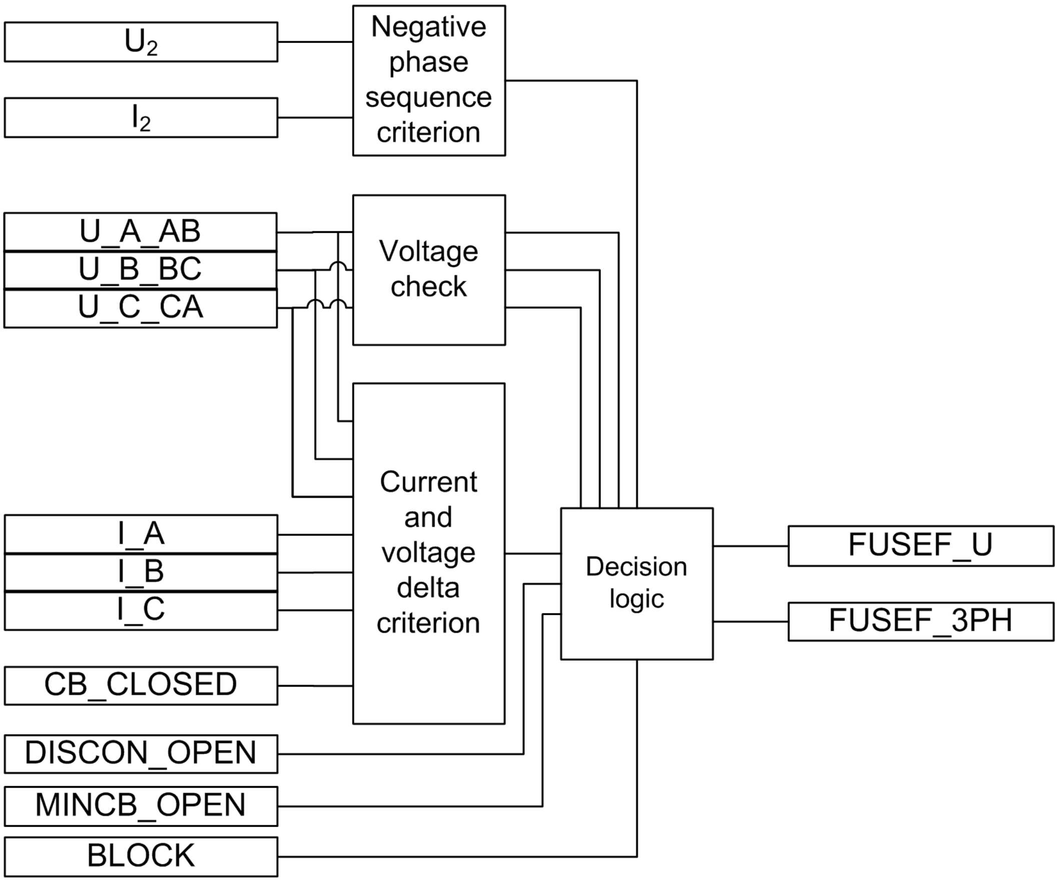


Figure 480: Functional module diagram

Negative phase-sequence criterion

A fuse failure based on the 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.

Current and voltage delta criterion

The delta function can be activated by setting the *Change rate enable* parameter to "True". 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 to calculate:

- 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 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 and 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 SEQSPVC with an open breaker. If this is considered to be an important disadvantage, the `CB_CLOSED` input is to be connected to FALSE. In 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 a 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

If voltages are Wye-connected, it is recommended to scale the default values of voltage-based settings with 1/sqrt(3) because the default setting values apply for Delta-connected settings.

The fuse failure detection outputs FUSEF_U and FUSEF_3PH are controlled according to the detection criteria or external signals.

Table 867: 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.
	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.
	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 a protection relay 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 output signal to block

Table continues on the next page

Fuse failure detection criterion	Conditions and function response
	all the voltage-related functions when MCB is in the open state.
	The DISCON_OPEN input signal is supposed to be connected through a protection relay 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.

It is recommended to always set *Enable seal in* to "True". This secures that the blocked protection functions remain blocked until normal voltage conditions are restored if the fuse failure has been active for 5 seconds, that is, the fuse failure outputs are deactivated when the normal voltage conditions are restored.

The activation of the BLOCK input deactivates both FUSEF_U and FUSEF_3PH outputs.

6.5.5 Application

Some protection functions operate on the basis of the measured voltage value in the protection relay point. These functions can fail if there is a fault in the measuring circuits between the voltage transformer (or combi sensor or voltage sensor) and protection relay.

A fault in the voltage-measuring circuit is called 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.

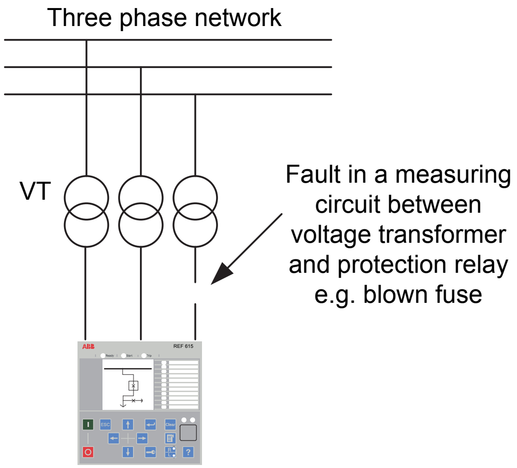


Figure 481: Fault in a circuit from the voltage transformer to the protection relay

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 be intact. 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, SEQSPVC has two outputs for this purpose.

6.5.6 Signals

Table 868: SEQSPVC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative sequence current
U_A_AB	SIGNAL	0	Phase A voltage
U_B_BC	SIGNAL	0	Phase B voltage
U_C_CA	SIGNAL	0	Phase C voltage
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block of function
CB_CLOSED	BOOLEAN	0=False	Active when circuit breaker is closed
DISCON_OPEN	BOOLEAN	0=False	Active when line disconnector is open
MINCB_OPEN	BOOLEAN	0=False	Active when external MCB opens protected voltage circuit

Table 869: SEQSPVC Output signals

Name	Type	Description
FUSEF_3PH	BOOLEAN	Three-phase start of function
FUSEF_U	BOOLEAN	General start of function

6.5.7 Settings

Table 870: SEQSPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 871: SEQSPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Neg Seq current Lev	0.03...0.20	xIn	0.01	0.03	Operate level of neg seq undercurrent element
Neg Seq voltage Lev	0.03...0.20	xUn	0.01	0.10	Operate level of neg seq overvoltage element
Current change rate	0.01...0.50	xIn	0.01	0.15	Operate level of change in phase current
Voltage change rate	0.25...0.90	xUn	0.01	0.40	Operate level of change in phase voltage
Change rate enable	0=False 1=True			0=False	Enabling operation of change based function
Min Op voltage delta	0.01...1.00	xUn	0.01	0.50	Minimum operate level of phase voltage for delta calculation
Min Op current delta	0.01...1.00	xIn	0.01	0.10	Minimum operate level of phase current for delta calculation
Seal in voltage	0.01...1.00	xUn	0.01	0.50	Operate level of seal-in phase voltage
Enable seal in	0=False 1=True			0=False	Enabling seal in functionality
Current dead Lin Val	0.05...1.00	xIn	0.01	0.05	Operate level for open phase current detection

6.5.8 Monitored data

Table 872: SEQSPVC Monitored data

Name	Type	Values (Range)	Unit	Description
SEQSPVC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.5.9 Technical data

Table 873: SEQSPVC Technical data

Characteristic		Value	
Operate time [1]	NPS function	U_{Fault} = 1.1 × set *Neg Seq voltage Lev*	<33 ms
		U_{Fault} = 5.0 × set *Neg Seq voltage Lev*	<18 ms
	Delta function	ΔU = 1.1 × set *Voltage change rate*	<30 ms
		ΔU = 2.0 × set *Voltage change rate*	<24 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

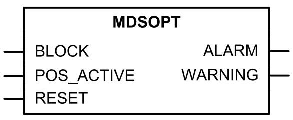


Figure 482: Function block

6.6.3 Functionality

The runtime counter for machines and devices function 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

[1] Includes the delay of the signal output contact, f_n = 50 Hz, fault voltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements.

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 function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MDSOPT can be described using a module diagram. All the modules in the diagram are explained in the next sections.

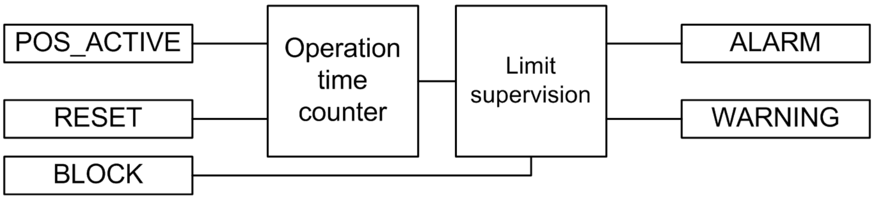


Figure 483: Functional module diagram

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. At any time 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 non-volatile 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 can reset 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 respectively when the counts exceed the levels.

The activation of the WARNING and ALARM outputs depends on the *Operating time mode* setting. Both WARNING and ALARM occur immediately after the conditions are met if *Operating time mode* is set to “Immediate”. 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 some 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 874: MDSOPT Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block input status
POS_ACTIVE	BOOLEAN	0=False	When active indicates the equipment is running
RESET	BOOLEAN	0=False	Resets the accumulated operation time to initial value

Table 875: 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 876: MDSOPT Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Warning value	0...299999	h	1	8000	Warning value for operation time supervision
Alarm value	0...299999	h	1	10000	Alarm value for operation time supervision

Table 877: MDSOPT Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Initial value	0...299999	h	1	0	Initial value for operation time supervision
Operating time hour	0...23	h	1	0	Time of day when alarm and warning will occur
Operating time mode	1=Immediate 2=Timed Warn 3=Timed Warn Alm			1=Immediate	Operating time mode for warning and alarm

6.6.8 Monitored data

Table 878: MDSOPT Monitored data

Name	Type	Values (Range)	Unit	Description
MDSOPT	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
OPR_TIME	INT32	0...299999	h	Total operation time in hours

6.6.9 Technical data

Table 879: MDSOPT Technical data

Description	Value
Motor runtime measurement accuracy [1]	±0.5 %

6.6.10 Technical revision history

Table 880: MDSOPT Technical revision history

Technical revision	Change
B	Internal improvement.
C	Internal improvement.
D	Internal improvement.

[1] Of the reading, for a stand-alone relay, without time synchronization

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

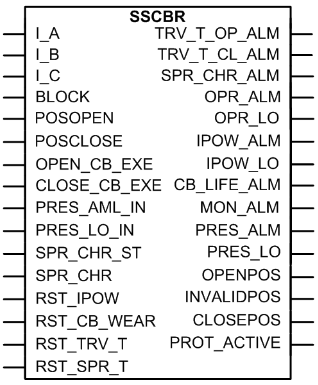


Figure 484: Function block

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 which can be used to block the function outputs.

7.1.4 Operation principle

The circuit breaker condition monitoring function includes different metering and monitoring sub-functions. 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 SSCBR can be described with a module diagram. All the modules in the diagram are explained in the next sections.

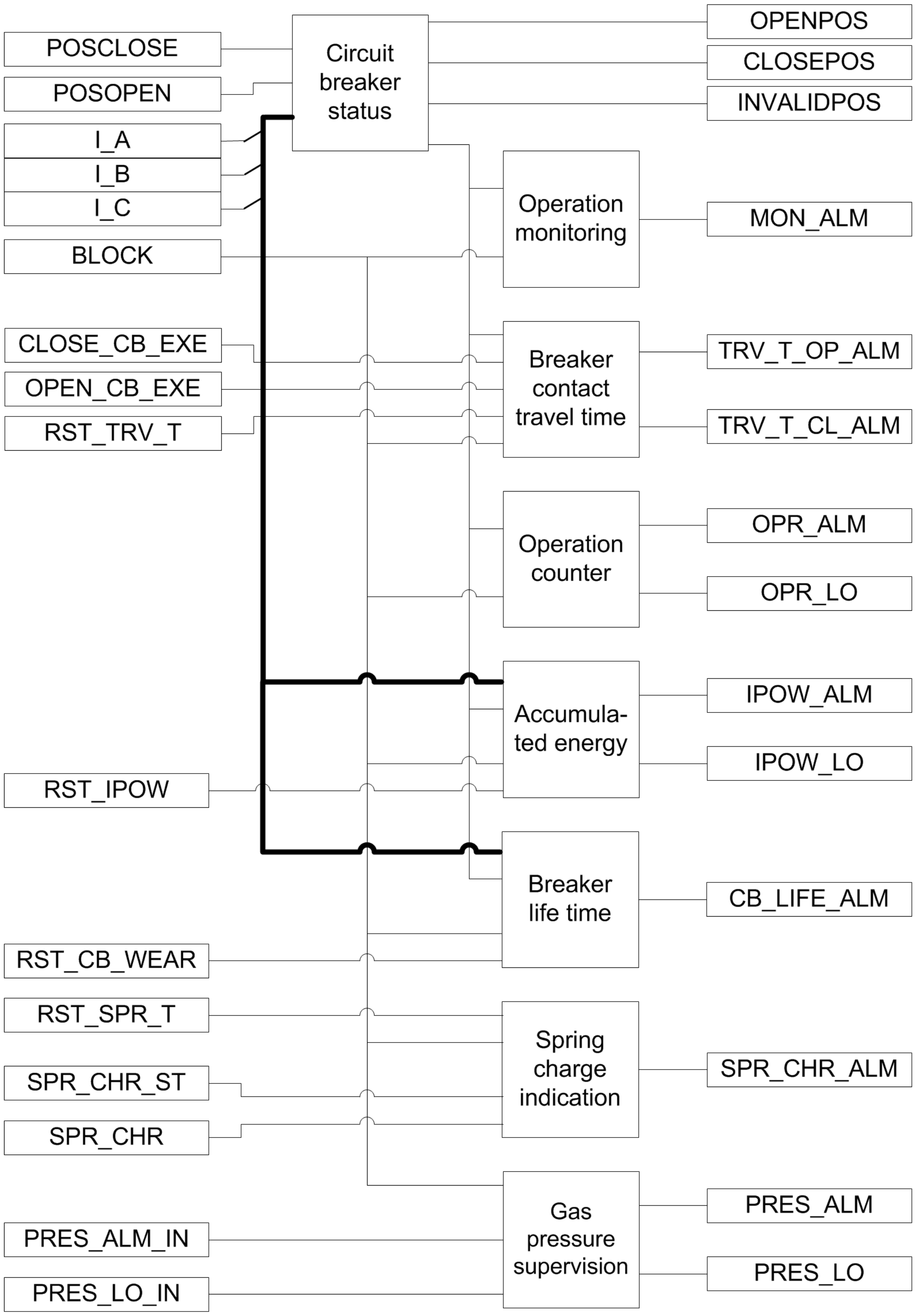


Figure 485: Functional module diagram

7.1.4.1 Circuit breaker status

The Circuit breaker status sub-function monitors the position of the circuit breaker, that is, whether the breaker is in open, closed or invalid position. The operation of the breaker status monitoring can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

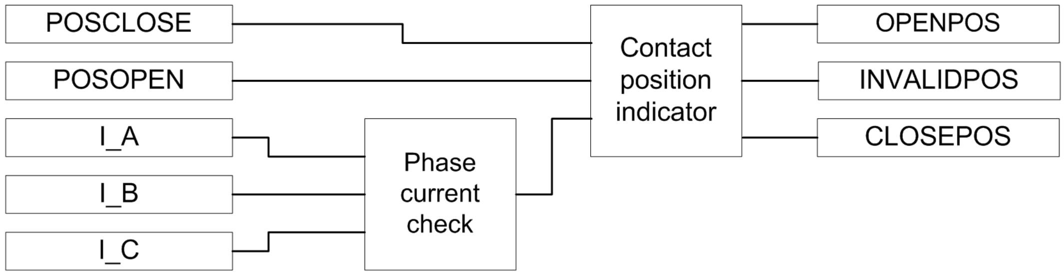


Figure 486: Functional module diagram for monitoring circuit breaker status

Phase current check

This module compares the three phase currents to the setting *Acc stop current*. If the current in a phase exceeds the set level, information about the phase is reported to the contact position indicator module.

Contact position indicator

The `OPENPOS` output is activated when the auxiliary input contact `POSCLOSE` is FALSE, the `POSOPEN` input is TRUE and all the phase currents are below the setting *Acc stop current*.

The `CLOSEPOS` output is activated when the auxiliary `POSOPEN` input is FALSE and the `POSCLOSE` input is TRUE.

The `INVALIDPOS` output is activated when both the auxiliary contacts have the same value, that is, both are in the same logical level, or if the auxiliary input contact `POSCLOSE` is FALSE and the `POSOPEN` input is TRUE and any of the phase currents exceed the setting `Acc stop current`.

The status of the breaker is indicated by the binary outputs `OPENPOS`, `INVALIDPOS` and `CLOSEPOS` for open, invalid 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.

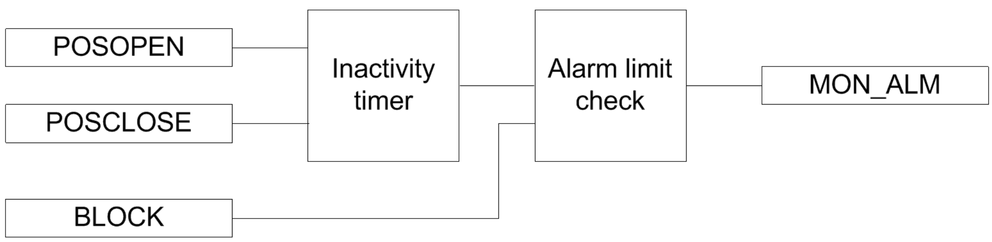


Figure 487: Functional module diagram for calculating inactive days and alarm for circuit breaker operation monitoring

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.

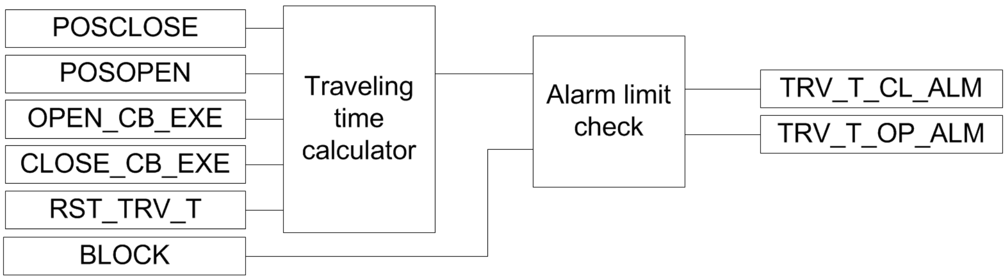


Figure 488: Functional module diagram for breaker contact travel time

Traveling time calculator

The travel time can be calculated using two different methods based on the setting *Travel time Clc mode*.

When the setting *Travel time Clc mode* is “From Pos to Pos”, 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. The travel time is also measured between the opening of the POSOPEN auxiliary contact and the closing of the POSCLOSE auxiliary contact.

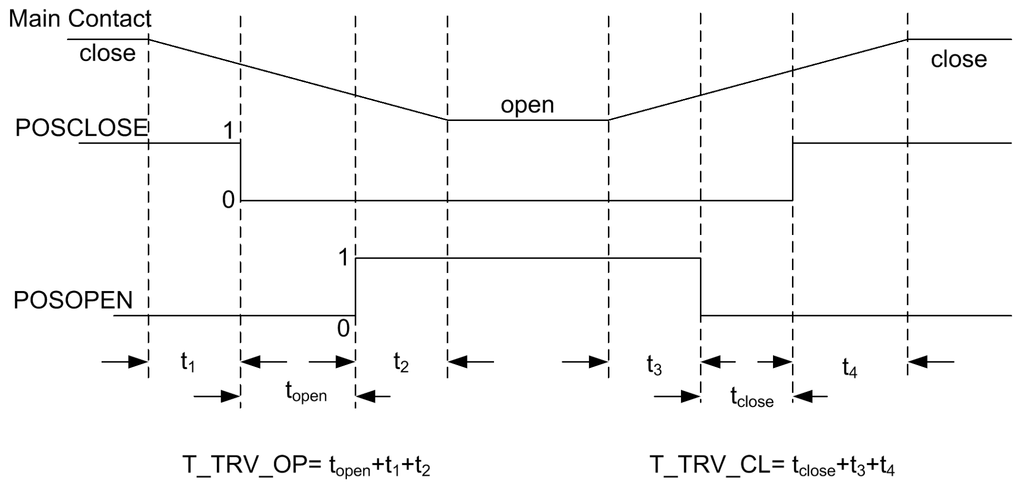


Figure 489: Travel time calculation when Travel time Clc mode is "From Pos to Pos"

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. 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.

When the setting *Travel time Clc mode* is "From Cmd to Pos", the contact travel time of the breaker is calculated from the time between the circuit breaker opening or closing command and the auxiliary contacts' state change. The opening travel time is measured between the rising edge of the OPEN_CB_EXE command and the POSOPEN auxiliary contact. The closing travel time is measured between the rising edge of the CLOSE_CB_EXEC command and the POSCLOSE auxiliary contact.

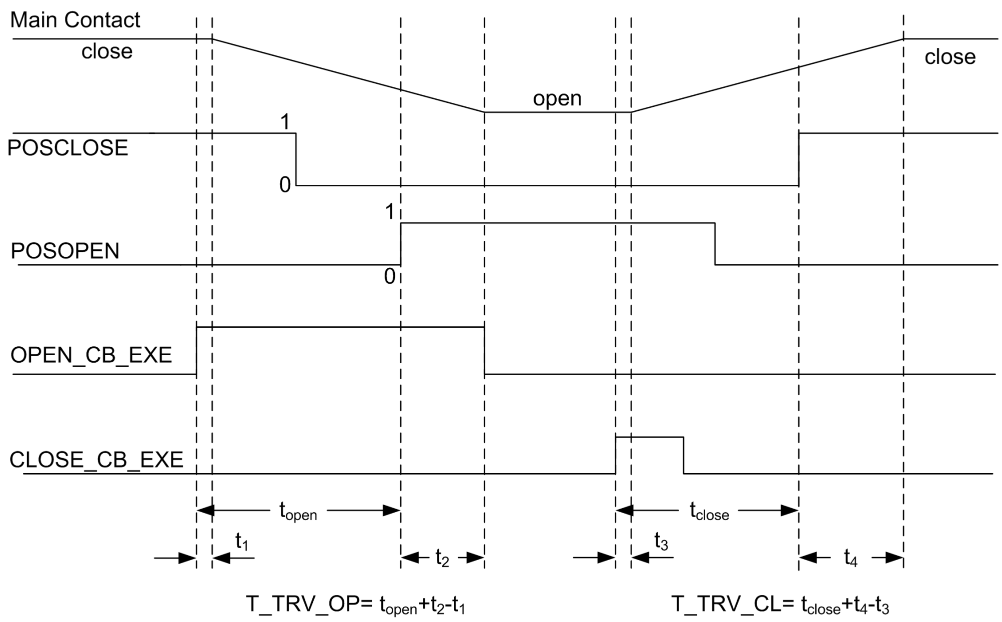


Figure 490: Travel time calculation when Travel time Clc mode is "From Cmd to Pos"

There is a time difference t_1 between the start of the main contact opening and the OPEN_CB_EXE command. 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 times t_1 and 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_2 - t_1) setting. The closing time is calculated by adding the value set with the *Closing time Cor*(t_4 - t_3) 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.

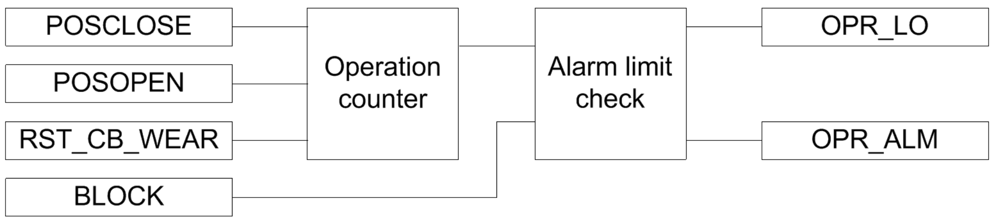


Figure 491: Functional module diagram for counting circuit breaker operations

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 *Initial CB Rmn life* 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.

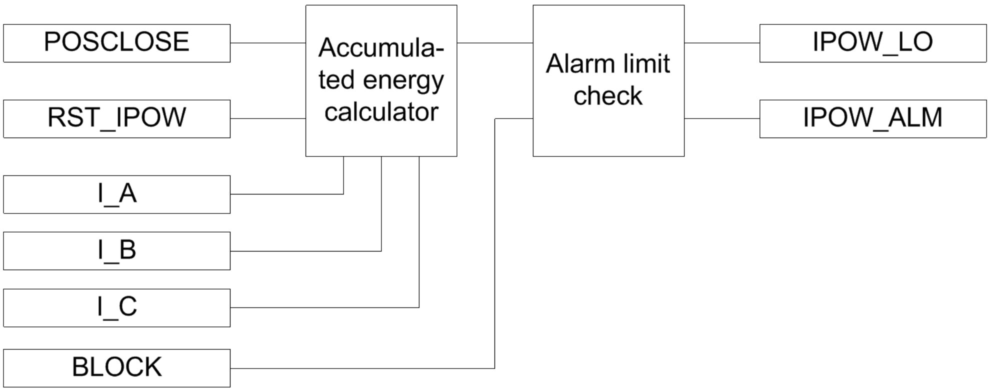


Figure 492: Functional module diagram for calculating accumulative energy and alarm

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.

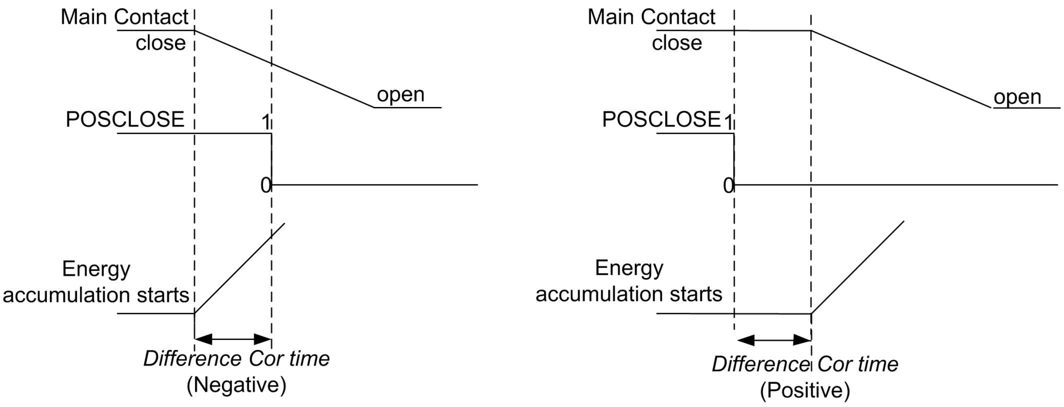


Figure 493: Significance of the Difference Cor time setting

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 *Initial CB Rmn life* 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 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.

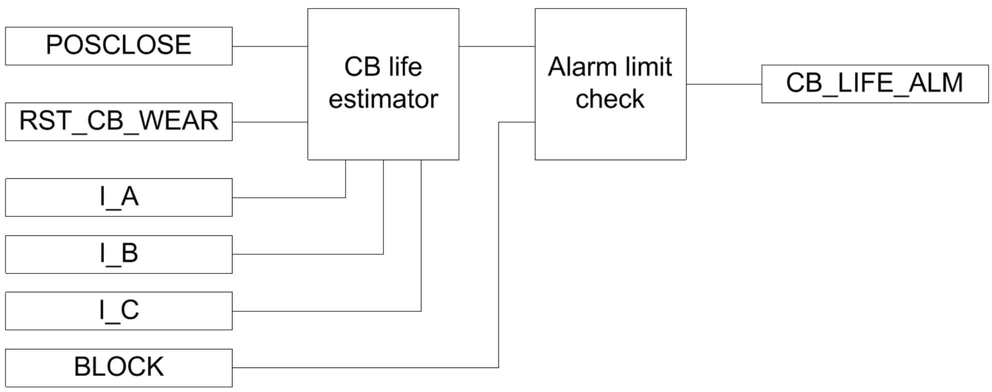


Figure 494: Functional module diagram for estimating the life of the circuit breaker

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.

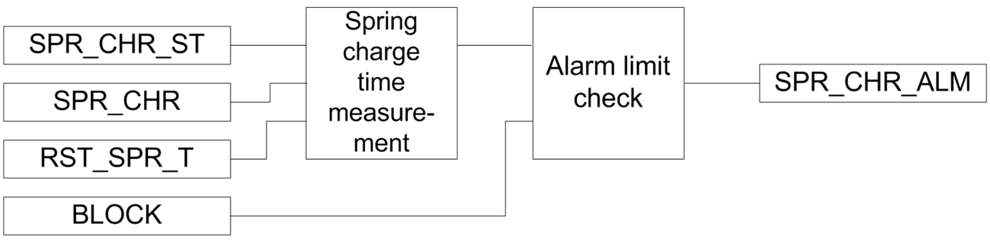


Figure 495: Functional module diagram for circuit breaker spring-charged indication and alarm

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 on the LHMI or through tools via communications.

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.

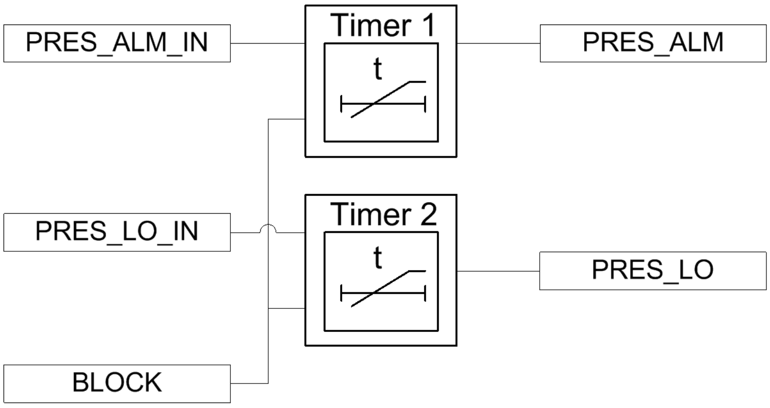


Figure 496: Functional module diagram for circuit breaker gas pressure alarm

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.

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 traveling times indicate the need for the maintenance of the circuit breaker mechanism. Therefore, detecting excessive traveling 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 closed 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 y t

Accumulation of $I^{y}t$ calculates the accumulated energy $\Sigma I^{y}t$, 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

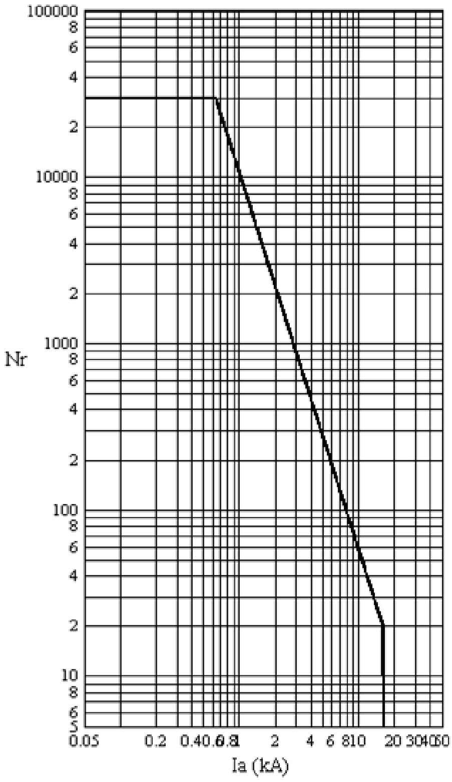


Figure 497: Trip Curves for a typical 12 kV, 630 A, 16 kA vacuum interrupter

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 175)

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

Figure 497 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.

$$Remaining\ \ life\ \ reduction = \left(\frac{I}{I_r} \right)^{-Directional\ Coef}$$

(Equation 176)

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 881: SSCBR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block input status
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for close position of apparatus from I/O
OPEN_CB_EXE	BOOLEAN	0=False	Signal for open command to coil
CLOSE_CB_EXE	BOOLEAN	0=False	Signal for close command to coil
PRES_ALM_IN	BOOLEAN	0=False	Binary pressure alarm input
PRES_LO_IN	BOOLEAN	0=False	Binary pressure input for lockout indication
SPR_CHR_ST	BOOLEAN	0=False	CB spring charging started input

Table continues on the next page

Name	Type	Default	Description
SPR_CHR	BOOLEAN	0=False	CB spring charged input
RST_IPOW	BOOLEAN	0=False	Reset accumulation energy
RST_CB_WEAR	BOOLEAN	0=False	Reset input for CB remaining life and operation counter
RST_TRV_T	BOOLEAN	0=False	Reset input for CB closing and opening travel times
RST_SPR_T	BOOLEAN	0=False	Reset input for the charging time of the CB spring

Table 882: 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 exceeded alarm limit
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 883: SSCBR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Acc stop current	5.00...500.00	A	0.01	10.00	RMS current setting below which engy acm stops
Open alarm time	0...200	ms	1	40	Alarm level setting for open travel time in ms
Close alarm time	0...200	ms	1	40	Alarm level Setting for close travel time in ms
Spring charge time	0...60000	ms	10	15000	Setting of alarm for spring charging time of CB in ms
Alarm Op number	0...99999		1	200	Alarm limit for number of operations
Lockout Op number	0...99999		1	300	Lock out limit for number of operations
Current exponent	0.00...2.00		0.01	2.00	Current exponent setting for energy calculation
Difference Cor time	-10...10	ms	1	5	Corr. factor for time dif in aux. and main contacts open time
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
Directional Coef	-3.00...-0.50		0.01	-1.50	Directional coefficient for CB life calculation
Initial CB Rmn life	0...99999		1	5000	Initial value for the CB remaining life
Rated Op current	100.00...5000.00	A	0.01	1000.00	Rated operating current of the breaker
Rated fault current	500.00...75000.00	A	0.01	5000.00	Rated fault current of the breaker
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
Inactive Alm days	0...9999		1	2000	Alarm limit value of the inactive days counter
Travel time Clc mode	1=From Cmd to Pos 2=From Pos to Pos			2=From Pos to Pos	Travel time calculation mode selection

Table 884: SSCBR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Opening time Cor	-100...100	ms	1	10	Correction factor for open travel time in ms
Closing time Cor	-100...100	ms	1	10	Correction factor for CB close travel time in ms
Counter initial Val	0...99999		1	0	The operation numbers counter initialization value
Ini Acc currents Pwr	0.00...20000.00		0.01	0.00	Initial value for accumulation energy (Iyt)
Life alarm level	0...99999		1	500	Alarm level for CB remaining life
Pressure alarm time	0...60000	ms	1	10	Time delay for gas pressure alarm in ms
Pres lockout time	0...60000	ms	10	10	Time delay for gas pressure lockout in ms
Ini inactive days	0...9999		1	0	Initial value of the inactive days counter
Inactive Alm hours	0...23	h	1	0	Alarm time of the inactive days counter in hours

7.1.8 Monitored data

Table 885: SSCBR Monitored data

Name	Type	Values (Range)	Unit	Description
T_TRV_OP	FLOAT32	0...60000	ms	Travel time of the CB during opening operation
T_TRV_CL	FLOAT32	0...60000	ms	Travel time of the CB during closing operation
T_SPR_CHR	FLOAT32	0.00...99.99	s	The charging time of the CB spring
NO_OPR	INT32	0...99999		Number of CB operation cycle
INA_DAYS	INT32	0...9999		The number of days CB has been inactive
CB_LIFE_A	INT32	-99999...99999		CB Remaining life phase A
CB_LIFE_B	INT32	-99999...99999		CB Remaining life phase B

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
CB_LIFE_C	INT32	-99999...99999		CB Remaining life phase C
IPOW_A	FLOAT32	0.000...30000.000		Accumulated currents power (Iyt), phase A
IPOW_B	FLOAT32	0.000...30000.000		Accumulated currents power (Iyt), phase B
IPOW_C	FLOAT32	0.000...30000.000		Accumulated currents power (Iyt), phase C
SSCBR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

7.1.9 Technical data

Table 886: SSCBR Technical data

Characteristic	Value
Current measuring accuracy	±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
Travelling time measurement	+10 ms / -0 ms

7.1.10 Technical revision history

Table 887: SSCBR Technical revision history

Technical revision	Change
B	Added the possibility to reset spring charge time and breaker travel times
C	Removed the DIFTRVTOPALM and DIFTRVT-CLALM outputs and the corresponding *Open*

Table continues on the next page

Technical revision	Change
	Dif alarm time and *Close Dif alarm time* setting parameters
D	The *Operation cycle* setting parameter renamed to *Initial CB Rmn life*. The IPOW_A (_B, _C) range changed.
E	Maximum value of initial circuit breaker remaining life time setting (*Initial CB Rmn life*) changed from 9999 to 99999. Added support for measuring circuit breaker travelling time from opening/closing command and auxiliary contact state signal change.
F	*Alarm Op number* range increased from 9999 to 99999. *Lockout Op* number setting range increased from 9999 to 99999. *Counter initial value* setting range increased from 9999 to 99999.

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 function VMMXU is used for monitoring and metering the phase-to-phase voltages of the power system. The phase-to-earth voltages are also available in VMMXU.

The single-phase voltage measurement function VAMMXU is used for monitoring and metering the phase-to-phase voltage of the power system. The phase-to-earth voltage is also available in VAMMXU.

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 frequency measurement FMMXU is used for monitoring and metering the power system frequency.

The three-phase power and energy measurement PEMMXU is used for monitoring and metering the active power (P), reactive power (Q), apparent power (S) and power factor (PF) and for calculating the accumulated energy separately as forward active, reversed active, forward reactive and reversed reactive. PEMMXU calculates these quantities using the fundamental frequency phasors, that is, the DFT values of the measured phase current and phase voltage signals.

The information of the measured quantity is available for the operator both locally in LHMI or WHMI and remotely to a network control center with communication.

If the measured data in LHMI or WHMI is within parentheses, there are some problems to express the data.

8.1.2 Measurement functionality

The functions can be enabled or disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

Some of the measurement functions operate on two alternative measurement modes: "DFT" and "RMS". The measurement mode is selected with the *X Measurement mode* setting. Depending on the measuring function if the measurement mode cannot be selected, the measuring mode is "DFT".

Demand value calculation

The demand values are calculated separately for each measurement function and per phase when applicable. The available measurement modes are "Linear" and "Logarithmic". The "Logarithmic" measurement mode is only effective for phase current and residual current demand value calculations. The demand value calculation mode is selected with the setting parameter **Configuration** > **Measurements** > **A demand Av mode**. The time interval for all demand value calculations is selected with the setting parameter **Configuration** > **Measurements** > **Demand interval**.

If the *Demand interval* setting is set to "15 minutes", for example, the demand values are updated every quarter of an hour. The demand time interval is synchronized to the real-time clock of the protection relay. When the demand time interval or calculation mode is changed, it initializes the demand value calculation. For the very first demand value calculation interval, the values are stated as invalid until the first refresh is available.

The "Linear" calculation mode uses the periodic sliding average calculation of the measured signal over the demand time interval. A new demand value is obtained once in a minute, indicating the analog signal demand over the demand time interval proceeding the update time. The actual rolling demand values are stored in the memory until the value is updated at the end of the next time interval.

The "Logarithmic" calculation mode uses the periodic calculation using a log10 function over the demand time interval to replicate thermal demand ammeters. The logarithmic demand calculates a snapshot of the analog signal every 1/15 x demand time interval.

Each measurement function has its own recorded data values. In protection relay, these are found in **Monitoring** > **Recorded data** > **Measurements**. In the technical manual these are listed in the monitored data section of each measurement function. These values are periodically updated with the maximum and minimum demand values. The time stamps are provided for both values.

Reset of Recorded data initializes a present demand value to the minimum and maximum demand values.

Value reporting

The measurement functions are capable of reporting new values for network control center (SCADA system) based on various functions.

- Zero-point clamping
- Deadband supervision
- Limit value supervision

In the three-phase voltage measurement function VMMXU the supervision functions are based on the phase-to-phase voltages. However, the phase-to-earth voltage values are also reported with the phase-to-phase voltages.

GOOSE is an event based protocol service. Analog GOOSE uses the same event generation functions as vertical SCADA communication for updating the measurement values. Update interval of 500 ms is used for data that do not have zero-point clamping, deadband supervision or limit value supervision.

Zero-point clamping

A measured value under the zero-point clamping limit is forced to zero. This allows the noise in the input signal to be ignored. The active clamping function forces both the actual measurement value and the angle value of the measured signal to zero. In the three-phase or sequence measuring functions, each phase or sequence component has a separate zero-point clamping function. The zero-value detection operates so that once the measured value exceeds or falls below the value of the zero-clamping limit, new values are reported.

Table 888: Zero-point clamping limits

Function	Zero-clamping limit
Three-phase current measurement (CMMXU)	1 % of nominal (In)
Three-phase voltage measurement (VMMXU)	1 % of nominal (Un)
Residual current measurement (RESCMMXU)	1 % of nominal (In)
Residual voltage measurement (RESVMMXU)	1 % of nominal (Un)
Phase sequence current measurement (CSMSQI)	1 % of the nominal (In)
Phase sequence voltage measurement (VSMSQI)	1 % of the nominal (Un)
Three-phase power and energy measurement (PEMMXU)	1.5 % of the nominal (Sn)

When the frequency measurement function FMMXU is unable to measure the network frequency in the undervoltage situation, the measured values are set to the nominal and also the quality information of the data set accordingly. The undervoltage limit is fixed to 10 percent of the nominal for the frequency measurement.

Limit value supervision

The limit value supervision function indicates whether the measured value of X_INST exceeds or falls below the set limits. The measured value has the corresponding range information X_RANGE and has a value in the range of 0 to 4:

- 0: "normal"
- 1: "high"
- 2: "low"
- 3: "high-high"
- 4: "low-low"

The range information changes and the new values are reported.

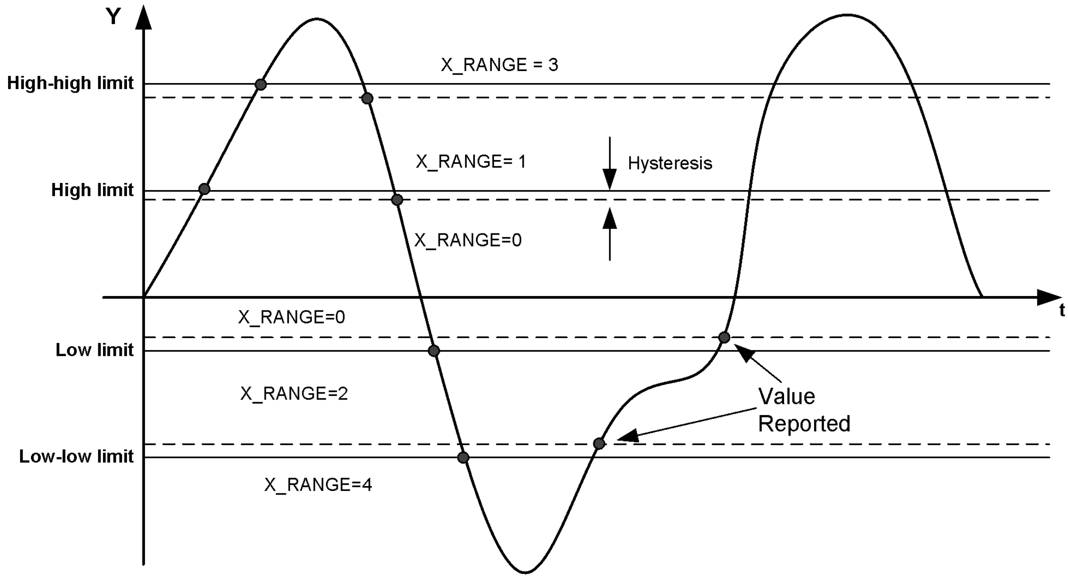


Figure 498: Presentation of operating limits

The range information can also be decoded into boolean output signals on some of the measuring functions and the number of phases required to exceed or undershoot the limit before activating the outputs and can be set with the *Num of phases* setting in the three-phase measurement functions CMMXU and VMMXU. The limit supervision boolean alarm and warning outputs can be blocked.

Table 889: Settings for limit value supervision

Function	Settings for limit value supervision	
Three-phase current measurement (CMMXU)	High limit	*A high limit*
	Low limit	*A low limit*
	High-high limit	*A high high limit*
	Low-low limit	*A low low limit*
Three-phase voltage measurement (VMMXU)	High limit	*V high limit*
	Low limit	*V low limit*
	High-high limit	*V high high limit*
	Low-low limit	*V low low limit*
Residual current measurement (RE-SCMMXU)	High limit	*A high limit res*
	Low limit	-
	High-high limit	*A Hi high limit res*
	Low-low limit	-
Frequency measurement (FMMXU)	High limit	*F high limit*
	Low limit	*F low limit*
	High-high limit	*F high high limit*
	Low-low limit	*F low low limit*
Residual voltage measurement (RE-SVMMXU)	High limit	*V high limit res*

Table continues on the next page

Function	Settings for limit value supervision	
	Low limit	-
	High-high limit	*V Hi high limit res*
	Low-low limit	-
Phase sequence current measurement (CSMSQI)	High limit	*Ps Seq A high limit, Ng Seq A high limit, Zro A high limit*
	Low limit	*Ps Seq A low limit, Ng Seq A low limit, Zro A low limit*
	High-high limit	*Ps Seq A Hi high Lim, Ng Seq A Hi high Lim, Zro A Hi high Lim*
	Low-low limit	*Ps Seq A low low Lim, Ng Seq A low low Lim, Zro A low low Lim*
Phase sequence voltage measurement (VSMSQI)	High limit	*Ps Seq V high limit, Ng Seq V high limit, Zro V high limit*
	Low limit	*Ps Seq V low limit, Ng Seq V low limit, Zro V low limit*
	High-high limit	*Ps Seq V Hi high Lim, Ng Seq V Hi high Lim, Zro V Hi high Lim*
	Low-low limit	*Ps Seq V low low Lim, Ng Seq V low low Lim,*
Three-phase power and energy measurement (PEMMXU)	High limit	-
	Low limit	-
	High-high limit	-
	Low-low limit	-

Deadband supervision

The deadband supervision function reports the measured value according to integrated changes over a time period.

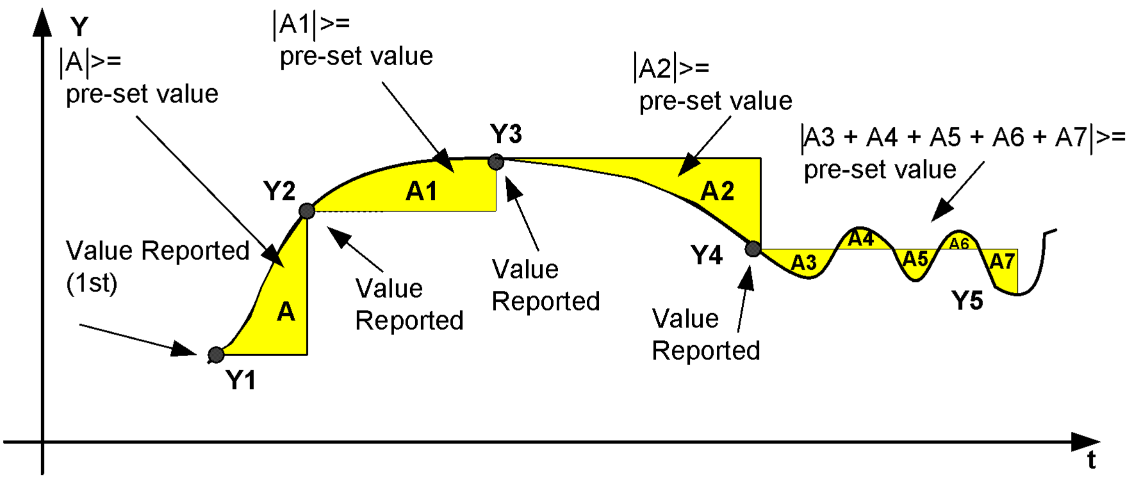


Figure 499: Integral deadband supervision

The deadband value used in the integral calculation is configured with the *X deadband* setting. The value represents the percentage of the difference between the maximum and minimum limit in the units of 0.001 percent x seconds.

The reporting delay of the integral algorithms in seconds is calculated with the formula:

$$t(s) = \frac{(max - min) \times deadband / 1000}{|\Delta Y| \times 100\%}$$

(Equation 177)

Example for CMMXU:

A deadband = 2500 (2.5% of the total measuring range of 40)

I_INST_A = I_DB_A = 0.30

If I_INST_A changes to 0.40, the reporting delay is:

$$t(s) = \frac{(40 - 0) \times 2500 / 1000}{|0.40 - 0.30| \times 100\%} = 10\,s$$

Table 890: Parameters for deadband calculation

Function	Settings	Maximum/minimum (=range)
Three-phase current measurement (CMMXU)	*A deadband*	*40/0 (=40xIn)*
Three-phase voltage measurement (VMMXU)	*V Deadband*	*4/0 (=4xUn)*
Residual current measurement (RESCMMXU)	*A deadband res*	*40/0 (=40xIn)*
Residual voltage measurement (RESVMMXU)	*V deadband res*	*4/0 (=4xUn)*

Table continues on the next page

Function	Settings	Maximum/minimum (=range)
Frequency measurement (FMMXU)	*F deadband*	*75/35 (=40 Hz)*[1]
Phase sequence current measurement (CSMSQI)	*Ps Seq A deadband, Ng Seq A deadband, Zro A deadband*	*40/0 (=40xIn)*
Phase sequence voltage measurement (VSMSQI)	*Ps Seq V deadband, Ng Seq V deadband, Zro V deadband*	*4/0 (=4xUn)*
Three-phase power and energy measurement (PEMMXU)	-	

In the three-phase power and energy measurement function PEMMXU, the deadband supervision is done separately for apparent power S, with the preset value of fixed 10 percent of the Sn, and the power factor PF, with the preset values fixed at 0.10.. All the power measurement-related values P, Q, S and PF are reported simultaneously when either one of the S or PF values exceeds the preset limit.

Power and energy calculation

The three-phase power is calculated from the phase-to-earth voltages and phase-to-earth currents. The power measurement function is capable of calculating a complex power based on the fundamental frequency component phasors (DFT).

$$\bar{S} = (\bar{U}_A \cdot \bar{I}^*_A + \bar{U}_B \cdot \bar{I}^*_B + \bar{U}_C \cdot \bar{I}^*_C)$$

(Equation 178)

Once the complex apparent power is calculated, P, Q, S and PF are calculated with the equations:

$$P = \mathrm{Re}(\bar{S})$$

(Equation 179)

$$Q = \mathrm{Im}(\bar{S})$$

(Equation 180)

$$S = |\bar{S}| = \sqrt{P^2 + Q^2}$$

(Equation 181)

$$Cos\varphi = \frac{P}{S}$$

(Equation 182)

Depending on the unit multiplier selected with *Power unit Mult*, the calculated power values are presented in units of kVA/kW/kVAr or in units of MVA/MW/MVAr.

[1] The value provided is for 50 Hz network. The value for 60 Hz network is 90/36 (=54 Hz)

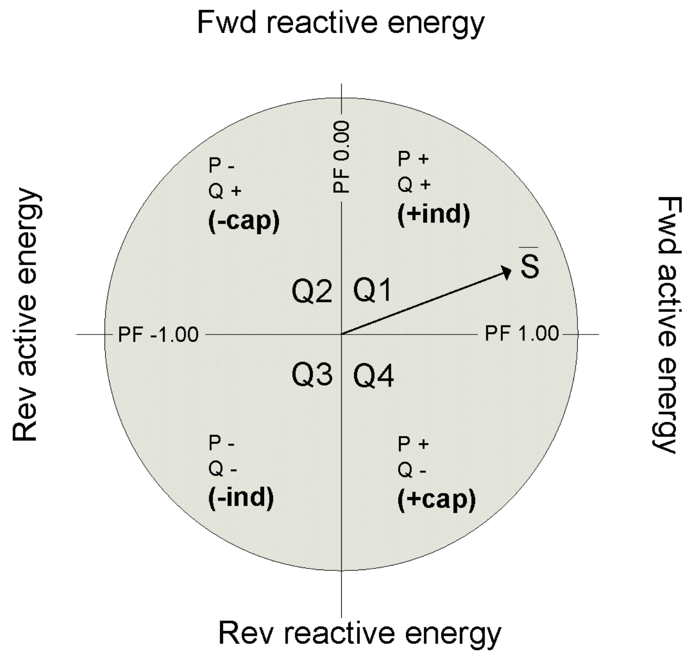


Figure 500: Complex power and power quadrants

Table 891: 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

The active power P direction can be selected between forward and reverse with *Active power Dir* and correspondingly the reactive power Q direction can be selected with *Reactive power Dir*. This affects also the accumulated energy directions.

The accumulated energy is calculated separately as forward active (EA_FWD_ACM), reverse active (EA_RV_ACM), forward reactive (ER_FWD_ACM) and reverse reactive (ER_RV_ACM). Depending on the value of the unit multiplier selected with *Energy unit Mult*, the calculated power values are presented in units of kWh/kVArh or in units of MWh/MVArh.

When the energy counter reaches its defined maximum value, the counter value is reset and restarted from zero. Changing the value of the *Energy unit Mult* setting resets the accumulated energy values to the initial values, that is, EA_FWD_ACM to *Forward Wh Initial*, EA_RV_ACM to *Reverse Wh Initial*, ER_FWD_ACM to *Forward VArh Initial* and ER_RV_ACM to *Reverse VArh Initial*. It is also possible to reset the accumulated energy to initial values through a parameter or with the RSTACM input.

Sequence components

The phase-sequence components are calculated using the phase currents and phase voltages. More information on calculating the phase-sequence components can be found in *Chapter 11.6 Calculated measurements* in this manual.

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, with IEC 61850. The possibility to continuously monitor the measured values of active power, reactive power, currents, voltages, power factors and so on, is vital for 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 testing and commissioning of protection relays to verify the proper operation and connection of instrument transformers, that is, the current transformers (CTs) and voltage transformers (VTs). The proper operation of the protection relay analog measurement chain can be verified during normal service by a periodic comparison of the measured value from the protection relay to 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, prevent the noise to be shown in the user display. The zero clamping is done for the measured analog signals and angle values.

The demand values are used to neglect sudden changes in the measured analog signals when monitoring long time values for the input signal. The demand values are linear average values of the measured signal over a settable demand interval. The demand values are calculated for the measured analog three-phase current signals.

The limit supervision indicates, if the measured signal exceeds or goes below the set limits. Depending on the measured signal type, up to two high limits and up to two low limits can be set for the limit supervision.

The deadband supervision reports a new measurement value if the input signal has gone out of the deadband state. The deadband supervision can be used in value reporting between the measurement point and operation control. When the deadband supervision is properly configured, it helps in keeping the communication load in minimum and yet measurement values are reported frequently enough.

8.1.4 Three-phase current measurement 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

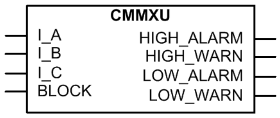


Figure 501: Function block

8.1.4.3 Signals

Table 892: CMMXU Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 893: CMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
LOW_WARN	BOOLEAN	Low warning
LOW_ALARM	BOOLEAN	Low alarm

8.1.4.4 Settings

Table 894: CMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required by limit supervision
A high high limit	0.00...40.00	xIn	1	1.40	High alarm current limit
A high limit	0.00...40.00	xIn	1	1.20	High warning current limit
A low limit	0.00...40.00	xIn	1	0.00	Low warning current limit
A low low limit	0.00...40.00	xIn	1	0.00	Low alarm current limit
A deadband	100...100000		1	2500	Deadband configuration value for integral calculation. (percentage of dif-

Parameter	Values (Range)	Unit	Step	Default	Description
					ference between min and max as 0,001 % s)

Table 895: CMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode

8.1.4.5 Monitored data

Table 896: CMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
IL1-A	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase A
IL2-A	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase B
IL3-A	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase C
Max demand IL1	FLOAT32	0.00...40.00	xIn	Maximum demand for Phase A
Max demand IL2	FLOAT32	0.00...40.00	xIn	Maximum demand for Phase B
Max demand IL3	FLOAT32	0.00...40.00	xIn	Maximum demand for Phase C
Min demand IL1	FLOAT32	0.00...40.00	xIn	Minimum demand for Phase A
Min demand IL2	FLOAT32	0.00...40.00	xIn	Minimum demand for Phase B
Min demand IL3	FLOAT32	0.00...40.00	xIn	Minimum demand for Phase C
Time max demand IL1	Timestamp			Time of maximum demand phase A

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Time max demand IL2	Timestamp			Time of maximum demand phase B
Time max demand IL3	Timestamp			Time of maximum demand phase C
Time min demand IL1	Timestamp			Time of minimum demand phase A
Time min demand IL2	Timestamp			Time of minimum demand phase B
Time min demand IL3	Timestamp			Time of minimum demand phase C
I_INST_A	FLOAT32	0.00...40.00	xIn	IL1 Amplitude, magnitude of instantaneous value
I_ANGL_A	FLOAT32	-180.00...180.00	deg	IL1 current angle
I_DB_A	FLOAT32	0.00...40.00	xIn	IL1 Amplitude, magnitude of reported value
I_DMD_A	FLOAT32	0.00...40.00	xIn	Demand value of IL1 current
I_RANGE_A	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		IL1 Amplitude range
I_INST_B	FLOAT32	0.00...40.00	xIn	IL2 Amplitude, magnitude of instantaneous value
I_ANGL_B	FLOAT32	-180.00...180.00	deg	IL2 current angle
I_DB_B	FLOAT32	0.00...40.00	xIn	IL2 Amplitude, magnitude of reported value
I_DMD_B	FLOAT32	0.00...40.00	xIn	Demand value of IL2 current
I_RANGE_B	Enum	0=normal 1=high 2=low		IL2 Amplitude range

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		3=high-high 4=low-low		
I_INST_C	FLOAT32	0.00...40.00	xIn	IL3 Amplitude, magnitude of instantaneous value
I_ANGL_C	FLOAT32	-180.00...180.00	deg	IL3 current angle
I_DB_C	FLOAT32	0.00...40.00	xIn	IL3 Amplitude, magnitude of reported value
I_DMD_C	FLOAT32	0.00...40.00	xIn	Demand value of IL3 current
I_RANGE_C	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		IL3 Amplitude range

8.1.4.6 Technical data

Table 897: CMMXU Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±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 × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.4.7 Technical revision history

Table 898: CMMXU Technical revision history

Technical revision	Change
B	Menu changes
C	Phase current angle values added to Monitored data view. Minimum demand value and time added to recorded data. Logarithmic demand calculation mode added and demand interval setting moved under Measure-

Table continues on the next page

Technical revision	Change
	ment menu as general setting to all demand calculations.
D	Internal improvement.
E	Internal improvement.

8.1.5 Three-phase voltage measurement VMMXU

8.1.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase voltage measurement	VMMXU	3U	3V

8.1.5.2 Function block

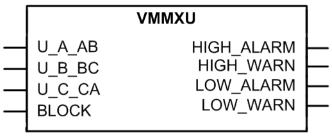


Figure 502: Function block

8.1.5.3 Signals

Table 899: VMMXU Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 900: VMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
LOW_WARN	BOOLEAN	Low warning
LOW_ALARM	BOOLEAN	Low alarm

8.1.5.4 Settings

Table 901: VMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required by limit supervision
V high high limit	0.00...4.00	xUn	1	1.40	High alarm voltage limit
V high limit	0.00...4.00	xUn	1	1.20	High warning voltage limit
V low limit	0.00...4.00	xUn	1	0.00	Low warning voltage limit
V low low limit	0.00...4.00	xUn	1	0.00	Low alarm voltage limit
V deadband	100...100000		1	10000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 902: VMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode

8.1.5.5 Monitored data

Table 903: VMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
U12-kV	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
				amplitude phase AB
U23-kV	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase BC
U31-kV	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase CA
U_INST_AB	FLOAT32	0.00...4.00	xUn	U12 Amplitude, magnitude of instantaneous value
U_ANGL_AB	FLOAT32	-180.00...180.00	deg	U12 angle
U_DB_AB	FLOAT32	0.00...4.00	xUn	U12 Amplitude, magnitude of reported value
U_DMD_AB	FLOAT32	0.00...4.00	xUn	Demand value of U12 voltage
U_RANGE_AB	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U12 Amplitude range
U_INST_BC	FLOAT32	0.00...4.00	xUn	U23 Amplitude, magnitude of instantaneous value
U_ANGL_BC	FLOAT32	-180.00...180.00	deg	U23 angle
U_DB_BC	FLOAT32	0.00...4.00	xUn	U23 Amplitude, magnitude of reported value
U_DMD_BC	FLOAT32	0.00...4.00	xUn	Demand value of U23 voltage
U_RANGE_BC	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U23 Amplitude range
U_INST_CA	FLOAT32	0.00...4.00	xUn	U31 Amplitude, magnitude of in-

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
				stantaneous val-ue
U_ANGL_CA	FLOAT32	-180.00...180.00	deg	U31 angle
U_DB_CA	FLOAT32	0.00...4.00	xUn	U31 Amplitude, magnitude of re-ported value
U_DMD_CA	FLOAT32	0.00...4.00	xUn	Demand value of U31 voltage
U_RANGE_CA	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U31 Amplitude range
U_INST_A	FLOAT32	0.00...5.00	xUn	UL1 Amplitude, magnitude of in-stantaneous val-ue
U_ANGL_A	FLOAT32	-180.00...180.00	deg	UL1 angle
U_DMD_A	FLOAT32	0.00...5.00	xUn	Demand value of UL1 voltage
U_INST_B	FLOAT32	0.00...5.00	xUn	UL2 Amplitude, magnitude of in-stantaneous val-ue
U_ANGL_B	FLOAT32	-180.00...180.00	deg	UL2 angle
U_DMD_B	FLOAT32	0.00...5.00	xUn	Demand value of UL2 voltage
U_INST_C	FLOAT32	0.00...5.00	xUn	UL3 Amplitude, magnitude of in-stantaneous val-ue
U_ANGL_C	FLOAT32	-180.00...180.00	deg	UL3 angle
U_DMD_C	FLOAT32	0.00...5.00	xUn	Demand value of UL3 voltage

8.1.5.6 Technical data

Table 904: VMMXU Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz

Table continues on the next page

Characteristic	Value
	At voltages in range 0.01…1.15 × U_n
	±0.5 % or ±0.002 × U_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.5.7 Technical revision history

Table 905: VMMXU Technical revision history

Technical revision	Change
B	Phase and phase-to-phase voltage angle values and demand values added to Monitored data view.
C	Internal improvement.
D	Internal improvement.

8.1.6 Single-phase voltage measurement VAMMXU

8.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Single-phase voltage measurement	VAMMXU	U_A	V_A

8.1.6.2 Function block

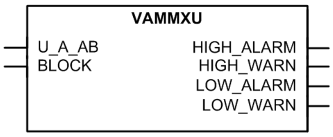


Figure 503: Function block symbol

8.1.6.3 Signals

Table 906: VAMMXU Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 907: VAMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
LOW_WARN	BOOLEAN	Low warning
LOW_ALARM	BOOLEAN	Low alarm

8.1.6.4 Settings

Table 908: VAMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
V high high limit	0.00...4.00	xUn	1	1.40	High alarm voltage limit
V high limit	0.00...4.00	xUn	1	1.20	High warning voltage limit

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
V low limit	0.00...4.00	xUn	1	0.00	Low warning voltage limit
V low low limit	0.00...4.00	xUn	1	0.00	Low alarm voltage limit
V deadband	100...100000		1	10000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 909: VAMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode

8.1.6.5 Monitored data

Table 910: VAMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
U12-kV	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase AB
UL1-kV	FLOAT32	0.00...5.00	xUn	Measured phase to earth voltage amplitude phase A
U_INST_AB	FLOAT32	0.00...4.00	xUn	U12 Amplitude, magnitude of instantaneous value
U_ANGL_AB	FLOAT32	-180.00...180.00	deg	U12 angle
U_DB_AB	FLOAT32	0.00...4.00	xUn	U12 Amplitude, magnitude of reported value
U_DMD_AB	FLOAT32	0.00...4.00	xUn	Demand value of U12 voltage
U_RANGE_AB	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U12 Amplitude range
U_INST_A	FLOAT32	0.00...5.00	xUn	UL1 Amplitude, magnitude of instantaneous value
U_ANGL_A	FLOAT32	-180.00...180.00	deg	UL1 angle
U_DB_A	FLOAT32	0.00...5.00	xUn	UL1 Amplitude, magnitude of reported value
U_DMD_A	FLOAT32	0.00...5.00	xUn	Demand value of UL1 voltage
U_RANGE_A	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		UL1 Amplitude range

8.1.6.6 Technical data

Table 911: VAMMXU Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz At voltages in range 0.01…1.15 × U_n
	±0.5 % or ±0.002 × 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 measurement RESCMMXU

8.1.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual current measurement	RESCMMXU	Io	In

8.1.7.2 Function block

Figure 504: Function block

8.1.7.3 Signals

Table 912: RESCMMXU Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 913: RESCMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning

8.1.7.4 Settings

Table 914: RESCMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
A Hi high limit res	0.00...40.00	xIn	1	0.20	High alarm current limit
A high limit res	0.00...40.00	xIn	1	0.05	High warning current limit
A deadband res	100...100000		1	2500	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 915: RESCMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode

8.1.7.5 Monitored data

Table 916: RESCMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
Io-A	FLOAT32	0.00...40.00	xIn	Measured residual current
I_INST_RES	FLOAT32	0.00...40.00	xIn	Residual current Amplitude, magnitude of instantaneous value
I_ANGL_RES	FLOAT32	-180.00...180.00	deg	Residual current angle
I_DB_RES	FLOAT32	0.00...40.00	xIn	Residual current Amplitude, magnitude of reported value
I_DMD_RES	FLOAT32	0.00...40.00	xIn	Demand value of residual current
I_RANGE_RES	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Residual current Amplitude range

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Max demand Io	FLOAT32	0.00...40.00	xIn	Maximum demand for residual current
Min demand Io	FLOAT32	0.00...40.00	xIn	Minimum demand for residual current
Time max demand Io	Timestamp			Time of maximum demand residual current
Time min demand Io	Timestamp			Time of minimum demand residual current

8.1.7.6 Technical data

Table 917: 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

8.1.7.7 Technical revision history

Table 918: RESCMMXU Technical revision history

Technical revision	Change
B	-
C	Residual current angle and demand value added to Monitored data view. Recorded data added for minimum and maximum values with timestamps.
D	Monitored data Min demand Io maximum value range (RESCMSTA2.MinAmps.maxVal.f) is corrected to 40.00.
E	Internal improvement

8.1.8 Residual voltage measurement RESVMMXU

8.1.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual voltage measurement	RESVMMXU	Uo	Vn

8.1.8.2 Function block

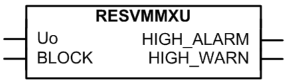


Figure 505: Function block

8.1.8.3 Signals

Table 919: RESVMMXU Input signals

Name	Type	Default	Description
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 920: RESVMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning

8.1.8.4 Settings

Table 921: RESVMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
V Hi high limit res	0.00...4.00	xUn	1	0.20	High alarm voltage limit
V high limit res	0.00...4.00	xUn	1	0.05	High warning voltage limit
V deadband res	100...100000		1	10000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 922: RESVMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode

8.1.8.5 Monitored data

Table 923: RESVMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
Uo-kV	FLOAT32	0.00...4.00	xUn	Measured residual voltage
U_INST_RES	FLOAT32	0.00...4.00	xUn	Residual voltage Amplitude, magnitude of instantaneous value
U_ANGL_RES	FLOAT32	-180.00...180.00	deg	Residual voltage angle
U_DB_RES	FLOAT32	0.00...4.00	xUn	Residual voltage Amplitude, magnitude of reported value
U_DMD_RES	FLOAT32	0.00...4.00	xUn	Demand value of residual voltage
U_RANGE_RES	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Residual voltage Amplitude range

8.1.8.6 Technical data

Table 924: RESVMMXU Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f/f_n = ±2 Hz
	±0.5 % or ±0.002 × U_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.8.7 Technical revision history

Table 925: RESVMMXU Technical revision history

Technical revision	Change
B	-
C	Residual voltage angle and demand value added to Monitored data view
D	Internal improvement
E	Internal improvement

8.1.9 Frequency measurement FMMXU

8.1.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Frequency measurement	FMMXU	f	f

8.1.9.2 Function block

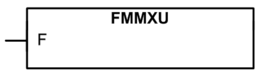


Figure 506: Function block

8.1.9.3 Functionality

The frequency measurement range is 35...75 Hz. The estimated frequencies outside the measurement range are considered to be out of range and the minimum and maximum values are then shown.

When the frequencies cannot be measured, for example, due to too low voltage amplitude, the default value for frequency measurement can be selected with the *Def frequency Sel* setting parameter. In the “Nominal” mode the frequency is set to 50 Hz (or 60 Hz) and in “Zero” mode the frequency is set to zero and shown in parentheses.

8.1.9.4 Signals

Table 926: FMMXU Input signals

Name	Type	Default	Description
F	SIGNAL	–	Measured system frequency

8.1.9.5 Settings

Table 927: FMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
F high high limit	35.00...75.00	Hz	1	60.00	High alarm frequency limit
F high limit	35.00...75.00	Hz	1	55.00	High warning frequency limit
F low limit	35.00...75.00	Hz	1	45.00	Low warning frequency limit
F low low limit	35.00...75.00	Hz	1	40.00	Low alarm frequency limit
F deadband	100...100000		1	1000	Deadband configuration value for integral calculation (percentage of difference between min and max as 0,001 % s)

Table 928: FMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Def frequency Sel	1=Nominal 2=Zero			1=Nominal	Default frequency selection

8.1.9.6 Monitored data

Table 929: FMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
f-Hz	FLOAT32	35.00...75.00	Hz	Measured frequency
F_INST	FLOAT32	35.00...75.00	Hz	Frequency, instantaneous value
F_DB	FLOAT32	35.00...75.00	Hz	Frequency, reported value
F_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Measured frequency range

8.1.9.7 Technical data

Table 930: FMMXU Technical data

Characteristic	Value
Operation accuracy	±10 mHz (in measurement range 35...75 Hz)

8.1.9.8 Technical revision history

Table 931: FMMXU Technical revision history

Technical revision	Change
B	Added new setting *Def frequency Sel*. Frequency measurement range lowered from 35 Hz to 10 Hz.

8.1.10 Sequence current measurement CSMSQI

8.1.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Sequence current measurement	CSMSQI	I1, I2, I0	I1, I2, I0

8.1.10.2 Function block

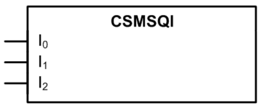


Figure 507: Function block

8.1.10.3 Signals

Table 932: CSMSQI Input signals

Name	Type	Default	Description
I_0	SIGNAL	0	Zero sequence current
I_1	SIGNAL	0	Positive sequence current
I_2	SIGNAL	0	Negative sequence current

8.1.10.4 Settings

Table 933: CSMSQI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Ps Seq A Hi high Lim	0.00...40.00	xIn	1	1.40	High alarm current limit for positive sequence current
Ps Seq A high limit	0.00...40.00	xIn	1	1.20	High warning current limit for positive sequence current
Ps Seq A low limit	0.00...40.00	xIn	1	0.00	Low warning current limit for positive sequence current
Ps Seq A low low Lim	0.00...40.00	xIn	1	0.00	Low alarm current limit for positive sequence current
Ps Seq A deadband	100...100000		1	2500	Deadband configuration value for positive sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)
Ng Seq A Hi high Lim	0.00...40.00	xIn	1	0.20	High alarm current limit for negative sequence current
Ng Seq A High limit	0.00...40.00	xIn	1	0.05	High warning current limit for negative sequence current
Ng Seq A low limit	0.00...40.00	xIn	1	0.00	Low warning current limit for negative sequence current
Ng Seq A low low Lim	0.00...40.00	xIn	1	0.00	Low alarm current limit for negative sequence current
Ng Seq A deadband	100...100000		1	2500	Deadband configuration value for negative sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)
Zro A Hi high Lim	0.00...40.00	xIn	1	0.20	High alarm current limit for zero sequence current
Zro A High limit	0.00...40.00	xIn	1	0.05	High warning current limit for zero sequence current
Zro A low limit	0.00...40.00	xIn	1	0.00	Low warning current limit for zero sequence current
Zro A low low Lim	0.00...40.00	xIn	1	0.00	Low alarm current limit for zero sequence current
Zro A deadband	100...100000		1	2500	Deadband configuration value for zero sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)

8.1.10.5 Monitored data

Table 934: CSMSQI Monitored data

Name	Type	Values (Range)	Unit	Description
NgSeq-A	FLOAT32	0.00...40.00	xIn	Measured negative sequence current
PsSeq-A	FLOAT32	0.00...40.00	xIn	Measured positive sequence current
ZroSeq-A	FLOAT32	0.00...40.00	xIn	Measured zero sequence current
I2_INST	FLOAT32	0.00...40.00	xIn	Negative sequence current amplitude, instantaneous value
I2_ANGL	FLOAT32	-180.00...180.00	deg	Negative sequence current angle
I2_DB	FLOAT32	0.00...40.00	xIn	Negative sequence current amplitude, reported value
I2_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Negative sequence current amplitude range
I1_INST	FLOAT32	0.00...40.00	xIn	Positive sequence current amplitude, instantaneous value
I1_ANGL	FLOAT32	-180.00...180.00	deg	Positive sequence current angle
I1_DB	FLOAT32	0.00...40.00	xIn	Positive sequence current amplitude, reported value
I1_RANGE	Enum	0=normal 1=high 2=low		Positive sequence current amplitude range

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		3=high-high 4=low-low		
I0_INST	FLOAT32	0.00...40.00	xIn	Zero sequence current amplitude, instantaneous value
I0_ANGL	FLOAT32	-180.00...180.00	deg	Zero sequence current angle
I0_DB	FLOAT32	0.00...40.00	xIn	Zero sequence current amplitude, reported value
I0_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Zero sequence current amplitude range

8.1.10.6 Technical data

Table 935: CSMSQI Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f/f_n = ±2 Hz
	±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 × f_n, where n = 2, 3, 4, 5,…

8.1.10.7 Technical revision history

Table 936: CSMSQI Technical revision history

Technical revision	Change
A	-
B	Sequence current angle values added to the Monitored data view.
C	Internal improvement.

8.1.11 Sequence voltage measurement VSMSQI

8.1.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Sequence voltage measurement	VSMSQI	U1, U2, U0	V1, V2, V0

8.1.11.2 Function block

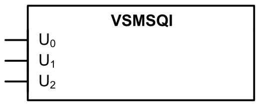


Figure 508: Function block

8.1.11.3 Signals

Table 937: VSMSQI Input signals

Name	Type	Default	Description
U_0	SIGNAL	0	Zero sequence voltage
U_1	SIGNAL	0	Positive phase sequence voltage
U_2	SIGNAL	0	Negative phase sequence voltage

8.1.11.4 Settings

Table 938: VSMSQI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Ps Seq V Hi high Lim	0.00...4.00	xUn	1	1.40	High alarm voltage limit for positive sequence voltage
Ps Seq V high limit	0.00...4.00	xUn	1	1.20	High warning voltage limit for positive sequence voltage
Ps Seq V low limit	0.00...4.00	xUn	1	0.00	Low warning voltage limit for positive sequence voltage
Ps Seq V low low Lim	0.00...4.00	xUn	1	0.00	Low alarm voltage limit for positive sequence voltage
Ps Seq V deadband	100...100000		1	10000	Deadband configuration value for positive sequence

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
					voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)
Ng Seq V Hi high Lim	0.00...4.00	xUn	1	0.20	High alarm voltage limit for negative sequence voltage
Ng Seq V High limit	0.00...4.00	xUn	1	0.05	High warning voltage limit for negative sequence voltage
Ng Seq V low limit	0.00...4.00	xUn	1	0.00	Low warning voltage limit for negative sequence voltage
Ng Seq V low low Lim	0.00...4.00	xUn	1	0.00	Low alarm voltage limit for negative sequence voltage
Ng Seq V deadband	100...100000		1	10000	Deadband configuration value for negative sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)
Zro V Hi high Lim	0.00...4.00	xUn	1	0.20	High alarm voltage limit for zero sequence voltage
Zro V High limit	0.00...4.00	xUn	1	0.05	High warning voltage limit for zero sequence voltage
Zro V low limit	0.00...4.00	xUn	1	0.00	Low warning voltage limit for zero sequence voltage
Zro V low low Lim	0.00...4.00	xUn	1	0.00	Low alarm voltage limit for zero sequence voltage
Zro V deadband	100...100000		1	10000	Deadband configuration value for zero sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)

8.1.11.5 Monitored data

Table 939: VSMSQI Monitored data

Name	Type	Values (Range)	Unit	Description
NgSeq-kV	FLOAT32	0.00...4.00	xUn	Measured negative sequence voltage
PsSeq-kV	FLOAT32	0.00...4.00	xUn	Measured positive sequence voltage

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
ZroSeq-kV	FLOAT32	0.00...4.00	xUn	Measured zero sequence voltage
U2_INST	FLOAT32	0.00...4.00	xUn	Negative sequence voltage amplitude, instantaneous value
U2_ANGL	FLOAT32	-180.00...180.00	deg	Negative sequence voltage angle
U2_DB	FLOAT32	0.00...4.00	xUn	Negative sequence voltage amplitude, reported value
U2_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Negative sequence voltage amplitude range
U1_INST	FLOAT32	0.00...4.00	xUn	Positive sequence voltage amplitude, instantaneous value
U1_ANGL	FLOAT32	-180.00...180.00	deg	Positive sequence voltage angle
U1_DB	FLOAT32	0.00...4.00	xUn	Positive sequence voltage amplitude, reported value
U1_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Positive sequence voltage amplitude range
U0_INST	FLOAT32	0.00...4.00	xUn	Zero sequence voltage amplitude, instantaneous value
U0_ANGL	FLOAT32	-180.00...180.00	deg	Zero sequence voltage angle

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
U0_DB	FLOAT32	0.00...4.00	xUn	Zero sequence voltage amplitude, reported value
U0_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Zero sequence voltage amplitude range

8.1.11.6 Technical data

Table 940: VSMSQI Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz At voltages in range 0.01…1.15 × U_n
	±1.0 % or ±0.002 × U_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

8.1.12 Three-phase power and energy measurement PEMMXU

8.1.12.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase power and energy measurement	PEMMXU	P, E	P, E

8.1.12.2 Function block

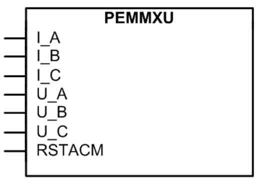


Figure 509: Function block

8.1.12.3 Signals

Table 941: PEMMXU Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
U_A	SIGNAL	0	Phase A voltage
U_B	SIGNAL	0	Phase B voltage
U_C	SIGNAL	0	Phase C voltage
RSTACM	BOOLEAN	0=False	Reset of accumulated energy reading

8.1.12.4 Settings

Table 942: PEMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Power unit Mult	3=Kilo 6=Mega			3=Kilo	Unit multiplier for presentation of the power related values
Energy unit Mult	3=Kilo 6=Mega			3=Kilo	Unit multiplier for presentation of the energy related values
Active power Dir	1=Forward 2=Reverse			1=Forward	Direction of active power flow: Forward, Reverse
Reactive power Dir	1=Forward 2=Reverse			1=Forward	Direction of reactive power flow: Forward, Reverse

Table 943: PEMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Forward Wh Initial	0...999999999		1	0	Preset Initial value for forward active energy
Reverse Wh Initial	0...999999999		1	0	Preset Initial value for reverse active energy
Forward VArh Initial	0...999999999		1	0	Preset Initial value for forward reactive energy
Reverse VArh Initial	0...999999999		1	0	Preset Initial value for reverse reactive energy

8.1.12.5 Monitored data

Table 944: PEMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
S-kVA	FLOAT32	-999999.9...999999.9	kVA	Total Apparent Power
P-kW	FLOAT32	-999999.9...999999.9	kW	Total Active Power
Q-kVAr	FLOAT32	-999999.9...999999.9	kVAr	Total Reactive Power
PF	FLOAT32	-1.00...1.00		Average Power factor
RSTACM	BOOLEAN	0=False 1=True		Reset of accumulated energy reading
S_INST	FLOAT32	-999999.9...999999.9	kVA	Apparent power, magnitude of instantaneous value
S_DB	FLOAT32	-999999.9...999999.9	kVA	Apparent power, magnitude of reported value
S_DMD	FLOAT32	-999999.9...999999.9	kVA	Demand value of apparent power
P_INST	FLOAT32	-999999.9...999999.9	kW	Active power, magnitude of instantaneous value
P_DB	FLOAT32	-999999.9...999999.9	kW	Active power, magnitude of reported value
P_DMD	FLOAT32	-999999.9...999999.9	kW	Demand value of active power
Q_INST	FLOAT32	-999999.9...999999.9	kVAr	Reactive power, magnitude of instantaneous value
Q_DB	FLOAT32	-999999.9...999999.9	kVAr	Reactive power, magnitude of reported value
Q_DMD	FLOAT32	-999999.9...999999.9	kVAr	Demand value of reactive power
PF_INST	FLOAT32	-1.00...1.00		Power factor, magnitude of instantaneous value

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
PF_DB	FLOAT32	-1.00...1.00		Power factor, magnitude of reported value
PF_DMD	FLOAT32	-1.00...1.00		Demand value of power factor
EA_RV_ACM	INT64	0...999999999	kWh	Accumulated reverse active energy value
ER_RV_ACM	INT64	0...999999999	kVArh	Accumulated reverse reactive energy value
EA_FWD_ACM	INT64	0...999999999	kWh	Accumulated forward active energy value
ER_FWD_ACM	INT64	0...999999999	kVArh	Accumulated forward reactive energy value
Max demand S	FLOAT32	-999999.9...999999.9	kVA	Maximum demand value of apparent power
Min demand S	FLOAT32	-999999.9...999999.9	kVA	Minimum demand value of apparent power
Max demand P	FLOAT32	-999999.9...999999.9	kW	Maximum demand value of active power
Min demand P	FLOAT32	-999999.9...999999.9	kW	Minimum demand value of active power
Max demand Q	FLOAT32	-999999.9...999999.9	kVAr	Maximum demand value of reactive power
Min demand Q	FLOAT32	-999999.9...999999.9	kVAr	Minimum demand value of reactive power
Time max dmd S	Timestamp			Time of maximum demand
Time min dmd S	Timestamp			Time of minimum demand
Time max dmd P	Timestamp			Time of maximum demand
Time min dmd P	Timestamp			Time of minimum demand

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Time max dmd Q	Timestamp			Time of maximum demand
Time min dmd Q	Timestamp			Time of minimum demand

8.1.12.6 Technical data

Table 945: PEMMXU 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_n ±1 Hz
	±1.5 % for apparent power S ±1.5 % for active power P and active energy ±1.5 % for reactive power Q and reactive energy ±0.015 for power factor
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

8.1.12.7 Technical revision history

Table 946: PEMMXU Technical revision history

Technical revision	Change
B	Demand values added to Monitored data. Recorded data added to store minimum and maximum demand values with timestamps.
C	Internal improvement.
D	Internal improvement.

8.2 Disturbance recorder RDRE

8.2.1 Functionality

The relay is provided with a disturbance recorder featuring up to 12 analog and 64 binary signal channels.The analog channels can be set to record either the waveform or the trend of the currents and voltages measured.

The analog channels can be set to trigger the recording function when the measured value falls below or exceeds the set values. The binary signal channels

[1] |PF| >0.5 which equals |cosφ| >0.5
[2] |PF| <0.86 which equals |sinφ| >0.5

can be set to start a recording either on the rising or the falling edge of the binary signal or on both.

By default, the binary channels are set to record external or internal relay signals, for example, the start or trip signals of the relay stages, or external blocking or control signals. Binary relay signals, such as protection start and trip signals, or an external relay control signal via a binary input, can be set to trigger the recording. Recorded information is stored in a nonvolatile memory and can be uploaded for subsequent fault analysis.

8.2.1.1 Recorded analog inputs

The user can map any analog signal type of the protection relay to each analog channel of the disturbance recorder by setting the *Channel selection* parameter of the corresponding analog channel. In addition, the user can enable or disable each analog channel of the disturbance recorder by setting the *Operation* parameter of the corresponding analog channel to "on" or "off".

All analog channels of the disturbance recorder that are enabled and have a valid signal type mapped are included in the recording.

8.2.1.2 Triggering alternatives

The recording can be triggered by any or several of the following alternatives:

- Triggering according to the state change of any or several of the binary channels of the disturbance recorder. The user can set the level sensitivity with the *Level trigger mode* parameter of the corresponding binary channel.
- Triggering on limit violations of the analog channels of the disturbance recorder (high and low limit)
- Manual triggering via the *Trig recording* parameter (LHMI or communication)
- Periodic triggering.

Regardless of the triggering type, each recording generates the Recording started and Recording made events. The Recording made event indicates that the recording has been stored to the non-volatile memory. In addition, every analog channel and binary channel of the disturbance recorder has its own *Channel triggered* parameter. Manual trigger has the *Manual triggering* parameter and periodic trigger has the *Periodic triggering* parameter.

Triggering by binary channels

Input signals for the binary channels of the disturbance recorder can be formed from any of the digital signals that can be dynamically mapped. A change in the status of a monitored signal triggers the recorder according to the configuration and settings. Triggering on the rising edge of a digital input signal means that the recording sequence starts when the input signal is activated. Correspondingly, triggering on the falling edge means that the recording sequence starts when the active input signal resets. It is also possible to trigger from both edges. In addition, if preferred, the monitored signal can be non-triggering. The trigger setting can be set individually for each binary channel of the disturbance recorder with the *Level trigger mode* parameter of the corresponding binary channel.

Triggering by analog channels

The trigger level can be set for triggering in a limit violation situation. The user can set the limit values with the *High trigger level* and *Low trigger level* parameters of the corresponding analog channel. Both high level and low level violation triggering can be active simultaneously for the same analog channel. If the duration of the limit violation condition exceeds the filter time of approximately 50 ms, the recorder triggers. In case of a low level limit violation, if the measured value falls below approximately 0.05 during the filter time, the situation is considered to be a circuit-breaker operation and therefore, the recorder does not trigger. This is useful especially in undervoltage situations. The filter time of approximately 50 ms is common to all the analog channel triggers of the disturbance recorder. The value used for triggering is the calculated peak-to-peak value. Either high or low analog channel trigger can be disabled by setting the corresponding trigger level parameter to zero.

Manual triggering

The recorder can be triggered manually via the LHMI or via communication by setting the *Trig recording* parameter to TRUE.

Periodic triggering

Periodic triggering means that the recorder automatically makes a recording at certain time intervals. The user can adjust the interval with the *Periodic trig time* parameter. If the value of the parameter is changed, the new setting takes effect when the next periodic triggering occurs. Setting the parameter to zero disables the triggering alternative and the setting becomes valid immediately. If a new non-zero setting needs to be valid immediately, the user should first set the *Periodic trig time* parameter to zero and then to the new value. The user can monitor the time remaining to the next triggering with the `Time to trigger` monitored data which counts downwards.

Periodic triggering feature is intended to be used temporarily for a short-time to record certain network conditions, when other triggering modes cannot be used. Continuous use of periodic triggering is forbidden as it may degrade flash memory life due to continuous frequent write operations.

8.2.1.3 Length of recordings

The user can define the length of a recording with the *Record length* parameter. The length is given as the number of fundamental cycles.

According to the memory available and the number of analog channels used, the disturbance recorder automatically calculates the remaining amount of recordings that fit into the available recording memory. The user can see this information with the Rem. amount of rec monitored data. The fixed memory size allocated for the recorder can fit in two recordings that are ten seconds long. The recordings contain data from all analog and binary channels of the disturbance recorder, at the sample rate of 32 samples per fundamental cycle.

The user can view the number of recordings currently in memory with the Number of recordings monitored data. The currently used memory space can be viewed with the Rec. memory used monitored data. It is shown as a percentage value.

The maximum number of recordings is 100.

8.2.1.4 Sampling frequencies

The sampling frequency of the disturbance recorder analog channels depends on the set rated frequency. One fundamental cycle always contains the amount of samples set with the *Storage rate* parameter. Since the states of the binary channels are sampled once per task execution of the disturbance recorder, the sampling frequency of binary channels is 400 Hz at the rated frequency of 50 Hz and 480 Hz at the rated frequency of 60 Hz.

Table 947: Sampling frequencies of the disturbance recorder analog channels

Storage rate (samples per fundamental cycle)	Recording length	Sampling frequency of analog channels, when the rated frequency is 50 Hz	Sampling frequency of binary channels, when the rated frequency is 50 Hz	Sampling frequency of analog channels, when the rated frequency is 60 Hz	Sampling frequency of binary channels, when the rated frequency is 60 Hz
32	1* Record length	1600 Hz	400 Hz	1920 Hz	480 Hz
16	2* Record length	800 Hz	400 Hz	960 Hz	480 Hz
8	4 * Record length	400 Hz	400 Hz	480 Hz	480 Hz

8.2.1.5 Uploading of recordings

The protection relay stores COMTRADE files to the C:\COMTRADE\ folder. The files can be uploaded with the PCM600 or any appropriate computer software that can access the C:\COMTRADE\ folder.

One complete disturbance recording consists of two COMTRADE file types: the configuration file and the data file. The file name is the same for both file types. The configuration file has .CFG and the data file .DAT as the file extension.

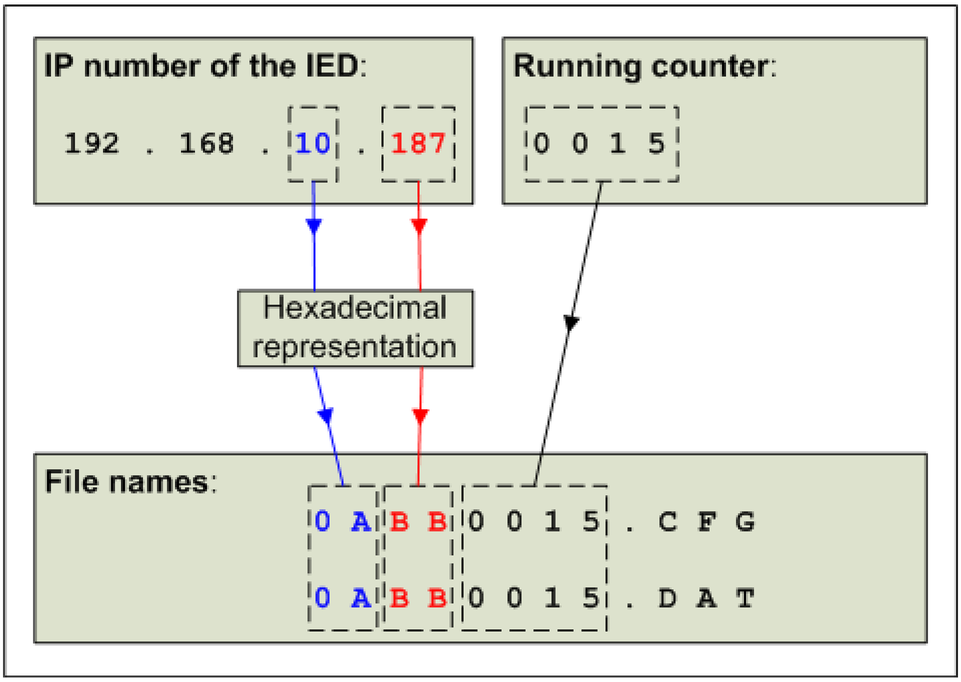


Figure 510: Disturbance recorder file naming

The naming convention of 8+3 characters is used in COMTRADE file naming. The file name is composed of the last two octets of the protection relay's IP number and a running counter, which has a range of 1...9999. A hexadecimal representation is used for the IP number octets. The appropriate file extension is added to the end of the file name.

8.2.1.6 Deletion of recordings

There are several ways to delete disturbance recordings. The recordings can be deleted individually or all at once.

Individual disturbance recordings can be deleted with PCM600 or any appropriate computer software, which can access the protection relay's C:\COMTRADE folder. The disturbance recording is not removed from the protection relay's memory until both of the corresponding COMTRADE files, .CFG and .DAT, are deleted. The user may have to delete both of the files types separately, depending on the software used.

Deleting all disturbance recordings at once is done either with PCM600 or any appropriate computer software, or from the LHMI via the **Clear** > **Disturbance records** menu. Deleting all disturbance recordings at once also clears the pre-trigger recording in progress.

8.2.1.7 Storage mode

The disturbance recorder can capture data in two modes: waveform and trend mode. The user can set the storage mode individually for each trigger source with the *Storage mode* parameter of the corresponding analog channel or binary channel, the *Stor. mode manual* parameter for manual trigger and the *Stor. mode periodic* parameter for periodic trigger.

In the waveform mode, the samples are captured according to the *Storage rate* and *Pre-trg length* parameters.

In the trend mode, one value is recorded for each enabled analog channel, once per fundamental cycle. The recorded values are RMS values, which are scaled to peak level. The binary channels of the disturbance recorder are also recorded once per fundamental cycle in the trend mode.

Only post-trigger data is captured in trend mode.

The trend mode enables recording times of 32 * *Record length*.

8.2.1.8 Pre-trigger and post-trigger data

The waveforms of the disturbance recorder analog channels and the states of the disturbance recorder binary channels are constantly recorded into the history memory of the recorder. The user can adjust the percentage of the data duration preceding the triggering, that is, the so-called pre-trigger time, with the *Pre-trg length* parameter. The duration of the data following the triggering, that is, the so-called post-trigger time, is the difference between the recording length and the pre-trigger time. Changing the pre-trigger time resets the history data and the current recording under collection.

8.2.1.9 Operation modes

Disturbance recorder has two operation modes: saturation and overwrite mode. The user can change the operation mode of the disturbance recorder with the *Operation mode* parameter.

Saturation mode

In saturation mode, the captured recordings cannot be overwritten with new recordings. Capturing the data is stopped when the recording memory is full, that is, when the maximum number of recordings is reached. In this case, the event is sent via the state change (TRUE) of the *Memory full* parameter. When there is memory available again, another event is generated via the state change (FALSE) of the *Memory full* parameter.

Overwrite mode

When the operation mode is "Overwrite" and the recording memory is full, the oldest recording is overwritten with the pre-trigger data collected for the next recording. Each time a recording is overwritten, the event is generated via the state change of the *Overwrite of rec.* parameter. The overwrite mode is recommended, if it is more important to have the latest recordings in the memory. The saturation mode is preferred, when the oldest recordings are more important.

New triggerings are blocked in both the saturation and the overwrite mode until the previous recording is completed. On the other hand, a new triggering can be accepted before all pre-trigger samples are collected for the new recording. In such a case, the recording is as much shorter as there were pre-trigger samples lacking.

8.2.1.10 Exclusion mode

Exclusion mode is on, when the value set with the *Exclusion time* parameter is higher than zero. During the exclusion mode, new triggerings are ignored if the triggering reason is the same as in the previous recording. The *Exclusion time* parameter controls how long the exclusion of triggerings of same type is active after a triggering. The exclusion mode only applies to the analog and binary channel triggerings, not to periodic and manual triggerings.

When the value set with the *Exclusion time* parameter is zero, the exclusion mode is disabled and there are no restrictions on the triggering types of the successive recordings.

The exclusion time setting is global for all inputs, but there is an individual counter for each analog and binary channel of the disturbance recorder, counting the remaining exclusion time. The user can monitor the remaining exclusion time with the *Exclusion time rem* parameter (only visible via communication, IEC 61850 data ExclTmRmn) of the corresponding analog or binary channel. The *Exclusion time rem* parameter counts downwards.

8.2.2 Configuration

The disturbance recorder can be configured with PCM600 or any tool supporting the IEC 61850 standard.

The disturbance recorder can be enabled or disabled with the *Operation* parameter under the **Configuration** > **Disturbance recorder** > **General** menu.

One analog signal type of the protection relay can be mapped to each of the analog channels of the disturbance recorder. The mapping is done with the *Channel selection* parameter of the corresponding analog channel. The name of the analog channel is user-configurable. It can be modified by writing the new name to the *Channel id text* parameter of the corresponding analog channel.

Any external or internal digital signal of the protection relay which can be dynamically mapped can be connected to the binary channels of the disturbance recorder. These signals can be, for example, the start and trip signals from protection function blocks or the external binary inputs of the protection relay. The connection is made with dynamic mapping to the binary channel of the disturbance recorder using, for example, SMT of PCM600. It is also possible to connect several digital signals to one binary channel of the disturbance recorder. In that case, the signals can be combined with logical functions, for example AND and OR. The name of the binary channel can be configured and modified by writing the new name to the *Channel id text* parameter of the corresponding binary channel.

Note that the *Channel id text* parameter is used in COMTRADE configuration files as a channel identifier.

The recording always contains all binary channels of the disturbance recorder. If one of the binary channels is disabled, the recorded state of the channel is continuously FALSE and the state changes of the corresponding channel are not recorded.
The corresponding channel name for disabled binary channels in the COMTRADE configuration file is Unused BI.

To enable or disable an analog or a binary channel of the disturbance recorder, the *Operation* parameter of the corresponding analog or binary channel is set to "on" or "off".

The states of manual triggering and periodic triggering are not included in the recording, but they create a state change to the *Periodic triggering* and *Manual triggering* status parameters, which in turn create events.

The TRIGGERED output can be used to control the indication LEDs of the protection relay. The TRIGGERED output is TRUE due to the triggering of the disturbance recorder, until all the data for the corresponding recording has been recorded.

The IP number of the protection relay and the content of the *Bay name* parameter are both included in the COMTRADE configuration file for identification purposes.

8.2.3 Application

The disturbance recorder is used for post-fault analysis and for verifying the correct operation of protection relays and circuit breakers. It can record both analog and binary signal information. The analog inputs are recorded as instantaneous values and converted to primary peak value units when the protection relay converts the recordings to the COMTRADE format.

COMTRADE is the general standard format used for storing disturbance recordings.

The binary channels are sampled once per task execution of the disturbance recorder. The task execution interval for the disturbance recorder is the same as for the protection functions. During the COMTRADE conversion, the digital status values are repeated so that the sampling frequencies of the analog and binary channels correspond to each other. This is required by the COMTRADE standard.

The disturbance recorder follows the 1999 version of the COMTRADE standard and uses the binary data file format.

8.2.4 Settings

Table 948: RDRE Non-group general settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off		1	1=on	Disturbance recorder on/off
Record length	10...500	fundamental cycles	1	50	Size of the recording in fundamental cycles
Pre-trg length	0...100	%	1	50	Length of the recording preceding the triggering

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	1=Saturation 2=Overwrite		1	1	Operation mode of the recorder
Exclusion time	0...1 000 000	ms	1	0	The time during which triggerings of same type are ignored
Storage rate	32, 16, 8	samples per fundamental cycle		32	Storage rate of the waveform recording
Periodic trig time	0...604 800	s	10	0	Time between periodic triggerings
Stor. mode periodic	0=Waveform 1=Trend / cycle		1	0	Storage mode for periodic triggering
Stor. mode manual	0=Waveform 1=Trend / cycle		1	0	Storage mode for manual triggering

Table 949: RDRE Non-group channel settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off		1	1=on	Analog channel is enabled or disabled
Channel selection	0=Disabled 1=Io 2=IL1 3=IL2 4=IL3 5=IoB 6=IL1B 7=IL2B 8=IL3B 9=Uo 10=U1 11=U2		0	0=Disabled	Select the signal to be recorded by this channel. Applicable values for this parameter are product variant dependent. Every product variant includes only the values that are applicable to that particular variant

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	12=U3 13=UoB 14=U1B 17=CIo 18=SI1 [1] 19=SI2 [1] 20=SU0 21=SU1 [1] 22=SU2 [1] 23=CIoB 24=SI1B [1] 25=SI2B [1] 52=U1C				
Channel id text	0 to 64 characters, alphanumeric			DR analog channel X	Identification text for the analog channel used in the COMTRADE format
High trigger level	0.00...60.00	pu	0.01	10.00	High trigger level for the analog channel
Low trigger level	0.00...2.00	pu	0.01	0.00	Low trigger level for the analog channel
Storage mode	0=Waveform 1=Trend / cycle		1	0	Storage mode for the analog channel

[1] Recordable values are available only in trend mode. In waveform mode, samples for this signal type are constant zeroes. However, these signal types can be used to trigger the recorder on limit violations of the corresponding analog channel.

Table 950: RDRE Non-group binary channel settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off		1	5=off	Binary channel is enabled or disabled
Level trigger mode	1=Positive or Rising 2=Negative or Falling 3=Both 4=Level trigger off		1	1=Rising	Level trigger mode for the binary channel
Storage mode	0=Waveform 1=Trend / cycle		1	0	Storage mode for the binary channel
Channel id text	0 to 64 characters, alphanumeric			DR binary channel X	Identification text for the analog channel used in the COMTRADE format

Table 951: RDRE Control data

Parameter	Values (Range)	Unit	Step	Default	Description
Trig recording	0=Cancel 1=Trig				Trigger the disturbance recording
Clear recordings	0=Cancel 1=Clear				Clear all recordings currently in memory

8.2.5 Monitored data

Table 952: RDRE Monitored data

Parameter	Values (Range)	Unit	Step	Default	Description
Number of recordings	0...100				Number of recordings cur-

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
					rently in memory
Rem. amount of rec.	0...100				Remaining amount of recordings that fit into the available recording memory, when current settings are used
Rec. memory used	0...100	%			Storage mode for the binary channel
Time to trigger	0...604 800	s			Time remaining to the next periodic triggering

8.2.6 Technical revision history

Table 953: RDRE Technical revision history

Technical revision	Change
B	ChNum changed to EChNum (RADR's) RADR9...12 added (Analog channels 9...12) RBDR33...64 added (Binary channels 33...64)
C	New channels added to parameter *Channel selection* Selection names for *Trig Recording* and *Clear Recordings updated*
D	Symbols in the *Channel selection* setting are updated
E	New channels IL1C, IL2C and IL3C added to *Channel selection* parameter
F	Internal improvement
G	Internal improvement

8.3 Tap changer position indicator TPOSYLTC

8.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Tap changer position indication	TPOSYLTC	TPOSM	84M

8.3.2 Function block

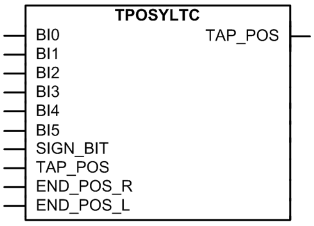


Figure 511: Function block

8.3.3 Functionality

The tap changer position indication function TPOSYLTC is used for transformer tap position supervision. The binary inputs can be used for converting a binary-coded tap changer position to a tap position status indication. The X130 (RTD) card, available as an option, provides the RTD sensor information to be used and the versatile analog inputs enabling the tap position supervision through mA.

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.

8.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off". When the function is disabled, the tap position quality information is changed accordingly. When the tap position information is not available, it is recommended to disable this function with the *Operation* setting.

The operation of TPOSYLTC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

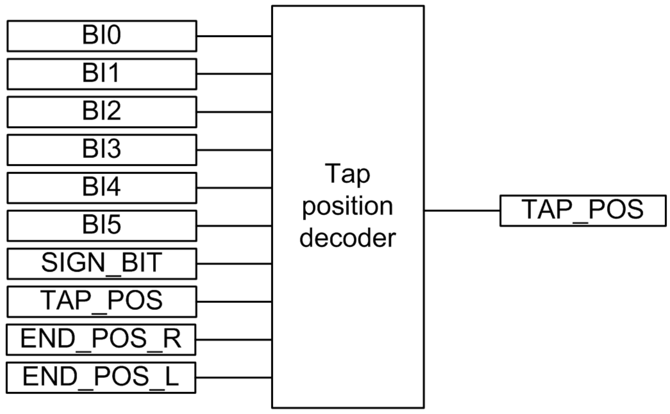


Figure 512: Functional module diagram

Tap position decoder

When there is a wired connection to the TAP_POS input connector, the corresponding tap changer position is decoded from the mA or RTD input. 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 tap changer position value and quality are internally shared to other functions. The value is available in the Monitored data view or as a TAP_POS output signal.

The function has three alternative user selectable operation modes: "NAT2INT", "BCD2INT" and "GRAY2INT". The operation mode is selected with the *Operation mode* setting. Each operation mode can be used to convert a maximum of 6–bit coded input to an 8–bit signed short integer output. For less than 6–bit input, for example 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 "NAT2INT" 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). The LSB has the factor 1. Each following bit has the previous factor multiplied by 2. This is also called dual coding.

The operation mode "BCD2INT" is selected when the binary-coded decimal coding is used for showing the position of the transformer tap changer. The basic principle with 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 output validity is regarded as bad.

The operation mode “GRAY2INT” 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 positions. 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 is set to FALSE (0). If the 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 is set to good in all valid cases. The quality is set to bad in invalid combinations in the binary inputs. For example, when the “BCD2INT” mode is selected and the input binary combination is “0001101”, the quality is set to bad. For negative values, when the SIGN_BIT is set to TRUE (1) and the input binary combination is “1011011”, the quality is set to bad.

If the tap changer has auxiliary contacts for indicating the extreme positions of the tap changer, their status can be connected to END_POS_R and END_POS_L inputs. The END_POS_R (End position raise or highest allowed tap position reached) status refers to the extreme position that results in the highest number of the taps in the tap changer. Similarly, END_POS_L (End position lower or lowest allowed tap position reached) status refers to the extreme position that results in the lowest number of the taps in the tap changer. TAP_POS output is dedicated for transferring the validated tap position for the functions that need tap position information, for example OLATCC and TRxPTDF. It includes both the actual position information and the status of reached end positions, assuming that inputs END_POS_R and END_POS_L are connected.

Table 954: Truth table of the decoding modes

Inputs							TAP_POS outputs		
SIGN_BIT	BI5	BI4	BI3	BI2	BI1	BI0	NAT2INT	BCD2INT	GRAY2INT
...		...		...		...	...	...	...
1	0	0	0	0	1	1	-3	-3	-2
1	0	0	0	0	1	0	-2	-2	-3
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

Table continues on the next page

Inputs							TAP_POS outputs		
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
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
...		...		...		...	...	...	...

8.3.5 Application

TPOSYLTC 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 are 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 input 1 (AI_VAL1) of the X130 (RTD) card. 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 XRGGIO130. Since the values of the XRGGIO130 outputs are floating point numbers, the float to integer (T_F32_INT8) conversion is needed before the tap position information can be fed to TPOSYLTC. When there is a wired connection to the TAP_POS connector, the validated tap changer position is presented in the TAP_POS output that is connected 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.

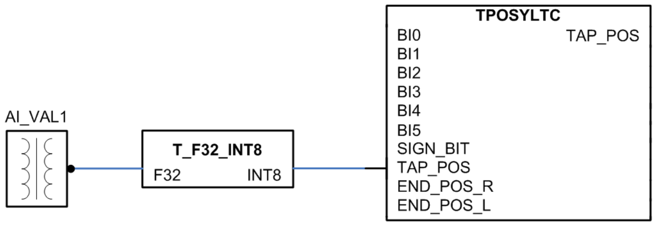


Figure 513: RTD/analog input configuration example

8.3.6 Signals

Table 955: TPOSYLTC Input signals

Name	Type	Default	Description
BI0	BOOLEAN	0=False	Binary input 1
BI1	BOOLEAN	0=False	Binary input 2
BI2	BOOLEAN	0=False	Binary input 3
BI3	BOOLEAN	0=False	Binary input 4
BI4	BOOLEAN	0=False	Binary input 5
BI5	BOOLEAN	0=False	Binary input 6
SIGN_BIT	BOOLEAN	0=False	Binary input sign bit
END_POS_R	BOOLEAN	0=False	End position raise or highest allowed tap position reached
END_POS_L	BOOLEAN	0=False	End position lower or lowest allowed tap position reached
TAP_POS	INT8	0	Tap position indication

Table 956: TPOSYLTC Output signals

Name	Type	Description
TAP_POS	INT8	Tap position indication

8.3.7 Settings

Table 957: TPOSYLTC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=NAT2INT 2=BCD2INT 3=GRAY2INT			2=BCD2INT	Operation mode selection

8.3.8 Monitored data

Table 958: TPOSYLTC Monitored data

Name	Type	Values (Range)	Unit	Description
TAP_POS	INT8	-63...63		Tap position indication

8.3.9 Technical data

Table 959: TPOSYLTC Technical data

Description	Value
Response time for binary inputs	Typical 100 ms

8.3.10 Technical revision history

Table 960: TPOSYLTC Technical revision history

Technical revision	Change
B	Added new input `TAP_POS`
C	Internal improvement
D	Added new inputs `END_TPOS_R` and `END_TPOS_L` Added a new output `TAP_POS`

9 Control functions

9.1 Circuit breaker control CBXCBR, Disconnector control DCXSWI and Earthing switch control ESXSWI

9.1.1 Identification

Function description	**IEC 61850 identification**	**IEC 60617 identification**	**ANSI/IEEE C37.2 device number**
Circuit breaker control	CBXCBR	I<->O CB	I<->O CB
Disconnector control	DCXSWI	I<->O DCC	I<->O DCC
Earthing switch control	ESXSWI	I<->O ESC	I<->O ESC

9.1.2 Function block

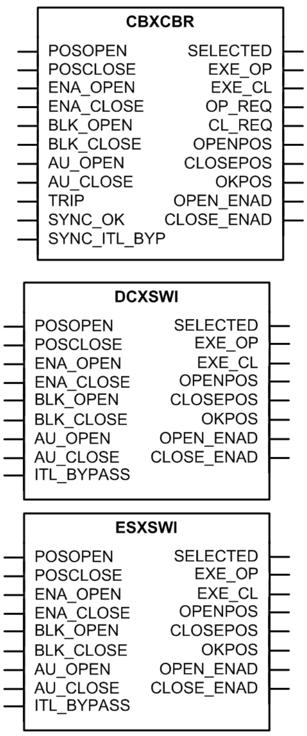


Figure 514: Function block

9.1.3 Functionality

CBXCBR, DCXSWI and ESXSWI are intended for circuit breaker, disconnector and earthing switch control and status information purposes. These functions execute commands and evaluate block conditions and different time supervision conditions. The functions perform an execution command only if all conditions indicate that a switch operation is allowed. If erroneous conditions occur, the functions indicate an appropriate cause value. The functions are designed according to the IEC 61850-7-4 standard with logical nodes CILO, CSWI and XSWI/XCBR.

The circuit breaker, disconnector and earthing switch control functions have an operation counter for closing and opening cycles. The counter value can be read and written remotely from the place of operation or via LHMI.

9.1.4 Operation principle

Status indication and validity check

The object state is defined by two digital inputs, POSOPEN and POSCLOSE, which are also available as outputs OPENPOS and CLOSEPOS together with the OKPOS according to *Table 961*. The debouncing and short disturbances in an input are eliminated by filtering. The binary input filtering time can be adjusted separately for each digital input used by the function block. The validity of the digital inputs that indicate the object state is used as additional information in indications and event logging. The reporting of faulty or intermediate position of the apparatus occurs after the *Event delay* setting, assuming that the circuit breaker is still in a corresponding state.

Table 961: Status indication

Input		Status	Output		
POSOPEN	POSCLOSE	POSITION (Monitored data)	OKPOS	OPENPOS	CLOSEPOS
1=True	0=False	1=Open	1=True	1=True	0=False
0=False	1=True	2=Closed	1=True	0=False	1=True
1=True	1=True	3=Faulty/Bad (11)	0=False	0=False	0=False
0=False	0=False	0=Intermedi-ate (00)	0=False	0=False	0=False

Enabling and blocking

CBXCBR, DCXSWI and ESXSWI have an enabling and blocking functionality for interlocking and synchrocheck purposes.

Circuit breaker control CBXCBR

Normally, the CB closing is enabled (that is, CLOSE_ENAD signal is TRUE) by activating both ENA_CLOSE and SYNC_OK inputs. Typically, the ENA_CLOSE comes from the interlocking, and SYNC_OK comes from the synchronism and energizing check. The input SYNC_ITL_BYP can be used for bypassing this control. The SYNC_ITL_BYP input can be used to activate CLOSE_ENAD discarding the ENA_CLOSE and SYNC_OK input states. However, the BLK_CLOSE input always blocks the CLOSE_ENAD output.

The CB opening (OPEN_ENAD) logic is the same as CB closing logic, except that SYNC_OK is used only in closing. The SYNC_ITL_BYP input is used in both CLOSE_ENAD and OPEN_ENAD logics.

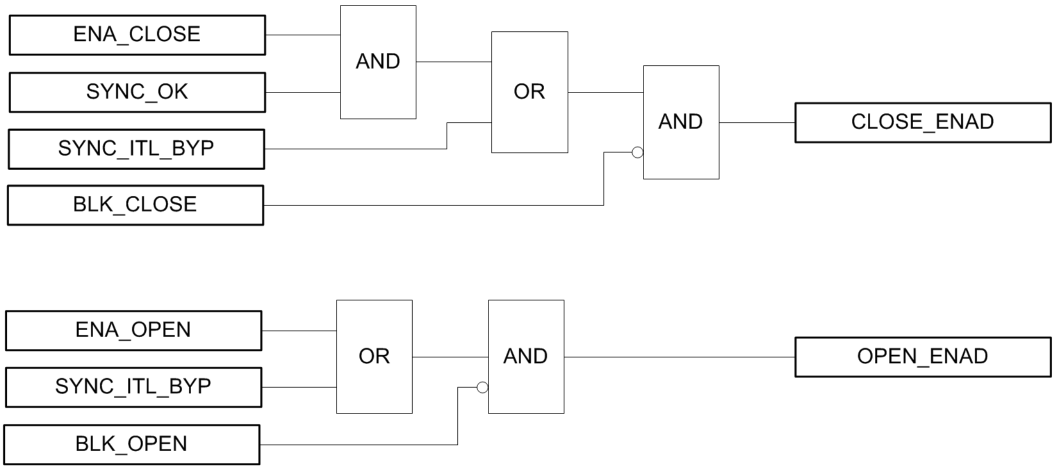


Figure 515: Enabling and blocking logic for CLOSE_ENAD and OPEN_ENAD signals

Opening and closing operations

The opening and closing operations are available via communication, binary inputs or LHMI commands. As a prerequisite for control commands, there are enabling and blocking functionalities for both opening and closing commands (CLOSE_ENAD and OPEN_ENAD signals). If the control command is executed against the blocking or if the enabling of the corresponding command is not valid, CBXCBR, DCXSWI and ESXSWI generate an error message.

When close command is given from communication, via LHMI or activating the AU_CLOSE input, it is carried out (the EXE_CL output) only if CLOSE_ENAD is TRUE.

If the SECRSYN function is used in “Command” mode, the CL_REQ output can be used in CBXCBR. Initially, the SYNC_OK input is FALSE. When the close command given, it activates the CL_REQ output, which should be routed to SECRSYN. The close command is then processed only after SYNC_OK is received from SECRSYN.

When using SECRSYN in the “Command” mode, the CBXCBR setting *Operation timeout* should be set longer than SECRSYN setting *Maximum Syn time*.

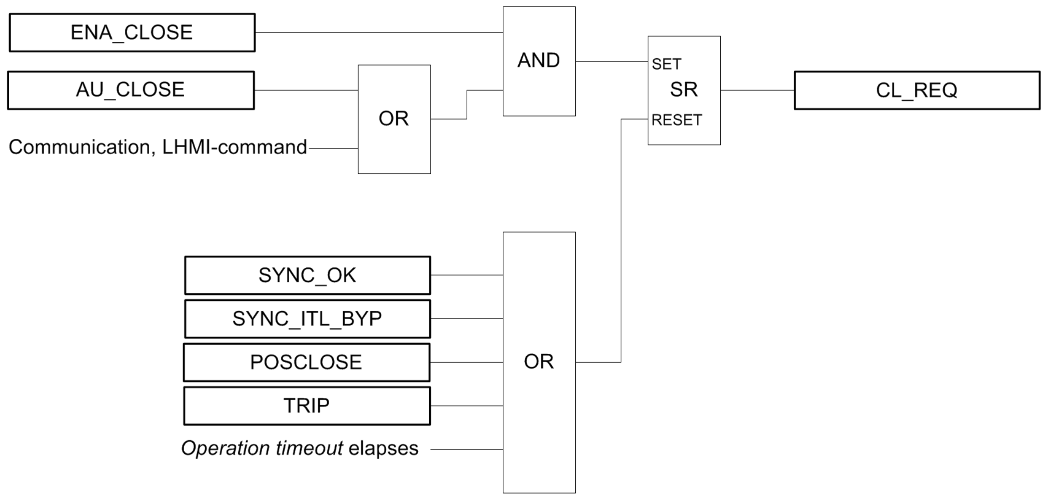


Figure 516: Condition for enabling the close request (CL_REQ) for CBXCBR

When the open command is given from communication, via LHMI or activating the `AU_OPEN` input, it is processed only if `OPEN_ENAD` is TRUE. `OP_REQ` output is also available.

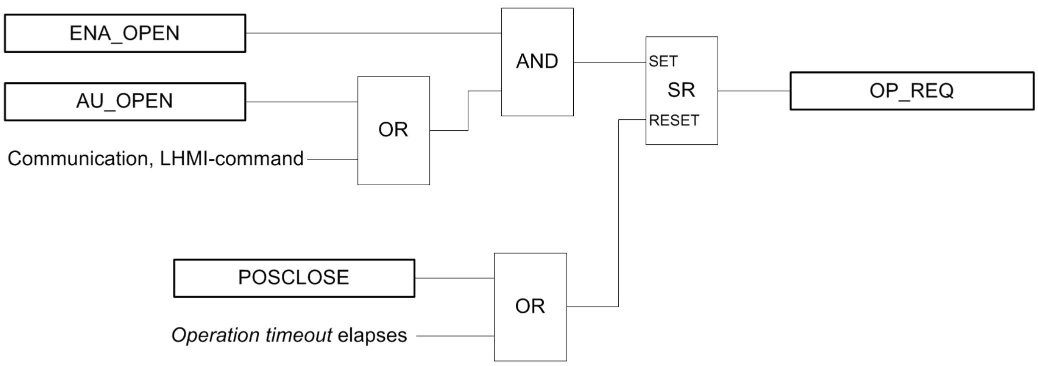


Figure 517: Condition for enabling the open request (OP_REQ) for CBXCBR

OPEN and CLOSE outputs

The `EXE_OP` output is activated when the open command is given (`AU_OPEN`, via communication or from LHMI) and `OPEN_ENAD` signal is TRUE. In addition, the protection trip commands can be routed through the CBXCBR function by using the `TRIP` input. When the `TRIP` input is TRUE, the `EXE_OP` output is activated immediately and bypassing all enabling or blocking conditions.

The `EXE_CL` output is activated when the close command is given (`AU_CLOSE`, via communication or from LHMI) and `CLOSE_ENAD` signal is TRUE. When the `TRIP` input is "TRUE", CB closing is not allowed.

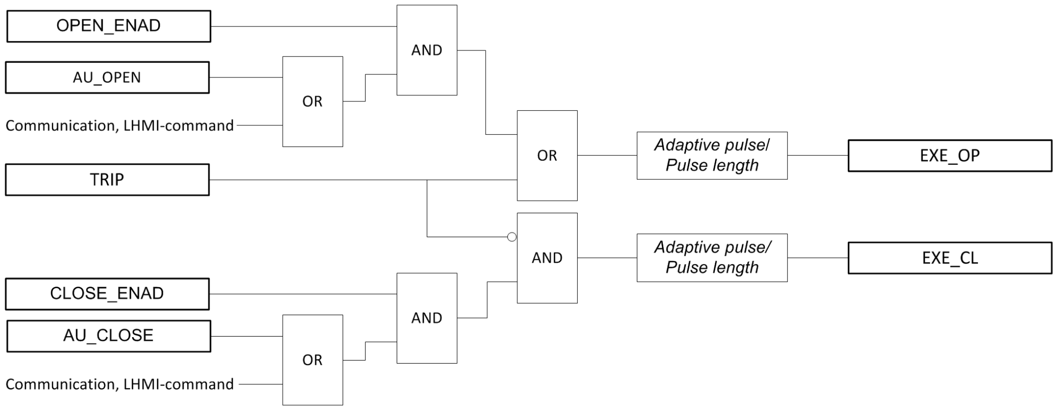


Figure 518: OPEN and CLOSE outputs logic for CBXCBR

Opening and closing pulse widths

The pulse width type can be defined with the *Adaptive pulse* setting. The function provides two modes to characterize the opening and closing pulse widths. When the *Adaptive pulse* is set to “TRUE”, it causes a variable pulse width, which means that the output pulse is deactivated when the object state shows that the apparatus has entered the correct state. If apparatus fails to enter the correct state, the output pulse is deactivated after the set *Operation timeout* setting, and an error message is displayed. When the *Adaptive pulse* is set to “FALSE”, the functions always use the maximum pulse width, defined by the user-configurable *Pulse length* setting. The *Pulse length* setting is the same for both the opening and closing commands. When the apparatus already is in the right position, the maximum pulse length is given.

The *Pulse length* setting does not affect the length of the trip pulse.

Control methods

The command execution mode can be set with the *Control model* setting. The alternatives for command execution are direct control and secured object control, which can be used to secure controlling.

The secured object control SBO is an important feature of the communication protocols that support horizontal communication, because the command reservation and interlocking signals can be transferred with a bus. All secured control operations require two-step commands: a selection step and an execution step. The secured object control is responsible for the several tasks.

- Command authority: ensures that the command source is authorized to operate the object
- Mutual exclusion: ensures that only one command source at a time can control the object
- Interlocking: allows only safe commands
- Execution: supervises the command execution
- Command canceling: cancels the controlling of a selected object.

In direct operation, a single message is used to initiate the control action of a physical device. The direct operation method uses less communication network capacity and bandwidth than the SBO method, because the procedure needs fewer messages for accurate operation.

The “status-only” mode means that control is not possible (non-controllable) via communication or from LHMI. However, it is possible to control a disconnector (DCXSWI) from AU_OPEN and AU_CLOSE inputs.

AU_OPEN and AU_CLOSE control the object directly regardless of the set *Control model*. These inputs can be used when control is wanted to be implemented purely based on ACT logic and no additional exception handling is needed. However, in case of simultaneous open and close control, the open control is always prioritized.

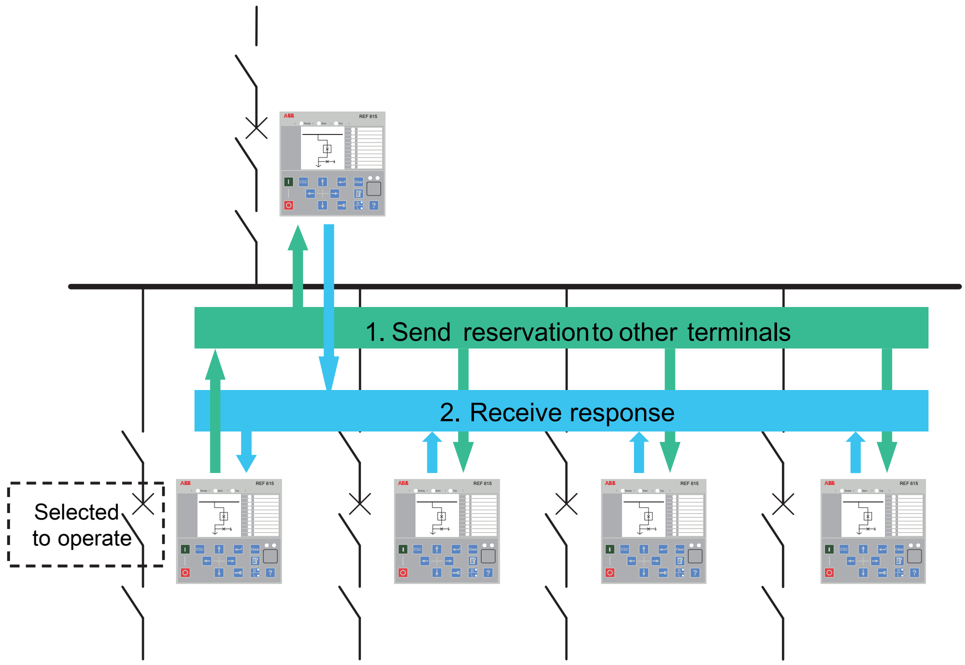


Figure 519: Control procedure in the SBO method

Local/Remote operations

The local/remote selection affects CBXCBR, DCXSWI and ESXSWI.

- Local: the opening and closing via communication is disabled.
- Remote: the opening and closing via LHMI is disabled.
- AU_OPEN and AU_CLOSE inputs function regardless of the local/remote selection.

9.1.5 Application

In the field of distribution and sub-transmission automation, reliable control and status indication of primary switching components both locally and remotely is in a significant role. They are needed especially in modern remotely controlled substations.

Control and status indication facilities are implemented in the same package with CBXCBR, DCXSWI and ESXSWI. When primary components are controlled in the energizing phase, for example, the correct execution sequence of the control commands must be ensured. This can be achieved, for example, with interlocking based on the status indication of the related primary components. The interlocking on substation level can be applied using the IEC 61850 GOOSE messages between feeders.

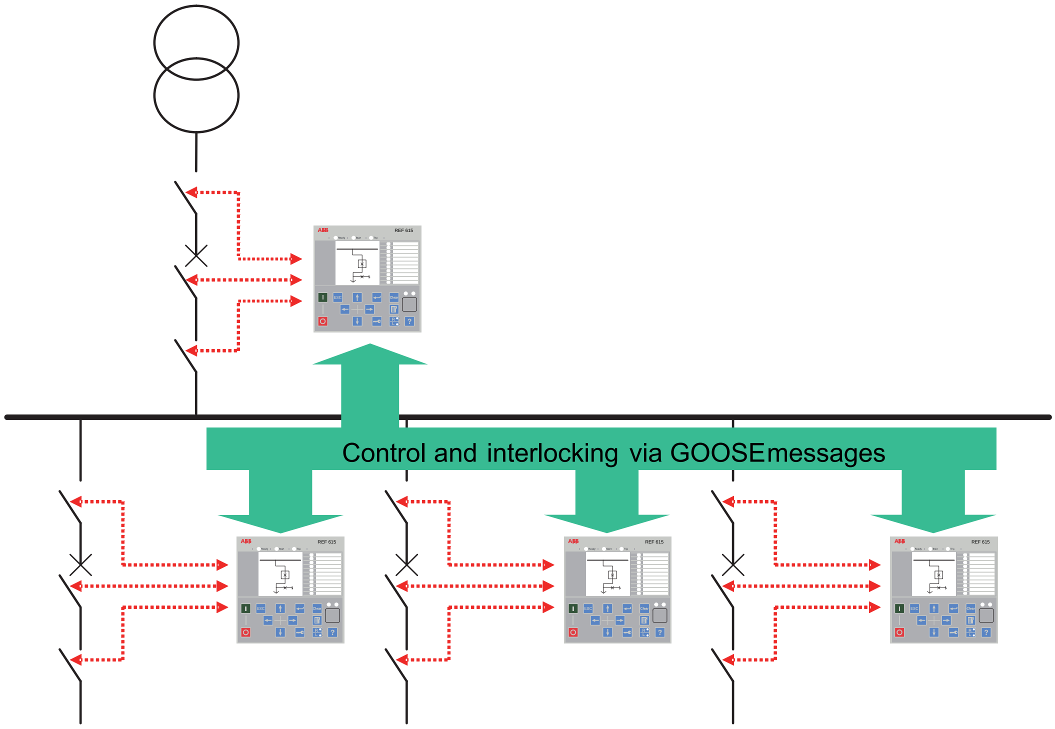


Figure 520: Status indication-based interlocking via the GOOSE messaging

9.1.6 Signals

Table 962: CBXCBR Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for close position of apparatus from I/O
ENA_OPEN	BOOLEAN	1=True	Enables opening
ENA_CLOSE	BOOLEAN	1=True	Enables closing
BLK_OPEN	BOOLEAN	0=False	Blocks opening
BLK_CLOSE	BOOLEAN	0=False	Blocks closing
AU_OPEN	BOOLEAN	0=False	Auxiliary open [1], [2]
AU_CLOSE	BOOLEAN	0=False	Auxiliary close [1], [2]
TRIP	BOOLEAN	0=False	Trip signal

Table continues on the next page

1 Not available for monitoring
2 Always direct operation

Name	Type	Default	Description
SYNC_OK	BOOLEAN	1=True	Synchronism-check OK
SYNC_ITL_BYP	BOOLEAN	0=False	Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE

Table 963: DCXSWI Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Apparatus open position
POSCLOSE	BOOLEAN	0=False	Apparatus close position
ENA_OPEN	BOOLEAN	1=True	Enables opening
ENA_CLOSE	BOOLEAN	1=True	Enables closing
BLK_OPEN	BOOLEAN	0=False	Blocks opening
BLK_CLOSE	BOOLEAN	0=False	Blocks closing
AU_OPEN	BOOLEAN	0=False	Executes the command for open direction [1], [2]
AU_CLOSE	BOOLEAN	0=False	Executes the command for close direction [1], [2]
ITL_BYPASS	BOOLEAN	0=False	Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE

Table 964: ESXSWI Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Apparatus open position
POSCLOSE	BOOLEAN	0=False	Apparatus close position
ENA_OPEN	BOOLEAN	1=True	Enables opening
ENA_CLOSE	BOOLEAN	1=True	Enables closing
BLK_OPEN	BOOLEAN	0=False	Blocks opening
BLK_CLOSE	BOOLEAN	0=False	Blocks closing
AU_OPEN	BOOLEAN	0=False	Executes the command for open direction [1], [2]
AU_CLOSE	BOOLEAN	0=False	Executes the command for close direction [1], [2]
ITL_BYPASS	BOOLEAN	0=False	Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE

Table 965: CBXCBR Output signals

Name	Type	Description
SELECTED	BOOLEAN	Object selected
EXE_OP	BOOLEAN	Executes the command for open direction

Table continues on the next page

Name	Type	Description
EXE_CL	BOOLEAN	Executes the command for close direction
OP_REQ	BOOLEAN	Open request
CL_REQ	BOOLEAN	Close request
OPENPOS	BOOLEAN	Signal for open position of apparatus from I/O
CLOSEPOS	BOOLEAN	Signal for close position of apparatus from I/O
OKPOS	BOOLEAN	Apparatus position is ok
OPEN_ENAD	BOOLEAN	Opening is enabled based on the input status
CLOSE_ENAD	BOOLEAN	Closing is enabled based on the input status

Table 966: DCXSWI Output signals

Name	Type	Description
SELECTED	BOOLEAN	Object selected
EXE_OP	BOOLEAN	Executes the command for open direction
EXE_CL	BOOLEAN	Executes the command for close direction
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok
OPEN_ENAD	BOOLEAN	Opening is enabled based on the input status
CLOSE_ENAD	BOOLEAN	Closing is enabled based on the input status

Table 967: ESXSWI Output signals

Name	Type	Description
SELECTED	BOOLEAN	Object selected
EXE_OP	BOOLEAN	Executes the command for open direction
EXE_CL	BOOLEAN	Executes the command for close direction
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok
OPEN_ENAD	BOOLEAN	Opening is enabled based on the input status
CLOSE_ENAD	BOOLEAN	Closing is enabled based on the input status

9.1.7 Settings

Table 968: CBXCBR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation mode on/off
Select timeout	10000...300000	ms	10000	30000	Select timeout in ms
Pulse length	10...60000	ms	1	200	Open and close pulse length
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model
Operation timeout	10...60000	ms	1	500	Timeout for negative termination
Identification				CBXCBR1 switch position	Control Object identification

Table 969: CBXCBR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation counter	0...10000		1	0	Breaker operation cycles
Adaptive pulse	0=False 1=True			1=True	Stop in right position
Event delay	0...10000	ms	1	200	Event delay of the intermediate position
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

Table 970: DCXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation mode on/off
Select timeout	10000...300000	ms	10000	30000	Select timeout in ms
Pulse length	10...60000	ms	1	100	Open and close pulse length
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model
Operation timeout	10...60000	ms	1	30000	Timeout for negative termination
Identification				DCXSWI1 switch position	Control Object identification

Table 971: DCXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation counter	0...10000		1	0	Breaker operation cycles
Adaptive pulse	0=False 1=True			1=True	Stop in right position
Event delay	0...60000	ms	1	10000	Event delay of the intermediate position
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

Table 972: ESXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation mode on/off
Select timeout	10000...300000	ms	10000	30000	Select timeout in ms
Pulse length	10...60000	ms	1	100	Open and close pulse length
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model
Operation timeout	10...60000	ms	1	30000	Timeout for negative termination
Identification				ESXSWI1 switch position	Control Object identification

Table 973: ESXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation counter	0...10000		1	0	Breaker operation cycles
Adaptive pulse	0=False 1=True			1=True	Stop in right position
Event delay	0...60000	ms	1	10000	Event delay of the intermediate position
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

9.1.8 Monitored data

Table 974: CBXCBR Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

Table 975: DCXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

Table 976: ESXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

9.1.9 Technical revision history

Table 977: CBXCBR Technical revision history

Technical revision	Change
B	Interlocking bypass input (ITL_BYPASS) and opening enabled (OPEN_ENAD)/closing enabled (CLOSE_ENAD) outputs added. ITL_BYPASS bypasses the ENA_OPEN and ENA_CLOSE states.
C	Internal improvement.
D	Added inputs TRIP and SYNC_OK. Renamed input ITL_BYPASS to SYNC_ITL_BYP. Added outputs CL_REQ and OP_REQ. Outputs OPENPOS and CLOSEPOS are forced to “FALSE” in case status is Faulty (11).

Table 978: DCXSWI Technical revision history

Technical revision	Change
B	Maximum and default values changed to 60 s and 10 s respectively for *Event delay* settings. Default value changed to 30 s for *Operation timeout* setting.
C	Outputs `OPENPOS` and `CLOSEPOS` are forced to "FALSE" in case status is Faulty (11).

Table 979: ESXSWI Technical revision history

Technical revision	Change
B	Maximum and default values changed to 60 s and 10 s respectively for *Event delay* settings. Default value changed to 30 s for *Operation timeout* setting.
C	Outputs `OPENPOS` and `CLOSEPOS` are forced to "FALSE" in case status is Faulty (11).

9.2 Disconnector position indicator DCSXSWI and earthing switch indication ESSXSWI

9.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Disconnector position indication	DCSXSWI	I<->O DC	I<->O DC
Earthing switch indication	ESSXSWI	I<->O ES	I<->O ES

9.2.2 Function block

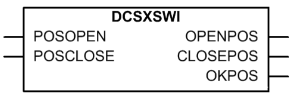


Figure 521: Function block

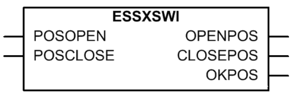


Figure 522: Function block

9.2.3 Functionality

The functions DCSXSWI and ESSXSWI indicate remotely and locally the open, close and undefined states of the disconnector and earthing switch. The functionality of both is identical, but each one is allocated for a specific purpose visible in the function names. For example, the status indication of disconnectors or circuit breaker truck can be monitored with the DCSXSWI function.

The functions are designed according to the IEC 61850-7-4 standard with the logical node XSWI.

9.2.4 Operation principle

Status indication and validity check

The object state is defined by the two digital inputs POSOPEN and POSCLOSE, which are also available as outputs OPENPOS and CLOSEPOS together with the OKPOS according to *Table 980*. The debounces and short disturbances in an input are eliminated by filtering. The binary input filtering time can be adjusted separately for each digital input used by the function block. The validity of digital inputs that indicate the object state is used as additional information in indications and event logging.

Table 980: Status indication

Input		Status	Output		
POSOPEN	**POSCLOSE**	**POSITION (Monitored data)**	**OKPOS**	**OPENPOS**	**CLOSEPOS**
1=True	0=False	1=Open	1=True	1=True	0=False
0=False	1=True	2=Closed	1=True	0=False	1=True
1=True	1=True	3=Faulty/Bad (11)	0=False	0=False	0=False
0=False	0=False	0=Intermediate (00)	0=False	0=False	0=False

9.2.5 Application

In the field of distribution and sub-transmission automation, the reliable control and status indication of primary switching components both locally and remotely is in a significant role. These features are needed especially in modern remote controlled substations. The application area of DCSXSWI and ESSXSWI functions covers remote and local status indication of, for example, disconnectors, air-break switches and earthing switches, which represent the lowest level of power switching devices without short-circuit breaking capability.

9.2.6 Signals

Table 981: DCSXSWI Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O [1]
POSCLOSE	BOOLEAN	0=False	Signal for closed position of apparatus from I/O [1]

Table 982: ESSXSWI Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O [1]
POSCLOSE	BOOLEAN	0=False	Signal for closed position of apparatus from I/O [1]

Table 983: DCSXSWI Output signals

Name	Type	Description
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok

Table 984: ESSXSWI Output signals

Name	Type	Description
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok

[1] Not available for monitoring

9.2.7 Settings

Table 985: DCSXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Identification				DCSXSWI1 switch position	Control Object identification

Table 986: DCSXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Event delay	0...60000	ms	1	30000	Event delay of the intermediate position
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

Table 987: ESSXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Identification				ESSXSWI1 switch position	Control Object identification

Table 988: ESSXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Event delay	0...60000	ms	1	30000	Event delay of the intermediate position
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

9.2.8 Monitored data

Table 989: DCSXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

Table 990: ESSXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

9.2.9 Technical revision history

Table 991: DCSXSWI Technical revision history

Technical revision	Change
B	Maximum and default values changed to 60 s and 30 s respectively for *Event delay* settings.
C	Outputs `OPENPOS` and `CLOSEPOS` are forced to “FALSE” in case status is Faulty (11).

Table 992: ESSXSWI Technical revision history

Technical revision	Change
B	Maximum and default values changed to 60 s and 30 s respectively for *Event delay* settings.
C	Outputs `OPENPOS` and `CLOSEPOS` are forced to “FALSE” in case status is Faulty (11).

9.3 Synchronism and energizing check SECRSYN

9.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Synchronism and energizing check	SECRSYN	SYNC	25

9.3.2 Function block

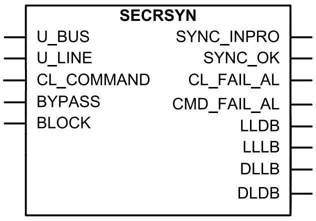


Figure 523: Function block

9.3.3 Functionality

The synchronism and energizing check function SECRSYN checks the condition across the circuit breaker from separate power system parts and gives the permission to close the circuit breaker. SECRSYN includes the functionality of synchrocheck and energizing check.

Asynchronous operation mode is provided for asynchronously running systems. The main purpose of the asynchronous operation mode is to provide a controlled closing of circuit breakers when two asynchronous systems are connected.

The synchrocheck operation mode checks that the voltages on both sides of the circuit breaker are perfectly synchronized. It is used to perform a controlled reconnection of two systems which are divided after islanding and it is also used to perform a controlled reconnection 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.

The function contains a blocking functionality. It is possible to block function outputs and timers.

9.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

SECRSYN has two parallel functionalities, the synchro check and energizing check functionality. The operation of SECRSYN can be described using a module diagram. All the modules in the diagram are explained in the next sections.

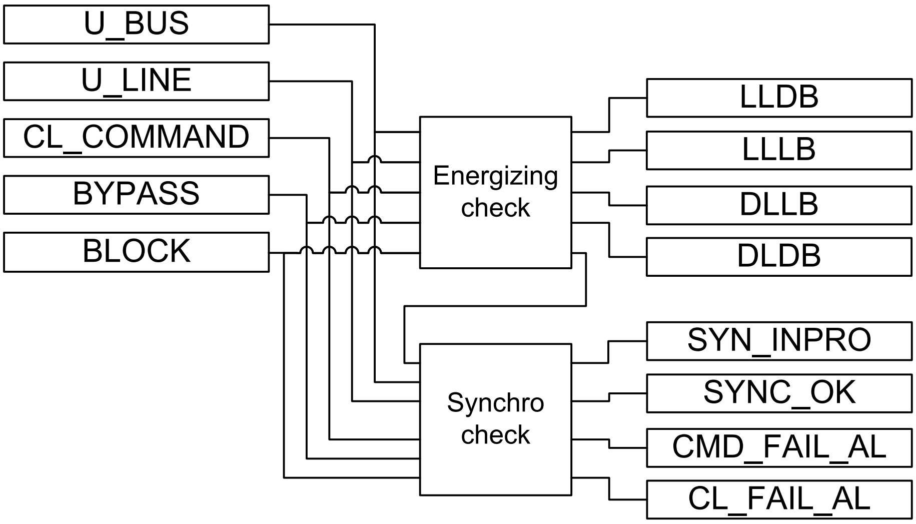


Figure 524: Functional module diagram

If Energizing check is passed, no further conditions need to be fulfilled to permit closing. Otherwise, Synchro check function can operate either with the U_AB or U_A voltages. The selection of used voltages is defined with the *VT connection* setting of the line voltage general parameters.

By default, voltages U_BUS and U_LINE are connected as presented in *Figure 533*. If necessary, connections can be switched by setting *Voltage source switch* to “True”.

Energizing check

The Energizing check function checks the energizing direction. Energizing is defined as a situation where a dead network part is connected to an energized section of the network. The conditions of the network sections to be controlled by the circuit breaker, that is, which side has to be live and which side dead, are determined by the setting. A situation where both sides are dead is possible as well. The actual value for defining the dead line or bus is given with the *Dead bus value* and *Dead line value* settings. Similarly, the actual values of live line or bus are defined with the *Live bus value* and *Live line value* settings.

Table 993: *Live dead mode* of operation under which switching can be carried out

Live dead mode	Description
Both Dead	Both line and bus de-energized
Live L, Dead B	Bus de-energized and line energized
Dead L, Live B	Line de-energized and bus energized
Dead Bus, L Any	Both line and bus de-energized or bus de-energized and line energized
Dead L, Bus Any	Both line and bus de-energized or line de-energized and bus energized

Table continues on the next page

Live dead mode	Description
One Live, Dead	Bus de-energized and line energized or line de-energized and bus energized
Not Both Live	Both line and bus de-energized or bus de-energized and line energized or line de-energized and bus energized

When the energizing direction corresponds to the settings, the situation has to be constant for a time set with the *Energizing time* setting before the circuit breaker closing is permitted. The purpose of this time delay is to ensure that the dead side remains de-energized and also that the situation is not caused by a temporary interference. If the conditions do not persist for a specified operation time, the timer is reset and the procedure is restarted when the conditions allow. The circuit breaker closing is not permitted if the measured voltage on the live side is greater than the set value of *Max energizing V*.

The measured energized state is available as a monitored data value ENERG_STATE and as four function outputs `LLDB` (live line / dead bus), `LLLB` (live line / live bus), `DLLB` (dead line / live bus) and `DLDB` (dead line / dead bus), of which only one can be active at a time. It is also possible that the measured energized state indicates “Unknown” if at least one of the measured voltages is between the limits set with the dead and live setting parameters.

Synchro check

The Synchro check function measures the difference between the line voltage and bus voltage. The function permits the closing of the circuit breaker when certain conditions are simultaneously fulfilled.

- The measured line and bus voltages are higher than the set values of *Live bus value*and *Live line value* (ENERG_STATE equals to "Both Live").
- The measured bus and line frequency are both within the range of 95 to 105 percent of the value of f_n.
- The measured voltages for the line and bus are less than the set value of *Max energizing V*.

In case *Syncro check mode* is set to "Syncronous", the additional conditions must be fulfilled.

- In the synchronous mode, the closing is attempted so that the phase difference at closing is close to zero.
- The synchronous mode is only possible when the frequency slip is below 0.1 percent of the value of f_n.
- The voltage difference must not exceed the 1 percent of the value of U_n.

In case *Syncro check mode* is set to “Asyncronous”, the additional conditions must be fulfilled.

- The measured difference of the voltages is less than the set value of *Difference voltage*.
- The measured difference of the phase angles is less than the set value of *Difference angle*.
- The measured difference in frequency is less than the set value of *Frequency difference*.
- The estimated breaker closing angle is decided to be less than the set value of *Difference angle*.

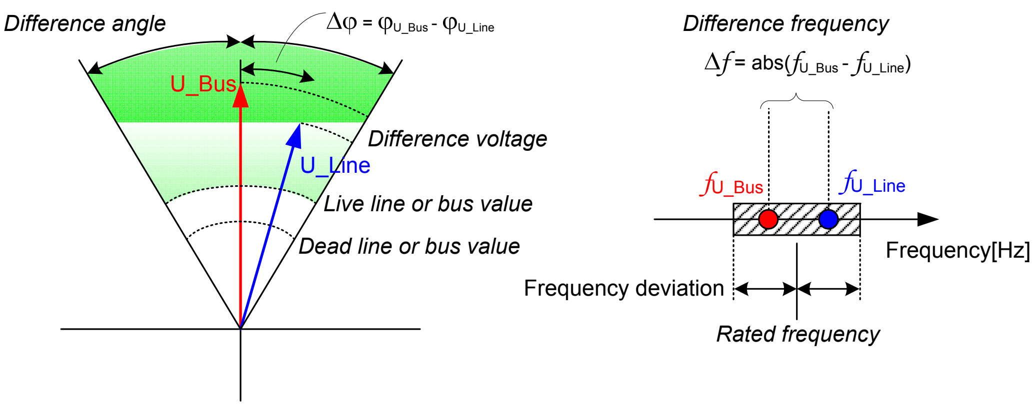


Figure 525: Conditions to be fulfilled when detecting synchronism between systems

When the frequency, phase angle and voltage conditions are fulfilled, the duration of the synchronism conditions is checked so as to ensure that they are still met when the condition is determined on the basis of the measured frequency and phase difference. Depending on the circuit breaker and the closing system, the delay from the moment the closing signal is given until the circuit breaker finally closes is about 50...250 ms. The selected *Closing time of CB* informs the function how long the conditions have to persist. The Synchro check function compensates for the measured slip frequency and the circuit breaker closing delay. The phase angle advance is calculated continuously with the formula.

$$Closing\ angle = \left|(\angle U_{Bus} - \angle U_{Line})^{\circ} + \left((f_{Bus} - f_{line}) \times (T_{CB} + T_{PL}) \times 360^{\circ}\right)\right|$$

(Equation 183)

$\angle U_{Bus}$	Measured bus voltage phase angle
$\angle U_{Line}$	Measured line voltage phase angle
f_{Bus}	Measured bus frequency
f_{line}	Measured line frequency
T_{CB}	Total circuit breaker closing delay, including the delay of the protection relay output contacts defined with the *Closing time of CB* setting parameter value

The closing angle is the estimated angle difference after the breaker closing delay.

The *Minimum Syn time* setting time can be set, if required, to demand the minimum time within which conditions must be simultaneously fulfilled before the SYNC_OK output is activated.

The measured voltage, frequency and phase angle difference values between the two sides of the circuit breaker are available as monitored data values U_DIFF_MEAS, FR_DIFF_MEAS and PH_DIFF_MEAS. Also, the indications of the conditions that are not fulfilled and thus preventing the breaker closing permission are available as monitored data values U_DIFF_SYNC, PH_DIF_SYNC and FR_DIFF_SYNC. These monitored data values are updated only when the Synchro check is enabled with the *Synchro check mode* setting and the measured ENERG_STATE is "Both Live".

Continuous mode

The continuous mode is activated by setting the parameter *Control mode* to "Continuous". In the continuous control mode, Synchro check is continuously checking the synchronism. When synchronism is detected (according to the settings), the SYNC_OK output is set to TRUE (logic '1') and it stays TRUE as long as the conditions are fulfilled. The command input is ignored in the continuous control mode. The mode is used for situations where Synchro check only gives the permission to the control block that executes the CB closing.

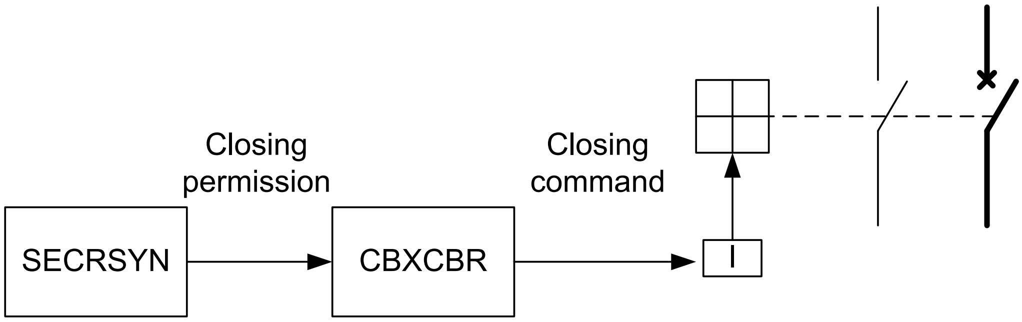


Figure 526: A simplified block diagram of the Synchro check function in the continuous mode operation

Command mode

If *Control mode* is set to "Command", the purpose of the Synchro check functionality in the command mode is to find the instant when the voltages on both sides of the circuit breaker are in synchronism. The conditions for synchronism are met when the voltages on both sides of the circuit breaker have the same frequency and are in phase with a magnitude that makes the concerned busbars or lines such that they can be regarded as live.

In the command mode operation, an external command signal CL_COMMAND, besides the normal closing conditions, is needed for delivering the closing signal. In the command control mode operation, the Synchro check function itself closes the breaker via the SYNC_OK output when the conditions are fulfilled. In this case, the control function block delivers the command signal to close the Synchro check function for the releasing of a closing-signal pulse to the circuit breaker. If the closing conditions are fulfilled during a permitted check time set with *Maximum Syn time*, the Synchro check function delivers a closing signal to the circuit breaker after the command signal is delivered for closing.

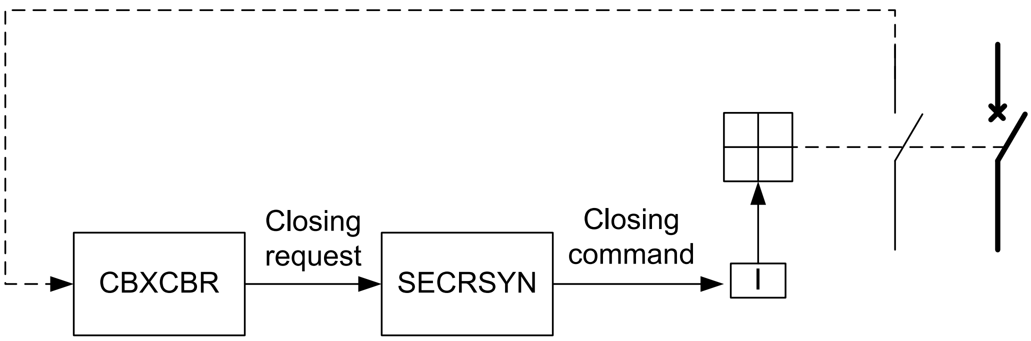


Figure 527: A simplified block diagram of SECRSYN in the command mode operation

The closing signal is delivered only once for each activated external closing command signal. The pulse length of the delivered closing is set with the *Close pulse* setting.

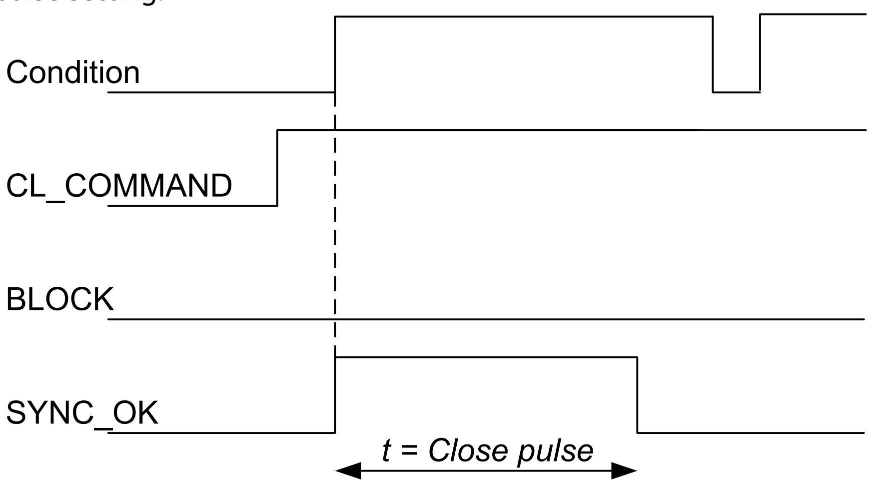


Figure 528: Determination of the pulse length of the closing signal

In the command control mode operation, there are alarms for a failed closing attempt (`CL_FAIL_AL`) and for a command signal that remains active too long (`CMD_FAIL_AL`).

If the conditions for closing are not fulfilled within the set time of *Maximum Syn time*, a failed closing attempt alarm is given. The `CL_FAIL_AL` alarm output signal is pulse-shaped and the pulse length is 500 ms. If the external command signal is removed too early, that is, before conditions are fulfilled and the closing pulse is given, the alarm timer is reset.

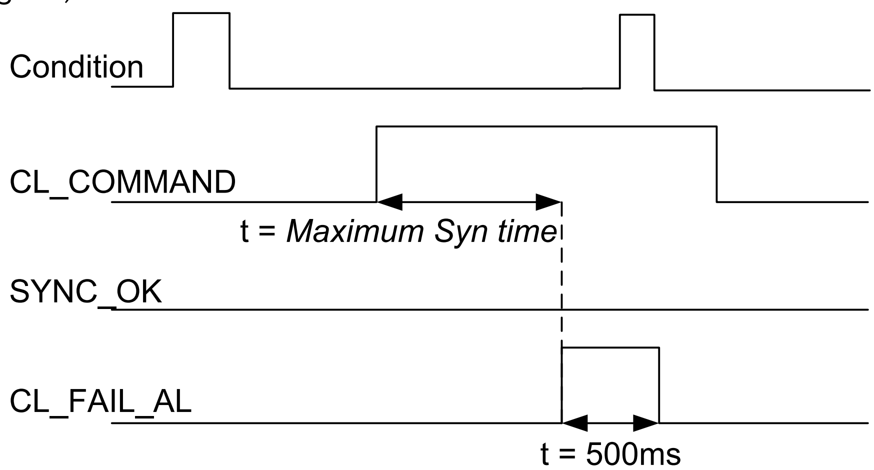


Figure 529: Determination of the checking time for closing

The control module receives information about the circuit breaker status and thus is able to adjust the command signal to be delivered to the Synchro check function. If the external command signal CL_COMMAND is kept active longer than necessary, the `CMD_FAIL_AL` alarm output is activated. The alarm indicates that the control module has not removed the external command signal after the closing operation. To avoid unnecessary alarms, the duration of the command signal should be set in such a way that the maximum length of the signal is always below *Maximum Syn time* + 5s.

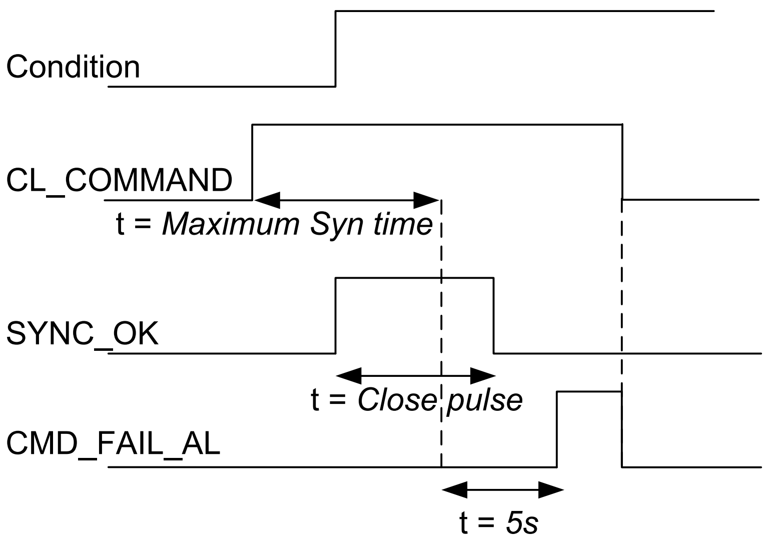


Figure 530: Determination of the alarm limit for a still-active command signal

Closing is permitted during *Maximum Syn time*, starting from the moment the external command signal CL_COMMAND is activated. The CL_COMMAND input must be kept active for the whole time that the closing conditions are waited to be fulfilled. Otherwise, the procedure is cancelled. If the closing-command conditions are fulfilled during *Maximum Syn time*, a closing pulse is delivered to the circuit breaker. If the closing conditions are not fulfilled during the checking time, the alarm CL_FAIL_AL is activated as an indication of a failed closing attempt. The closing pulse is not delivered if the closing conditions become valid after *Maximum Syn time* has elapsed. The closing pulse is delivered only once for each activated external command signal, and a new closing-command sequence cannot be started until the external command signal is reset and reactivated. The SYNC_INPRO output is active when the closing-command sequence is in progress and it is reset when the CL_COMMAND input is reset or *Maximum Syn time* has elapsed.

Bypass mode

SECRSYN can be set to the bypass mode by setting the parameters *Synchrocheck mode* and *Live dead mode* to "Off" or alternatively by activating the BYPASS input.

In the bypass mode, the closing conditions are always considered to be fulfilled by SECRSYN. Otherwise, the operation is similar to the normal mode.

Voltage angle difference adjustment

In application where the power transformer is located between the voltage measurement and the vector group connection gives phase difference to the voltages between the high- and low-voltage sides, the angle adjustment can be used to meet synchronism.

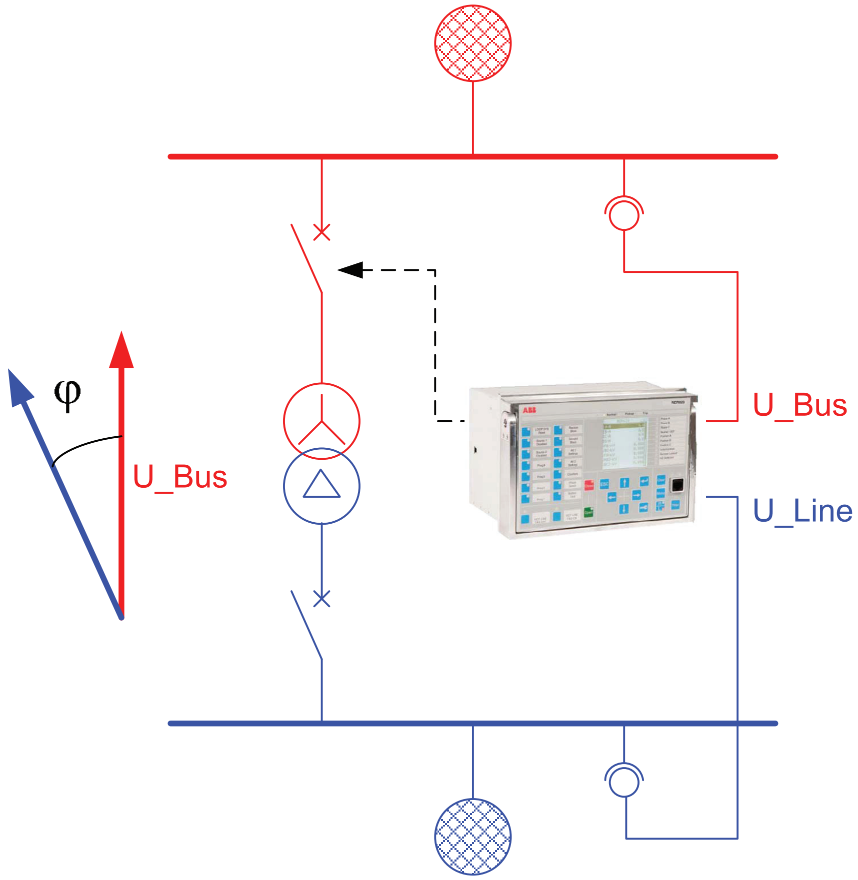


Figure 531: Angle difference when power transformer is in synchrocheck zone

The vector group of the power transformer is defined with clock numbers, where the value of the hour pointer defines the low-voltage-side phasor and the high-voltage-side phasor is always fixed to the clock number 12, which is same as zero. The angle between clock numbers is 30 degrees. When comparing phase angles, the `U_BUS` input is always the reference. This means that when the Yd11 power transformer is used, the low-voltage-side voltage phasor leads by 30 degrees or lags by 330 degrees the high-voltage-side phasor. The rotation of the phasors is counterclockwise.

The generic rule is that a low-voltage-side phasor lags the high-voltage-side phasor by clock number * 30º. This is called angle difference adjustment and can be set for SECRSYN with the *Phase shift* setting.

9.3.5 Application

The main purpose of the synchrocheck function is to provide control over the closing of the circuit breakers in power networks to prevent the closing if the conditions for synchronism are not detected. This function is also used to prevent the reconnection of two systems which are divided after islanding and a three-pole reclosing.

The Synchro check function block includes both the synchronism check function and the energizing function to allow closing when one side of the breaker is dead.

Network and the generator running in parallel with the network are connected through the line AB. When a fault occurs between A and B, the protection relay protection opens the circuit breakers A and B, thus isolating the faulty section from the network and making the arc that caused the fault extinguish. The first attempt to recover is a delayed autoreclosure made a few seconds later. Then, the autoreclose function DARREC gives a command signal to the synchrocheck function to close the circuit breaker A. SECRSYN performs an energizing check, as the line AB is de-energized (U_BUS> *Live bus value*, U_LINE< *Dead line value*) . After verifying the line AB is dead and the energizing direction is correct, the protection relay energizes the line (U_BUS -> U_LINE) by closing the circuit breaker A. The PLC of the power plant discovers that the line has been energized and sends a signal to the other synchrocheck function to close the circuit breaker B. Since both sides of the circuit breaker B are live (U_BUS > *Live bus value*, U_LINE > *Live bus value*), the synchrocheck function controlling the circuit breaker B performs a synchrocheck and, if the network and the generator are in synchronism, closes the circuit breaker.

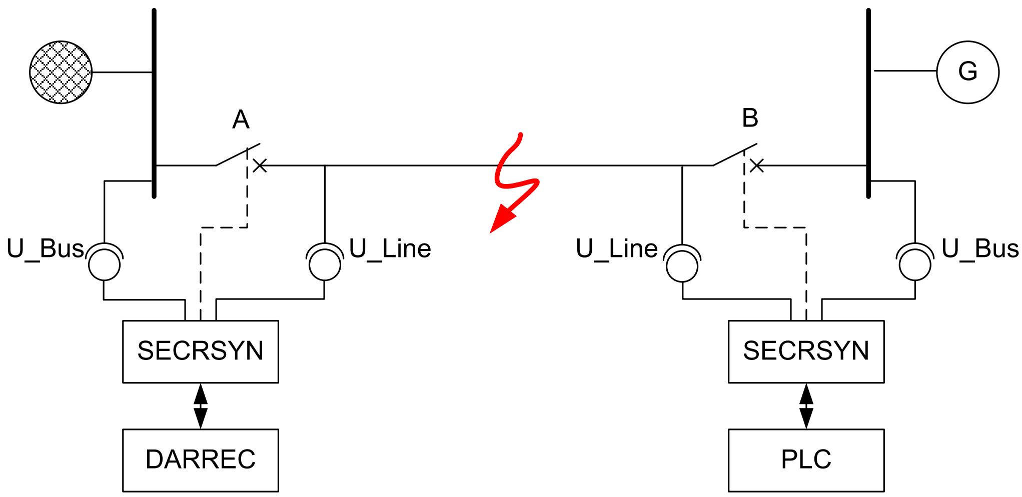


Figure 532: Synchrocheck function SECRSYN checking energizing conditions and synchronism

Connections

A special attention is paid to the connection of the protection relay. Furthermore it is checked that the primary side wiring is correct.

A faulty wiring of the voltage inputs of the protection relay causes a malfunction in the synchrocheck function. If the wires of an energizing input have changed places, the polarity of the input voltage is reversed (180°). In this case, the protection relay permits the circuit breaker closing in a situation where the voltages are in opposite phases. This can damage the electrical devices in the primary circuit. Therefore, it is extremely important that the wiring from the voltage transformers to the terminals on the rear of the protection relay is consistent regarding the energizing inputs U_BUS (bus voltage) and U_LINE (line voltage).

The wiring should be verified by checking the reading of the phase difference measured between the U_BUS and U_LINE voltages. The phase difference measured by the protection relay has to be close to zero within the permitted accuracy tolerances. The measured phase differences are indicated in the LHMI. At the same time, it is recommended to check the voltage difference and the frequency differences presented in the monitored data view. These values should be within the permitted tolerances, that is, close to zero.

Figure 533 shows an example where the synchrocheck is used for the circuit breaker closing between a busbar and a line. The phase-to-phase voltages are measured from the busbar and also one phase-to-phase voltage from the line is measured.

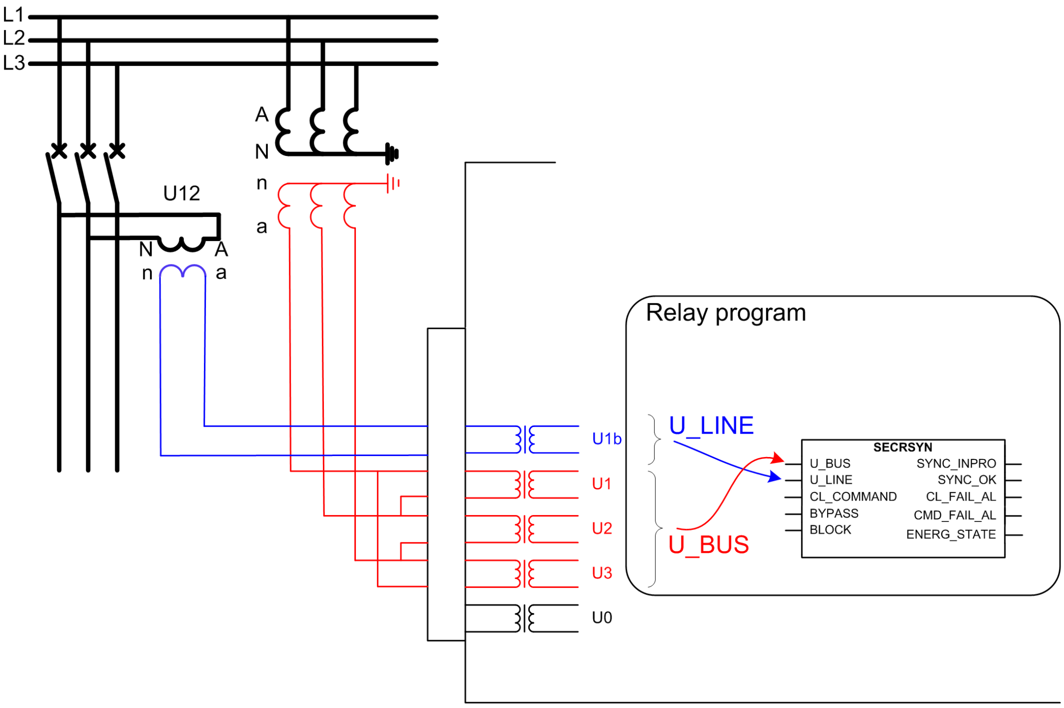


Figure 533: Connection of voltages for the protection relay and signals used in synchrocheck

9.3.6 Signals

Table 994: SECRSYN Input signals

Name	Type	Default	Description
U_BUS	SIGNAL	0	Busbar voltage
U_LINE	SIGNAL	0	Line voltage
BLOCK	BOOLEAN	0=False	Blocking signal of the synchro check and voltage check function
CL_COMMAND	BOOLEAN	0=False	External closing request
BYPASS	BOOLEAN	0=False	Request to bypass synchronism check and voltage check

Table 995: SECRSYN Output signals

Name	Type	Description
SYNC_INPRO	BOOLEAN	Synchronizing in progress
SYNC_OK	BOOLEAN	Systems in synchronism
CL_FAIL_AL	BOOLEAN	CB closing failed
CMD_FAIL_AL	BOOLEAN	CB closing request failed
LLDB	BOOLEAN	Live Line, Dead Bus
LLLB	BOOLEAN	Live Line, Live Bus
DLLB	BOOLEAN	Dead Line, Live Bus
DLDB	BOOLEAN	Dead Line, Dead Bus

9.3.7 Settings

Table 996: SECRSYN Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Live dead mode	-1=Off 1=Both Dead 2=Live L, Dead B 3=Dead L, Live B 4=Dead Bus, L Any 5=Dead L, Bus Any 6=One Live, Dead 7=Not Both Live			1=Both Dead	Energizing check mode
Difference voltage	0.01...0.50	xUn	0.01	0.05	Maximum voltage difference limit
Difference frequency	0.001...0.100	xFn	0.001	0.001	Maximum frequency difference limit
Difference angle	5...90	deg	1	5	Maximum angle difference limit

Table 997: SECRSYN Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Synchro check mode	1=Off 2=Synchronous 3=Asynchronous			3=Asynchronous	Synchro check operation mode
Dead line value	0.1...0.8	xUn	0.1	0.2	Voltage low limit line for energizing check
Live line value	0.2...1.0	xUn	0.1	0.8	Voltage high limit line for energizing check
Dead bus value	0.1...0.8	xUn	0.1	0.2	Voltage low limit bus for energizing check

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Live bus value	0.2...1.0	xUn	0.1	0.5	Voltage high limit bus for energizing check
Max energizing V	0.50...1.15	xUn	0.01	1.05	Maximum voltage for energizing

Table 998: SECRSYN Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Control mode	1=Continuous 2=Command			1=Continuous	Selection of synchro check command or Continuous control mode
Close pulse	200...60000	ms	10	200	Breaker closing pulse duration
Phase shift	-180...180	deg	1	0	Correction of phase difference between measured U_BUS and U_LINE
Minimum Syn time	0...60000	ms	10	0	Minimum time to accept synchronizing
Maximum Syn time	100...6000000	ms	10	2000	Maximum time to accept synchronizing
Energizing time	100...60000	ms	10	100	Time delay for energizing check
Closing time of CB	40...250	ms	10	60	Closing time of the breaker
Voltage source switch	0=False 1=True			0=False	Voltage source switch

9.3.8 Monitored data

Table 999: SECRSYN Monitored data

Name	Type	Values (Range)	Unit	Description
ENERG_STATE	Enum	0=Unknown 1=Both Live 2=Live L, Dead B 3=Dead L, Live B 4=Both Dead		Energization state of Line and Bus
U_DIFF_MEAS	FLOAT32	0.00...1.00	xUn	Calculated voltage amplitude difference
FR_DIFF_MEAS	FLOAT32	0.000...0.100	xFn	Calculated voltage frequency difference
PH_DIFF_MEAS	FLOAT32	0.00...180.00	deg	Calculated voltage phase angle difference

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
U_DIFF_SYNC	BOOLEAN	0=False 1=True		Voltage difference out of limit for synchronizing
PH_DIF_SYNC	BOOLEAN	0=False 1=True		Phase angle difference out of limit for synchronizing
FR_DIFF_SYNC	BOOLEAN	0=False 1=True		Frequency difference out of limit for synchronizing
SECRSYN	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.3.9 Technical data

Table 1000: SECRSYN Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±1 Hz
	Voltage: ±3.0 % of the set value or ±0.01 × U_n Frequency: ±10 mHz Phase angle: ±3°
Reset time	<50 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	±1.0 % of the set value or ±20 ms

9.4 Autoreclosing DARREC

9.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Autoreclosing	DARREC	O -> I	79

9.4.2 Function block

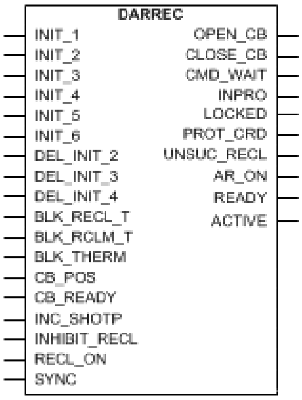


Figure 534: Function block

9.4.3 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 autoreclosing function DARREC can be used with any circuit breaker suitable for autoreclosing. The function provides five programmable autoreclosing shots which can perform one to five successive autoreclosings of desired type and duration, for instance one high-speed and one delayed autoreclosing.

When the reclosing is initiated with starting of the protection function, the autoreclosing 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.

9.4.3.1 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 1001: 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).

9.4.3.2 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.

9.4.3.3 Master and slave scheme

With the cooperation between the AR units in the same protection relay or between protection relays, 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.

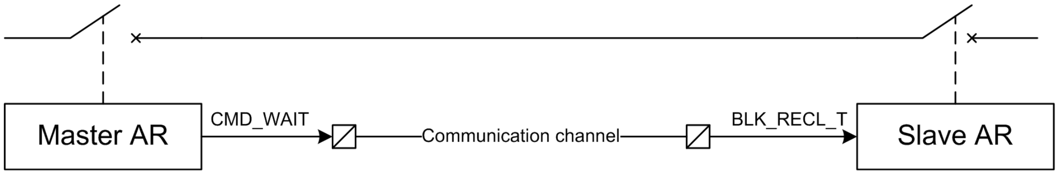


Figure 535: Master and slave scheme

If the AR unit is defined as a master by setting its terminal priority to high:

- 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 autoreclosing shot.

If the terminal priority of the AR unit is set to "none", the AR unit skips all these actions.

9.4.3.4 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 Thm 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.

9.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off". Setting *Operation* to "Off" resets non-volatile counters.

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. AR_ON is activated when reclosing operation is enabled.

The operation of DARREC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

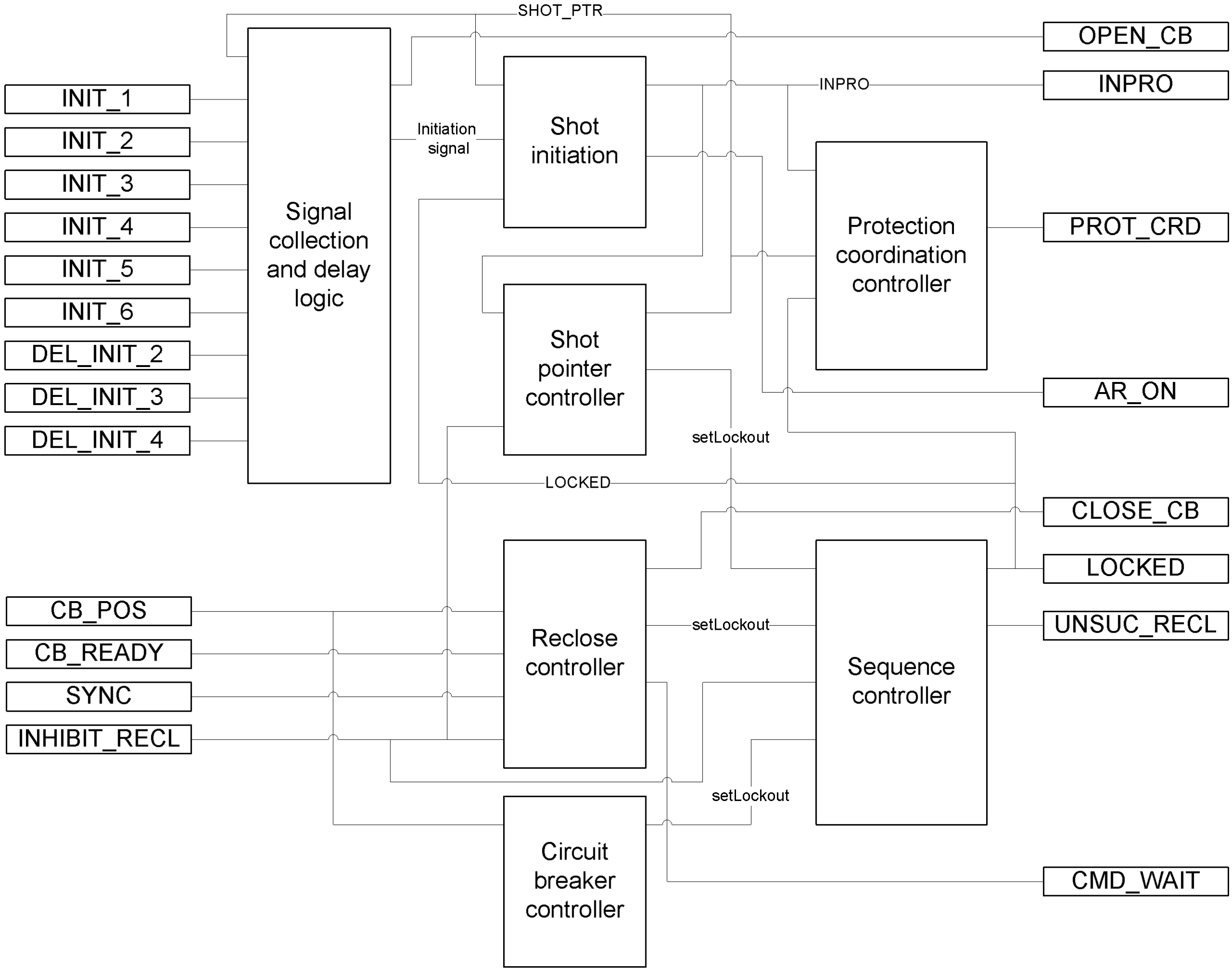


Figure 536: Functional module diagram

9.4.4.1 Signal collection and delay logic

When the protection trips, the initiation of autoreclosing 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.

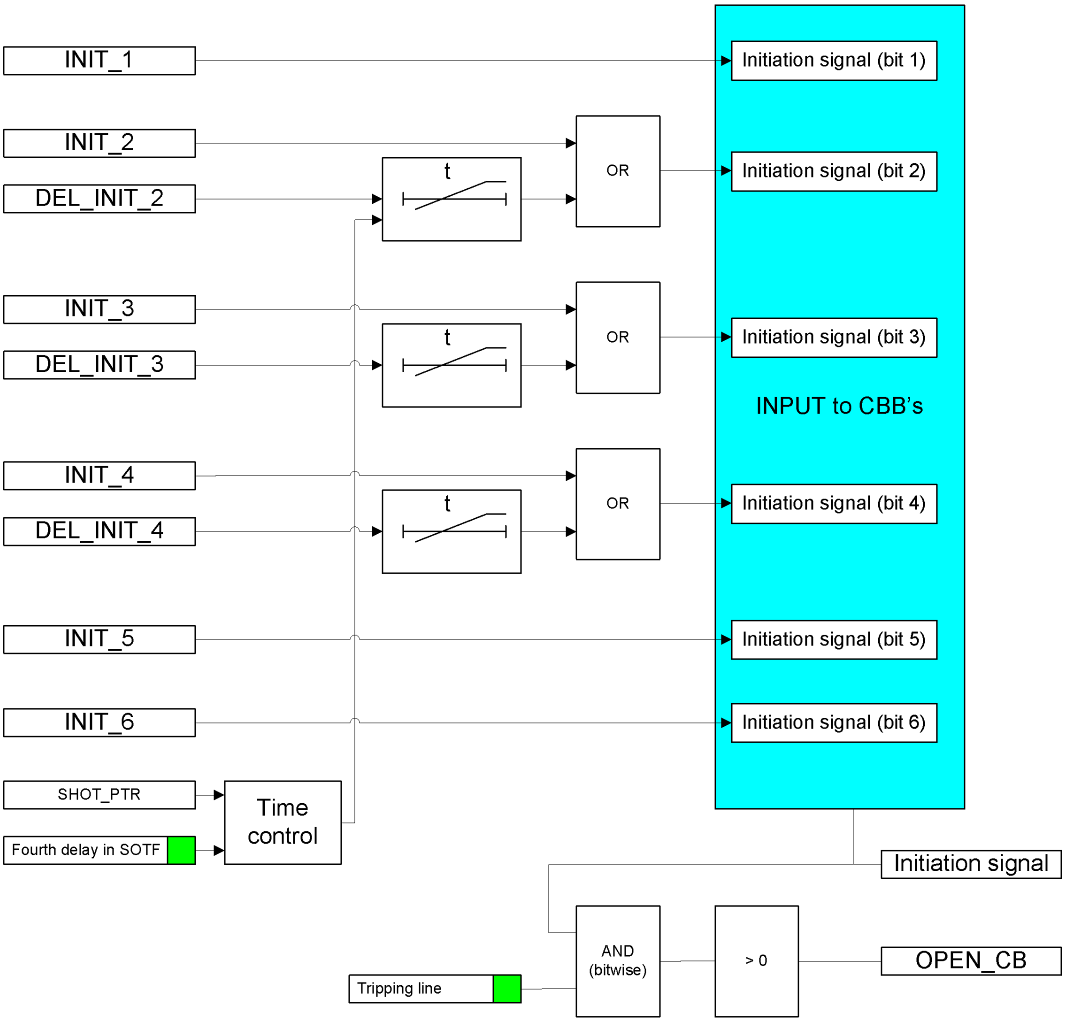


Figure 537: Schematic diagram of delayed initiation input signals

In total, the AR function contains six separate initiation lines used for the initiation or blocking of the autoreclosing 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

- *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

- *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

- *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 reclosing attempts are made. The third and fourth attempts are used to provide the so-called fast final trip to lockout.

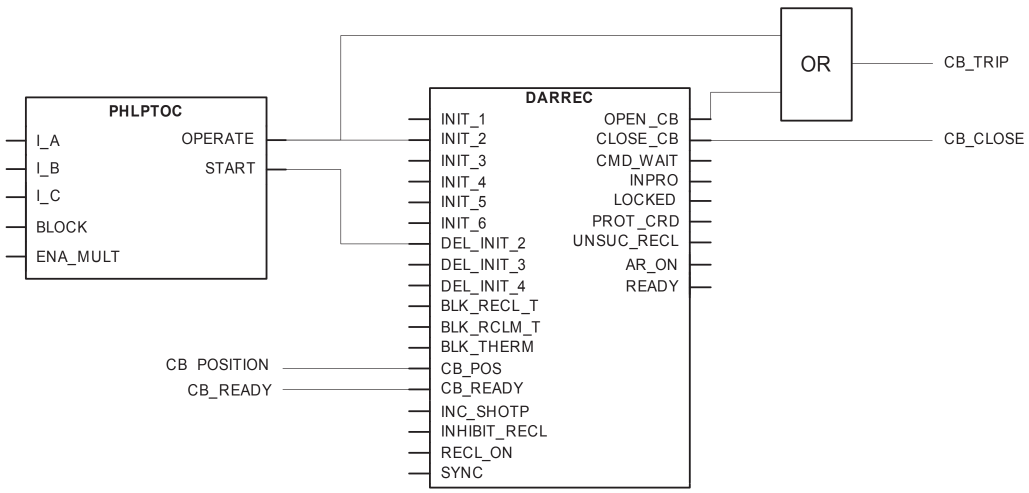


Figure 538: Autoreclosing configuration example

Delayed DEL_INIT_2...4 signals are used only when the autoreclosing shot is initiated with the start signal of a protection stage. After a start delay, the AR function opens the circuit breaker and an autoreclosing 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 autoreclosing 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 autoreclose situation is where one autoreclosing 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 autoreclosing sequence is successful: the reclaim time elapses and no new sequence is started.

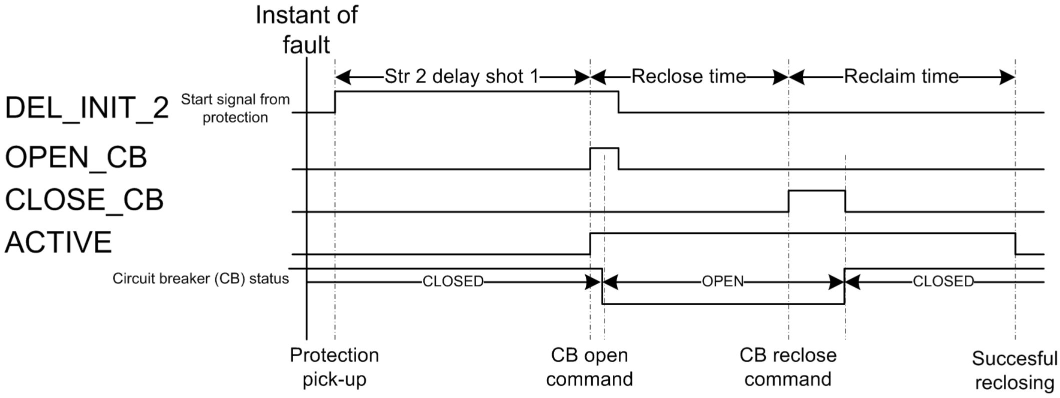


Figure 539: Signal scheme of autoreclosing operation initiated with protection start signal

The autoreclosing shot is initiated with a start signal of the protection function after the start delay time has elapsed. The autoreclosing starts when the *Str 2 delay shot 1* setting elapses.

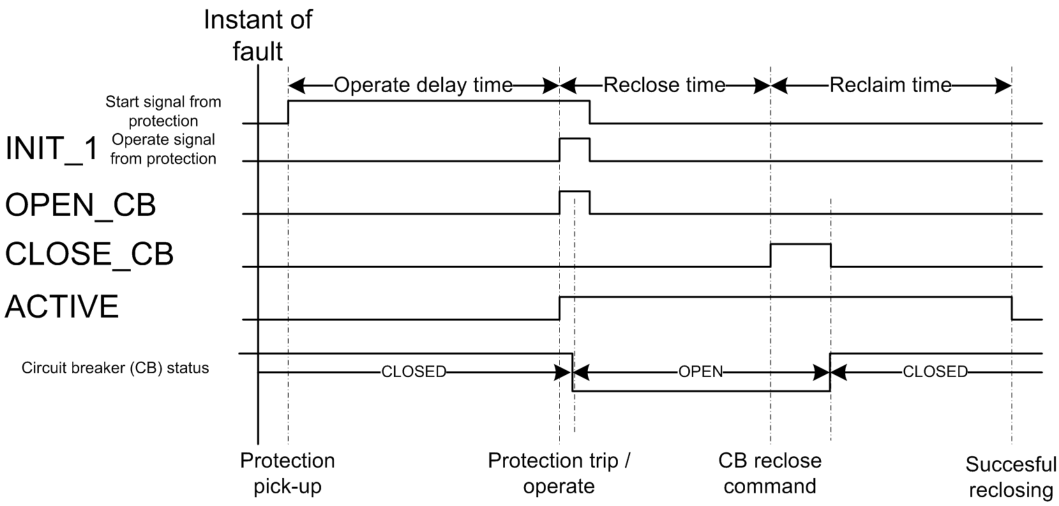


Figure 540: Signal scheme of autoreclosing operation initiated with protection operate signal

The autoreclosing shot is initiated with a trip signal of the protection function. The autoreclosing starts when the protection operate delay time elapses.

Normally, all trip and start signals are used to initiate an autoreclosing shot and trip the circuit breaker. `ACTIVE` output indicates reclosing sequence in progress. 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.

9.4.4.2 Shot initiation

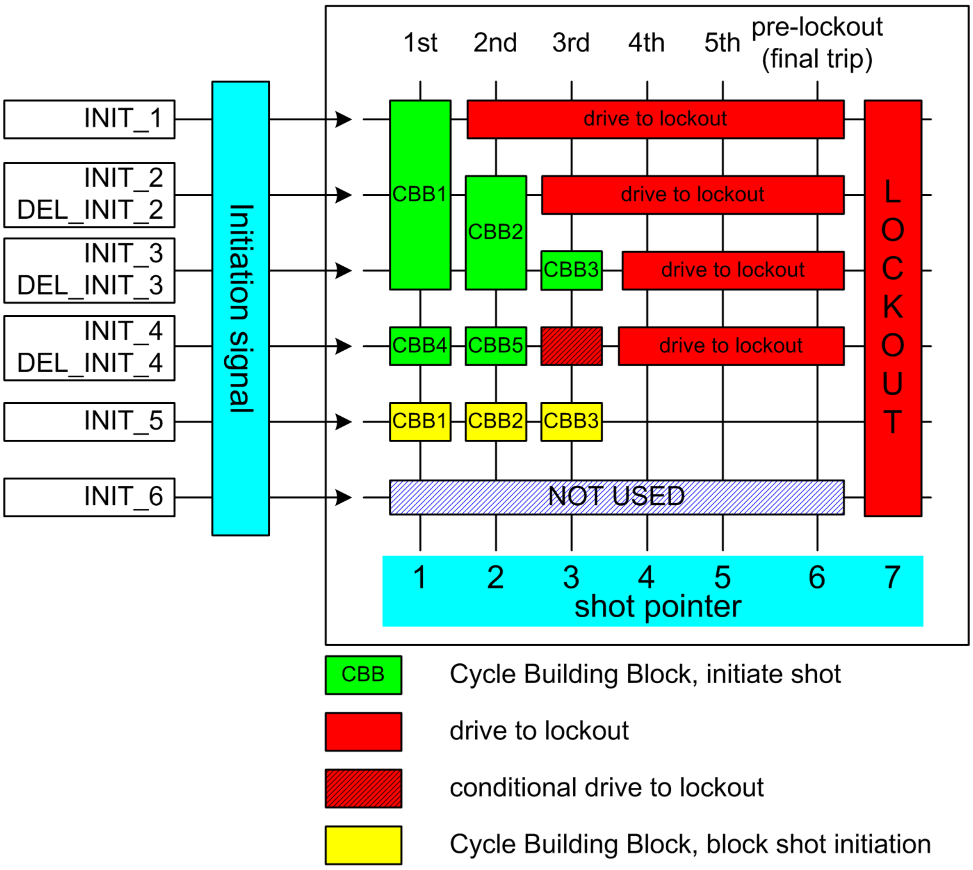


Figure 541: Example of an autoreclosing program with a reclose scheme matrix

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 autoreclose 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.

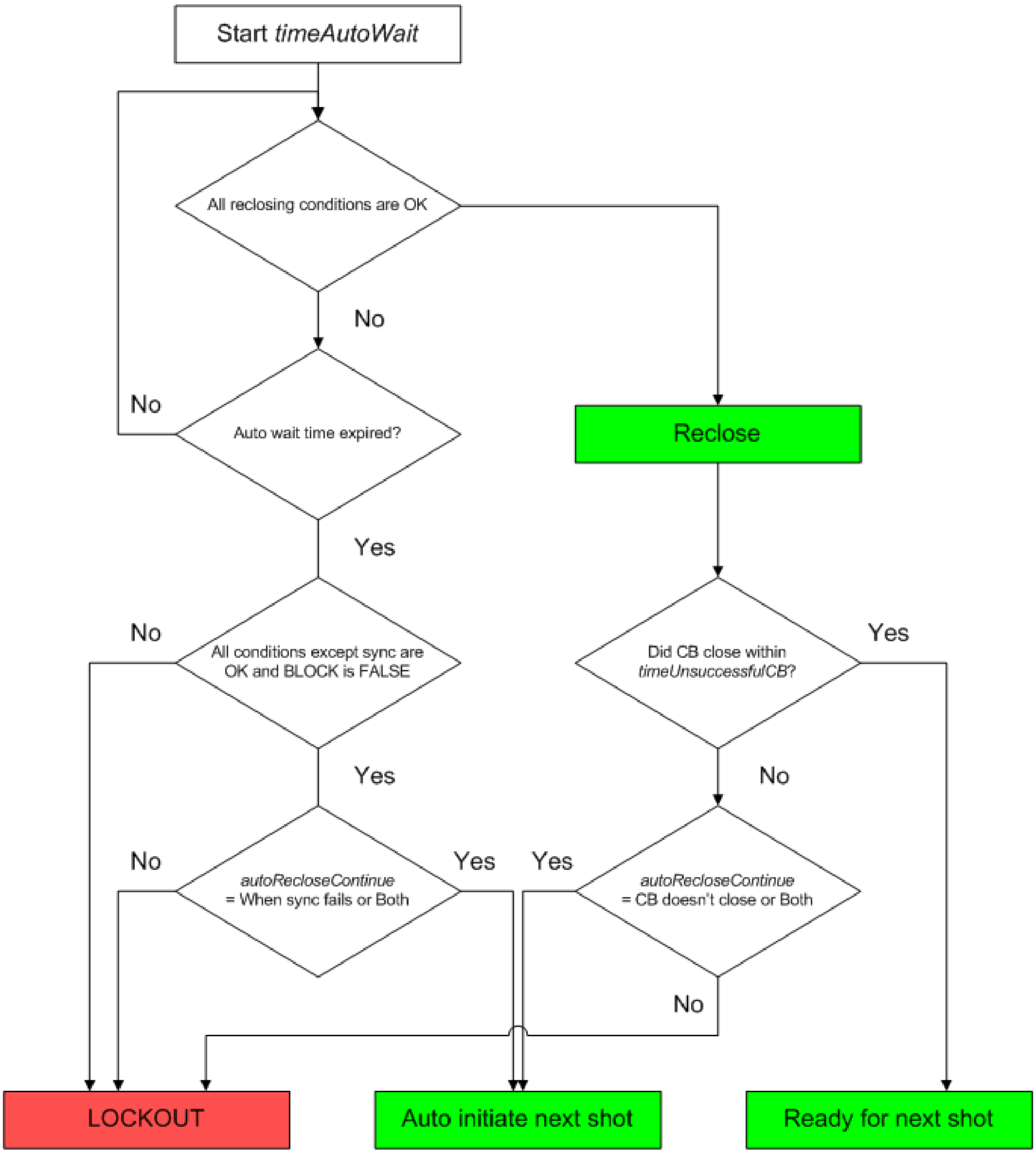


Figure 542: Logic diagram of auto-initiation sequence detection

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.

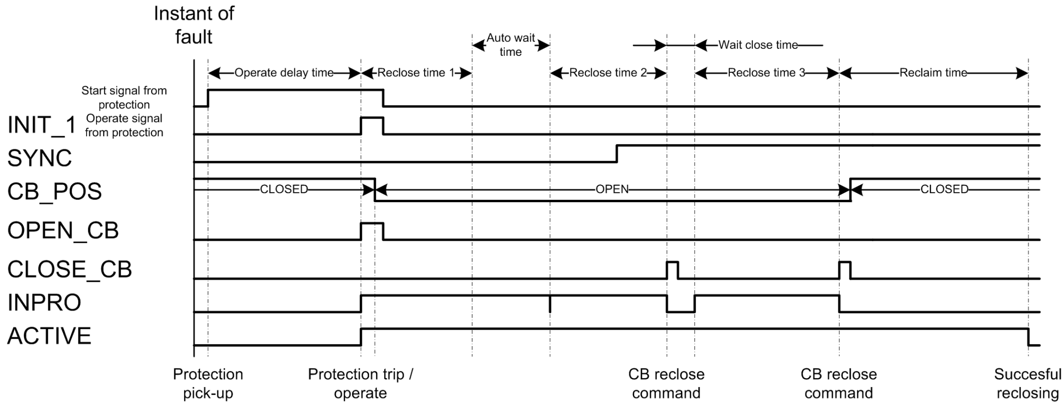


Figure 543: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

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.

9.4.4.3 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.

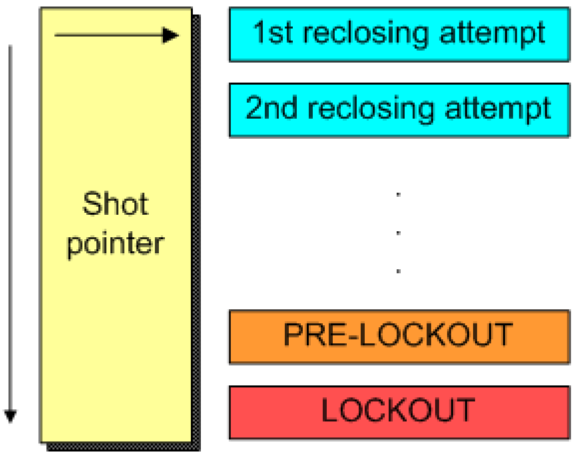


Figure 544: Shot pointer function

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.

9.4.4.4 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. This is indicated by active READY output.

If at least one of the conditions is not fulfilled within the time set with the *Auto wait time* parameter, the autoreclose 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.

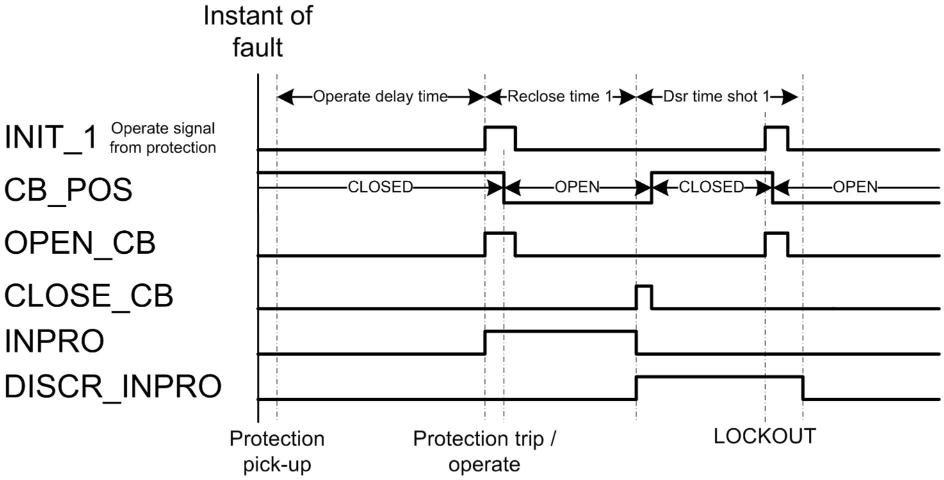


Figure 545: Initiation during discrimination time - AR function goes to lockout

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.

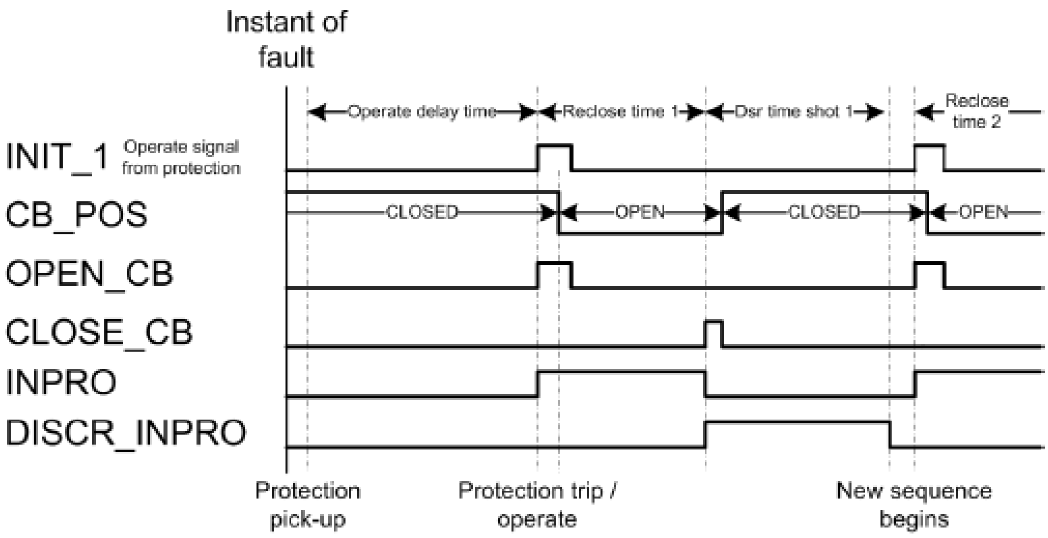


Figure 546: Initiation after elapsed discrimination time - new shot begins

9.4.4.5 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 *RecRs* parameter. The same functionality can also be found in the Clear menu (DARREC1 reset).
- 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 *RecRs* 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 autoreclosing sequence and the manual close mode is FALSE.

9.4.4.6 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

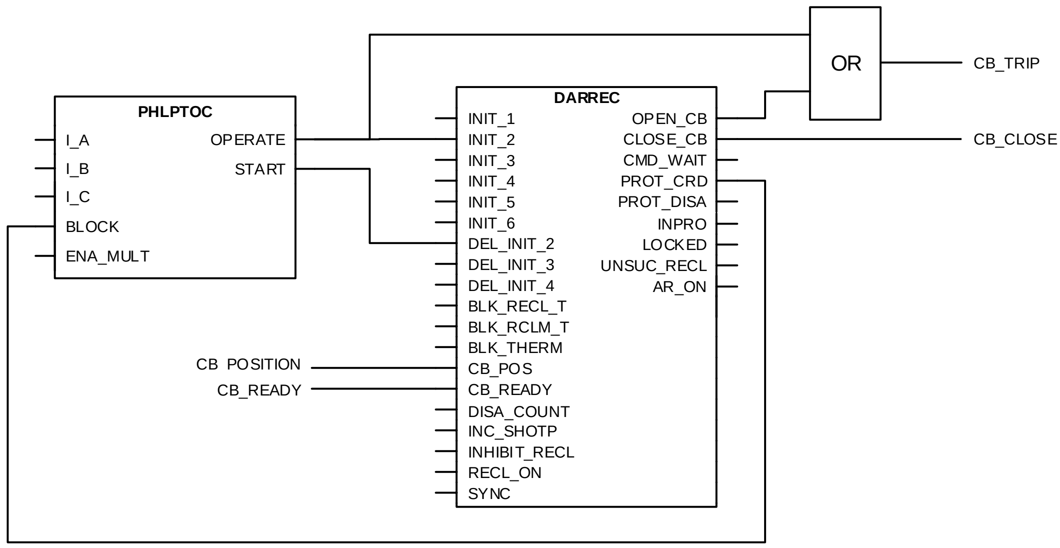


Figure 547: Configuration example of using the PROT_CRD output for protection blocking

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.

9.4.4.7 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 autoreclosing function is driven to lockout or, if allowed, an auto-initiation is activated.

The main motivation for autoreclosing 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 autoreclosing 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 parameter *SOTF* is active.

If the *Manual close mode* setting is set to FALSE and the circuit breaker has been manually closed during an autoreclosing 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 autoreclosing 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 autoreclosing function in cases where the fault causes repetitive autoreclosing sequences during a short period of time. For instance, if a tree causes a short circuit and, as a result, there are autoreclosing 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.

9.4.5 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 reclosing command. The counters count the following situations.

- COUNTER: counts every reclosing command activation
- CNT_SHOT1: counts reclosing commands that are executed from shot 1
- CNT_SHOT2: counts reclosing commands that are executed from shot 2
- CNT_SHOT3: counts reclosing commands that are executed from shot 3
- CNT_SHOT4: counts reclosing commands that are executed from shot 4
- CNT_SHOT5: counts reclosing 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 *CntRs* parameter. The same functionality can also be found in the clear menu (DARREC1 counters).

9.4.6 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, autoreclose 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 1002: Important definitions related to auto-reclosing

Autoreclose shot	An operation where after a preset time the breaker is closed from the breaker tripping caused by protection.
Autoreclose 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 autoreclose operations. Since no auto-reclosing follows, the circuit breaker remains open. This is called final trip or definite trip.

9.4.6.1 Shot initiation

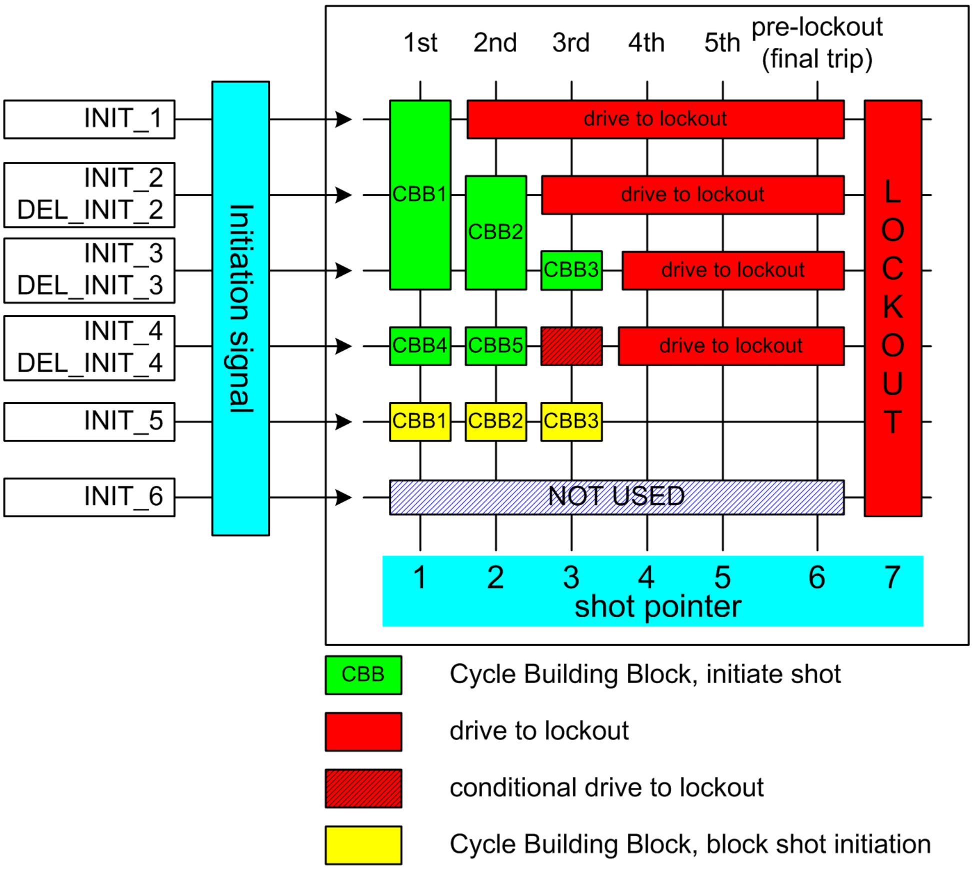


Figure 548: Example of an autoreclosing program with a reclose scheme matrix

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 autoreclose 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.

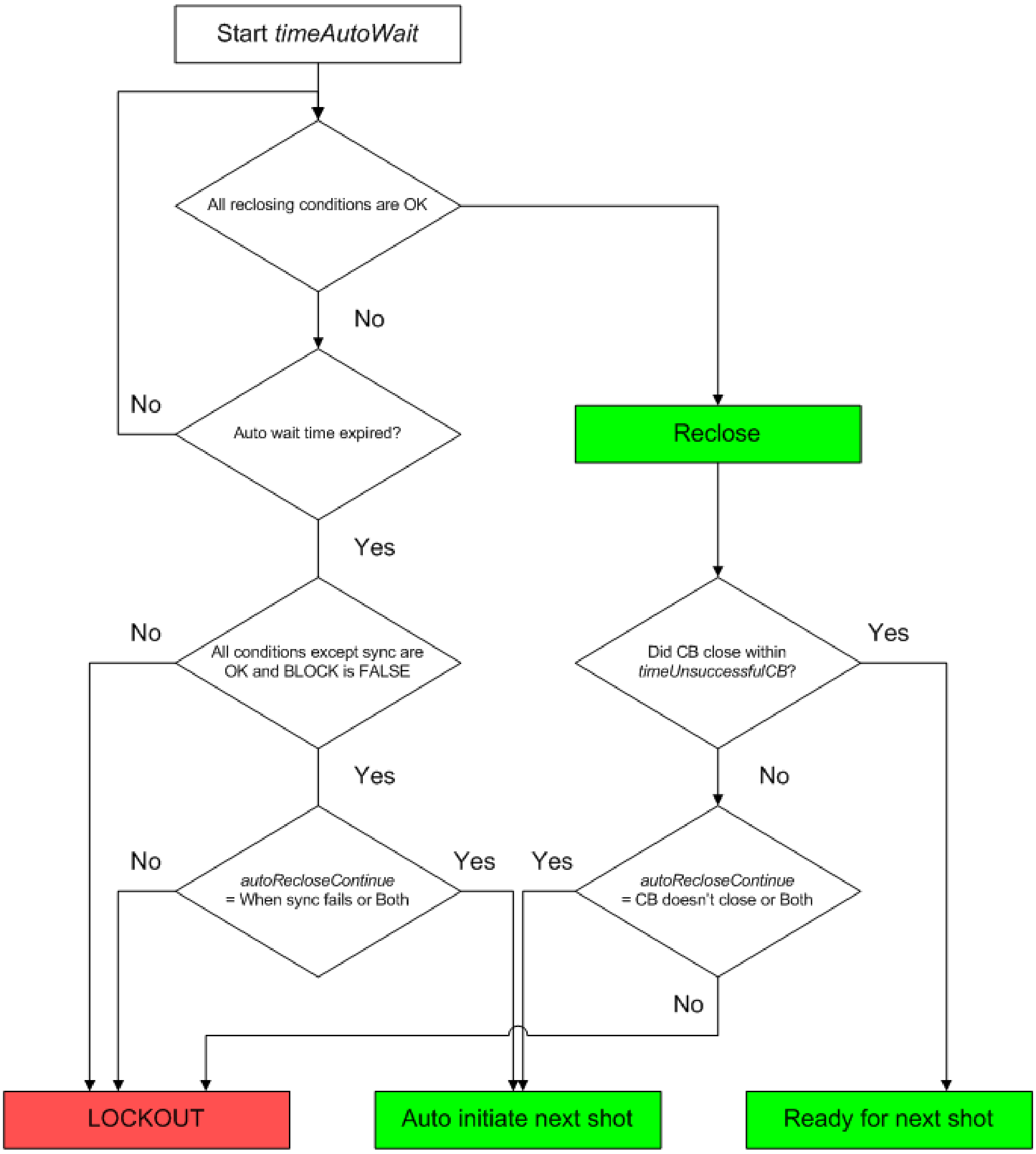


Figure 549: Logic diagram of auto-initiation sequence detection

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.

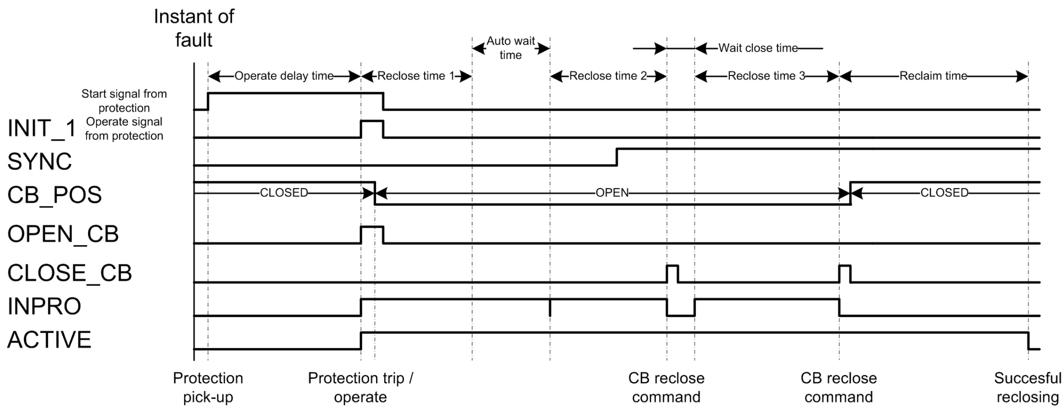


Figure 550: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

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.

9.4.6.2 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.

9.4.6.3 Configuration examples

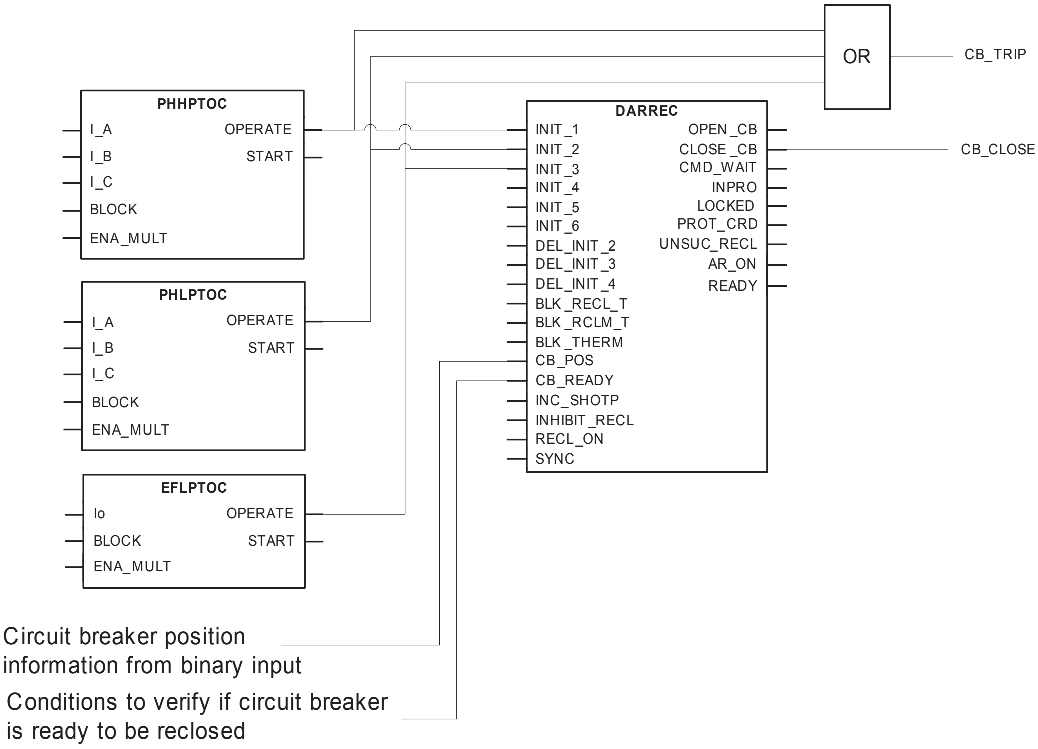


Figure 551: Example connection between protection and autoreclosing functions in protection relay configuration

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.

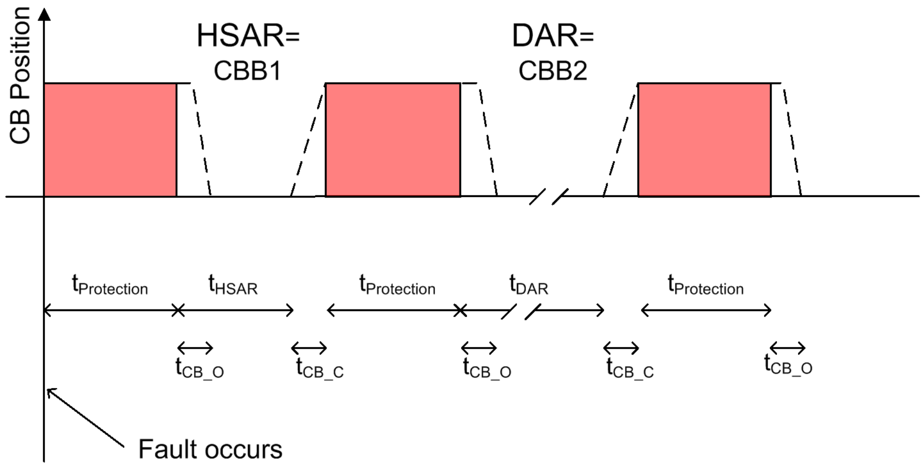


Figure 552: Autoreclosing sequence with two shots

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 described in *Table 1003* as follows:

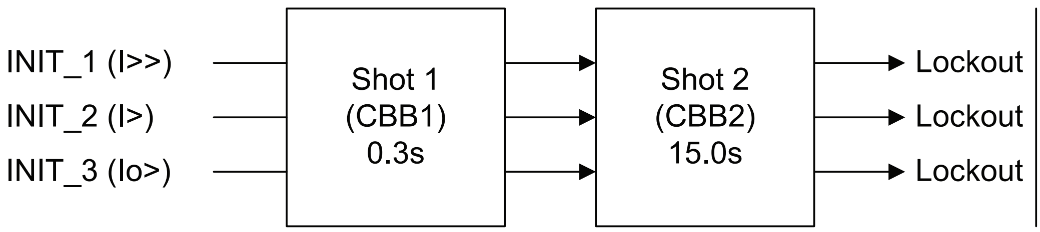


Figure 553: Two shots with three initiation lines

Table 1003: 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.

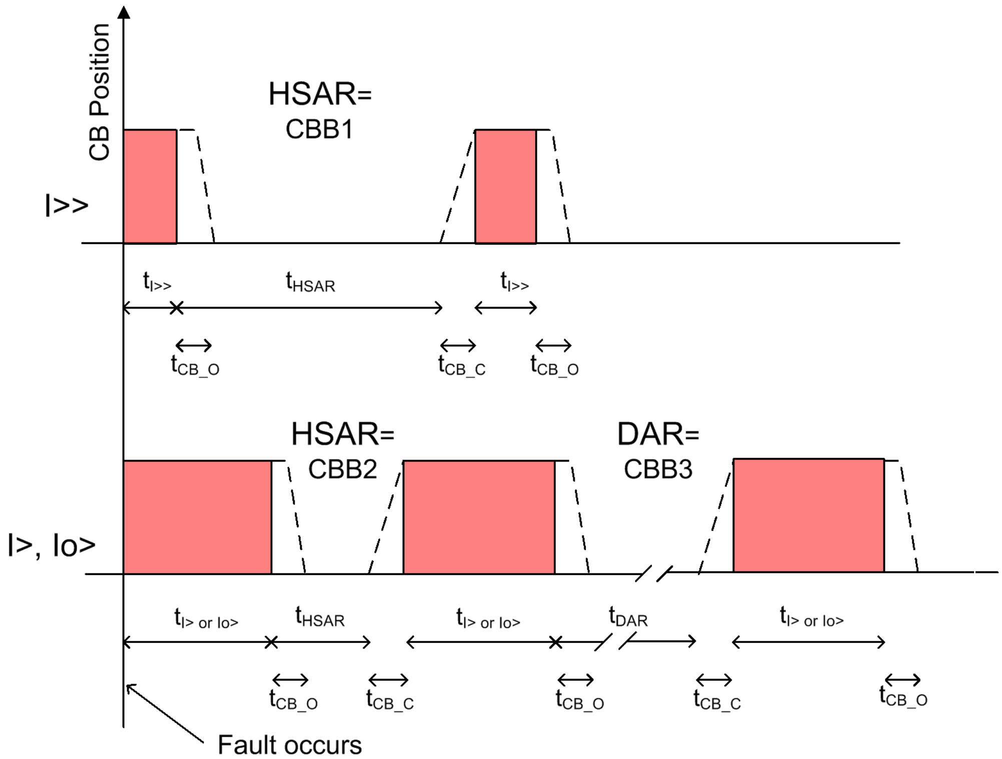


Figure 554: Autoreclosing sequence with two shots with different shot settings according to initiation signal

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 $t_{Io>}$	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.

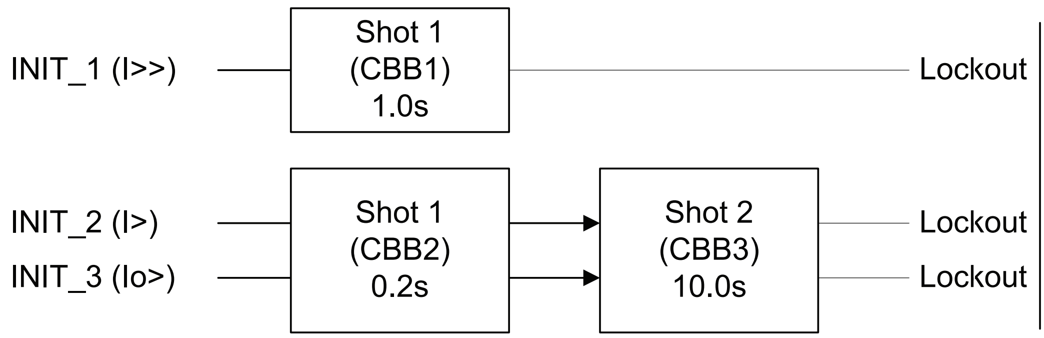


Figure 555: Three shots with three initiation lines

If the sequence is initiated from the INIT_1 line, that is, the overcurrent protection high stage, the sequence is one shot long. If the sequence is initiated from the INIT_2 or INIT_3 lines, the sequence is two shots long.

Table 1004: Settings for configuration example 2

Setting name	Setting value
Shot number CBB1	1
Init signals CBB1	1 (line 1)
First reclose time	0.0s (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

9.4.6.4 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.

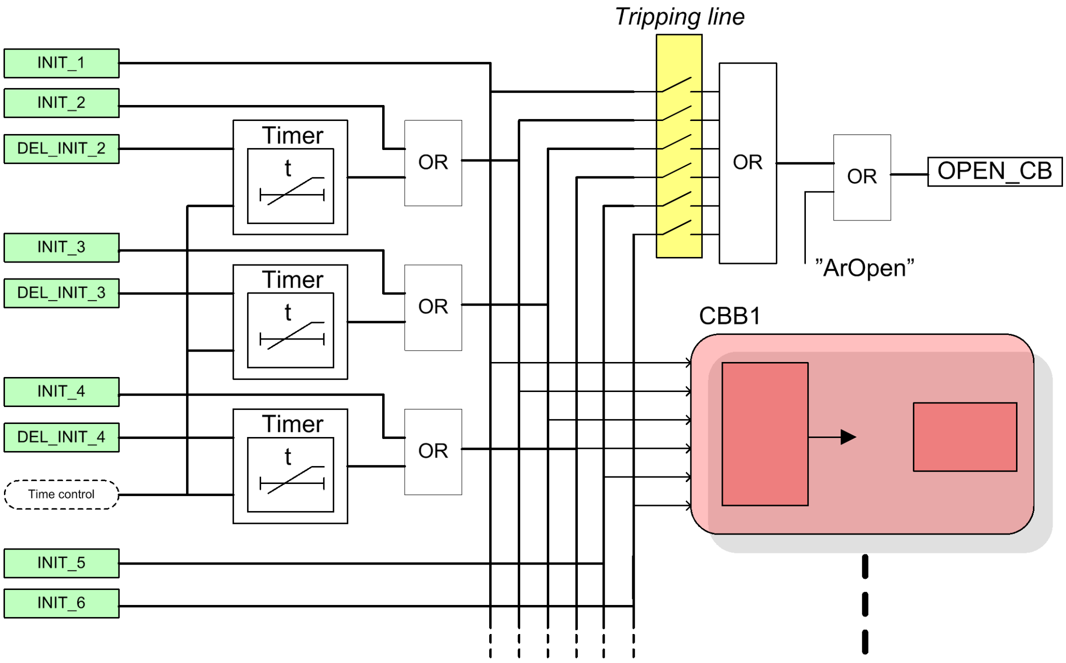


Figure 556: Simplified logic diagram of initiation lines

Each delayed initiation line has four different time settings:

Table 1005: 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.

9.4.6.5 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.

9.4.6.6 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.

9.4.7 Signals

Table 1006: DARREC Input signals

Name	Type	Default	Description
INIT_1	BOOLEAN	0=False	AR initialization / blocking signal 1
INIT_2	BOOLEAN	0=False	AR initialization / blocking signal 2
INIT_3	BOOLEAN	0=False	AR initialization / blocking signal 3
INIT_4	BOOLEAN	0=False	AR initialization / blocking signal 4
INIT_5	BOOLEAN	0=False	AR initialization / blocking signal 5
INIT_6	BOOLEAN	0=False	AR initialization / blocking signal 6
DEL_INIT_2	BOOLEAN	0=False	Delayed AR initialization / blocking signal 2
DEL_INIT_3	BOOLEAN	0=False	Delayed AR initialization / blocking signal 3
DEL_INIT_4	BOOLEAN	0=False	Delayed AR initialization / blocking signal 4
BLK_RECL_T	BOOLEAN	0=False	Blocks and resets reclose time
BLK_RCLM_T	BOOLEAN	0=False	Blocks and resets reclaim time
BLK_THERM	BOOLEAN	0=False	Blocks and holds the reclose shot from the thermal overload
CB_POS	BOOLEAN	0=False	Circuit breaker position input
CB_READY	BOOLEAN	1=True	Circuit breaker status signal
INC_SHOTP	BOOLEAN	0=False	A zone sequence coordination signal
INHIBIT_RECL	BOOLEAN	0=False	Interrupts and inhibits reclosing sequence
RECL_ON	BOOLEAN	0=False	Level sensitive signal for allowing (high) / not allowing (low) reclosing
SYNC	BOOLEAN	0=False	Synchronizing check fulfilled

Table 1007: 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

Table continues on the next page

Name	Type	Description
PROT_CRD	BOOLEAN	A signal for coordination between the AR and the protection
UNSUC_RECL	BOOLEAN	Indicates an unsuccessful reclosing sequence
AR_ON	BOOLEAN	Autoreclosing allowed
READY	BOOLEAN	Indicates that the AR is ready for a new sequence, i.e. the CB_READY input equals TRUE
ACTIVE	BOOLEAN	Reclosing sequence is in progress

9.4.8 Settings

Table 1008: DARREC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off/On
Reclosing operation	1=Off 2=External Ctl 3=On			1=Off	Reclosing operation (Off, External Ctl / On)
Close pulse time	10...10000	ms	10	200	CB close pulse time
Reclaim time	100...1800000	ms	100	10000	Reclaim time
Terminal priority	1=None 2=Low (follower) 3=High (master)			1=None	Terminal priority
Synchronisation set	0...127		1	0	Selection for synchronizing requirement for reclosing
Auto initiation cnd	1=Not allowed 2=When sync fails 3=CB doesn't close 4=Both			2=When sync fails	Auto initiation condition
Tripping line	0...63		1	0	Tripping line, defines INIT inputs which cause OPEN_CB activation
Fourth delay in SOTF	0=False 1=True			0=False	Sets 4th delay into use for all DEL_INIT signals during SOTF
First reclose time	0...300000	ms	10	5000	Dead time for CBB1
Second reclose time	0...300000	ms	10	5000	Dead time for CBB2
Third reclose time	0...300000	ms	10	5000	Dead time for CBB3
Fourth reclose time	0...300000	ms	10	5000	Dead time for CBB4
Fifth reclose time	0...300000	ms	10	5000	Dead time for CBB5
Sixth reclose time	0...300000	ms	10	5000	Dead time for CBB6
Seventh reclose time	0...300000	ms	10	5000	Dead time for CBB7

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Init signals CBB1	0...63		1	0	Initiation lines for CBB1
Init signals CBB2	0...63		1	0	Initiation lines for CBB2
Init signals CBB3	0...63		1	0	Initiation lines for CBB3
Init signals CBB4	0...63		1	0	Initiation lines for CBB4
Init signals CBB5	0...63		1	0	Initiation lines for CBB5
Init signals CBB6	0...63		1	0	Initiation lines for CBB6
Init signals CBB7	0...63		1	0	Initiation lines for CBB7
Shot number CBB1	0...5		1	0	Shot number for CBB1
Shot number CBB2	0...5		1	0	Shot number for CBB2
Shot number CBB3	0...5		1	0	Shot number for CBB3
Shot number CBB4	0...5		1	0	Shot number for CBB4
Shot number CBB5	0...5		1	0	Shot number for CBB5
Shot number CBB6	0...5		1	0	Shot number for CBB6
Shot number CBB7	0...5		1	0	Shot number for CBB7
Frq Op counter limit	0...250		1	0	Frequent operation counter lockout limit
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
Auto init	0...63		1	0	Defines INIT lines that are activated at auto initiation

Table 1009: DARREC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Manual close mode	0=False 1=True			0=False	Manual close mode
Wait close time	50...10000	ms	50	250	Allowed CB closing time after reclose command
Max wait time	100...1800000	ms	100	10000	Maximum wait time for BLK_RECL_T release
Max trip time	100...10000	ms	100	10000	Maximum wait time for deactivation of protection signals
Max Thm block time	100...1800000	ms	100	10000	Maximum wait time for thermal blocking signal deactivation
Cut-out time	0...1800000	ms	100	10000	Cutout time for protection coordination

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Dsr time shot 1	0...10000	ms	100	0	Discrimination time for first reclosing
Dsr time shot 2	0...10000	ms	100	0	Discrimination time for second reclos-ing
Dsr time shot 3	0...10000	ms	100	0	Discrimination time for third reclosing
Dsr time shot 4	0...10000	ms	100	0	Discrimination time for fourth reclosing
Auto wait time	0...60000	ms	10	2000	Wait time for re-closing condition fullfilling
Auto lockout reset	0=False 1=True			1=True	Automatic lockout reset
Protection crd limit	1...5		1	1	Protection coordi-nation shot limit
Protection crd mode	1=No condition 2=AR inoperative 3=CB close manual 4=AR inop, CB man 5=Always			4=AR inop, CB man	Protection coordi-nation mode
Control line	0...63		1	63	Control line, de-fines INIT inputs which are protec-tion signals
Enable shot jump	0=False 1=True			1=True	Enable shot jump-ing
CB closed Pos sta-tus	0=False 1=True			0=False	Circuit breaker closed position sta-tus
Blk signals CBB1	0...63		1	0	Blocking lines for CBB1
Blk signals CBB2	0...63		1	0	Blocking lines for CBB2
Blk signals CBB3	0...63		1	0	Blocking lines for CBB3
Blk signals CBB4	0...63		1	0	Blocking lines for CBB4
Blk signals CBB5	0...63		1	0	Blocking lines for CBB5
Blk signals CBB6	0...63		1	0	Blocking lines for CBB6
Blk signals CBB7	0...63		1	0	Blocking lines for CBB7
Str 2 delay shot 1	0...300000	ms	10	0	Delay time for start2, 1st reclose
Str 2 delay shot 2	0...300000	ms	10	0	Delay time for start2 2nd reclose
Str 2 delay shot 3	0...300000	ms	10	0	Delay time for start2 3rd reclose
Str 2 delay shot 4	0...300000	ms	10	0	Delay time for start2, 4th reclose
Str 3 delay shot 1	0...300000	ms	10	0	Delay time for start3, 1st reclose
Str 3 delay shot 2	0...300000	ms	10	0	Delay time for start3 2nd reclose
Str 3 delay shot 3	0...300000	ms	10	0	Delay time for start3 3rd reclose
Str 3 delay shot 4	0...300000	ms	10	0	Delay time for start3, 4th reclose

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Str 4 delay shot 1	0...300000	ms	10	0	Delay time for start4, 1st reclose
Str 4 delay shot 2	0...300000	ms	10	0	Delay time for start4 2nd reclose
Str 4 delay shot 3	0...300000	ms	10	0	Delay time for start4 3rd reclose
Str 4 delay shot 4	0...300000	ms	10	0	Delay time for start4, 4th reclose

9.4.9 Monitored data

Table 1010: DARREC Monitored data

Name	Type	Values (Range)	Unit	Description
DISA_COUNT	BOOLEAN	0=False 1=True		Signal for counter disabling
FRQ_OPR_CNT	INT32	0...2147483647		Frequent operation counter
FRQ_OPR_AL	BOOLEAN	0=False 1=True		Frequent operation counter alarm
STATUS	Enum	-1=Not defined 1=Ready 2=InProgress 3=Successful 4=WaitingForTrip 5=TripFromProtection 6=FaultDisappeared 7=WaitToComplete 8=CBclosed 9=CycleUnsuccessful 10=Unsuccessful 11=Aborted		AR status signal for IEC61850
INPRO_1	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 1
INPRO_2	BOOLEAN	0=False		Reclosing shot in progress, shot 2

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		1=True		
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 in progress
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	INT32	0...2147483647		Resetable operation counter, shot 1
CNT_SHOT2	INT32	0...2147483647		Resetable operation counter, shot 2
CNT_SHOT3	INT32	0...2147483647		Resetable operation counter, shot 3
CNT_SHOT4	INT32	0...2147483647		Resetable operation counter, shot 4
CNT_SHOT5	INT32	0...2147483647		Resetable operation counter, shot 5
COUNTER	INT32	0...2147483647		Resetable operation counter, all shots
SHOT_PTR	INT32	1...7		Shot pointer value
MAN_CB_CL	BOOLEAN	0=False 1=True		Indicates CB manual closing

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
				during reclosing sequence
SOTF	BOOLEAN	0=False 1=True		Switch-onto-fault
DARREC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.4.10 Technical data

Table 1011: DARREC Technical data

Characteristic	Value
Operate time accuracy	±1.0 % of the set value or ±20 ms

9.4.11 Technical revision history

Table 1012: DARREC Technical revision history

Technical revision	Change
B	The `PROT_DISA` output removed and removed the related settings
C	The default value of the *CB closed Pos status* setting changed from "True" to "False"
D	SHOT_PTR output range 0...7 (earlier 0...6)
E	Monitored data ACTIVE transferred to be ACT visible output. SHOT_PTR output range 1...7.
F	Internal improvement

9.5 Tap changer control with voltage regulator OLATCC

9.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Tap changer control with voltage regulator	OLATCC	COLTC	90V

9.5.2 Function block

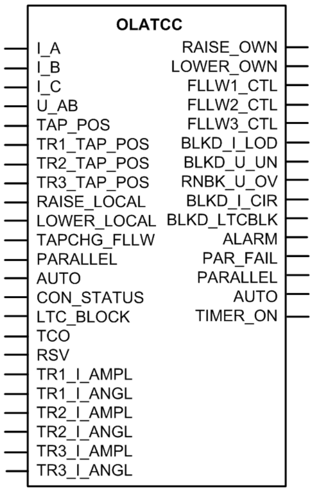


Figure 557: Function block

9.5.3 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 by using the raising or lowering 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.

9.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of OLATCC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

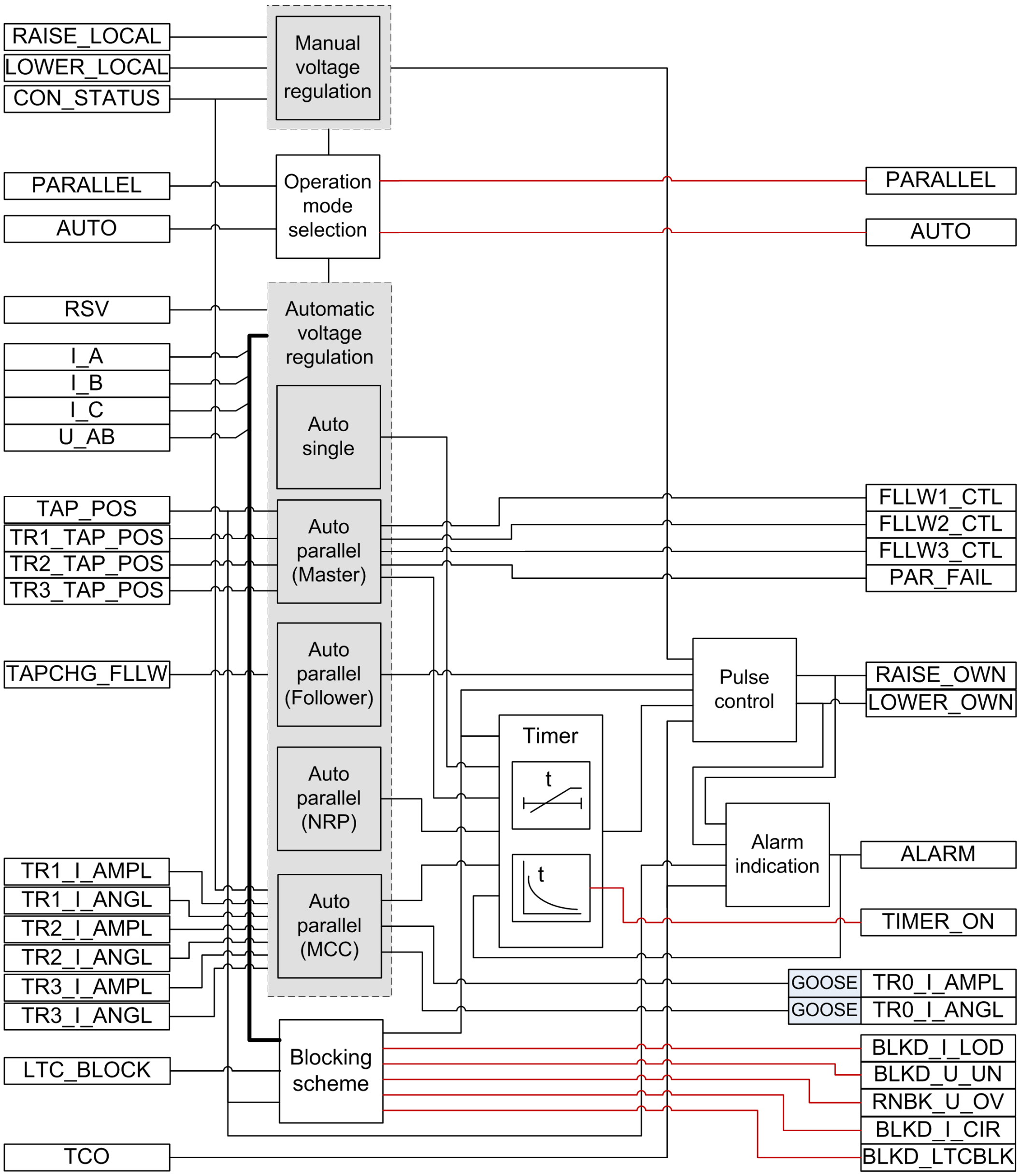


Figure 558: Functional module diagram

9.5.4.1 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.
- 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 186*, *Equation 187* and *Equation 189*.

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.

9.5.4.2 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 TPOSYLTC 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 TPOSYLTC binary inputs are FALSE by default and the value shown is (0). A value other than zero indicates bad quality. A bad-quality tap changer position is dealt by OLATCC like unconnected tap position information.

9.5.4.3 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", "Input control" and “Command”. If the *Operation mode* setting is set to "Input control", the acting operation mode is determined by the inputs PARALLEL and AUTO. When the *Operation mode* setting is set to "Command", the acting operation mode is determined by the IEC 61850 command data points Auto and ParOp. The PARALLEL input and ParOp define if the transformer (voltage regulator) is in the parallel or single mode. The AUTO input defines the operation status in the single mode. PARALLEL and AUTO Monitored data represent acting "Parallel or single operation" and "Auto/Manual indication" respectively.

Table 1013: Acting operation mode determined by the operation mode inputs and command signals

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 "Auto master", "Auto 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.

9.5.4.4 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".

The manual raising or lowering commands can be given locally either via the *Manual control* parameter ("Cancel"/"Lower"/"Raise") located in the HMI menu **Control** > **OLATCC1** or via the configuration inputs LOWER_LOCAL or RAISE_LOCAL.

A raising command is given by selecting the enumeration value "Raise" and the lowering command is given by selecting the enumeration value "Lower". An accepted manual raising/lowering command activates the corresponding output RAISE_OWN or LOWER_OWN to control the voltage of the own transformer.

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 559*. 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.

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.

9.5.4.5 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 184*. 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 559*.

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 559*, 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*.

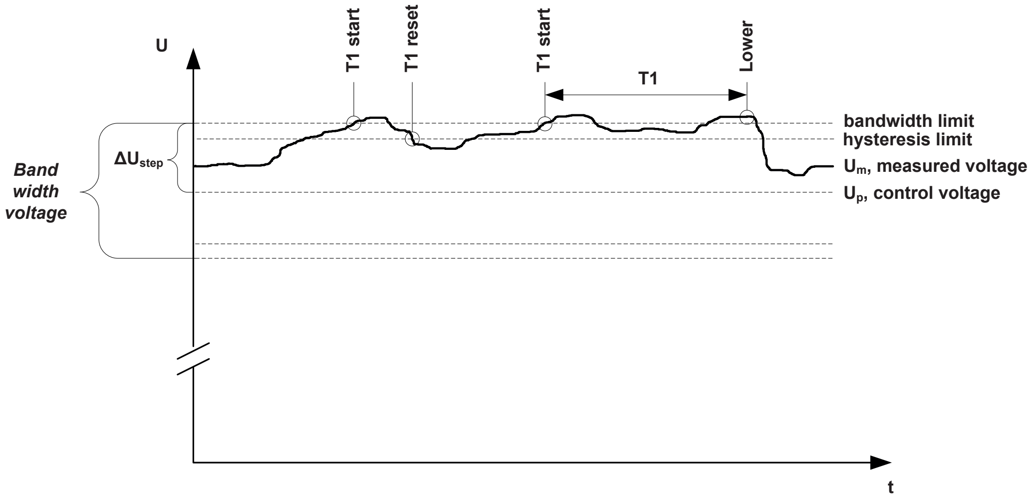


Figure 559: Voltage-regulating function. A control pulse to lower the voltage is issued after the elapsed T1.

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 191*. The bigger the difference in the voltage, the shorter the operating time. More information on the inverse time operation can be found in *Chapter 9.5.4.7 Timer characteristics*.

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 184)

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.

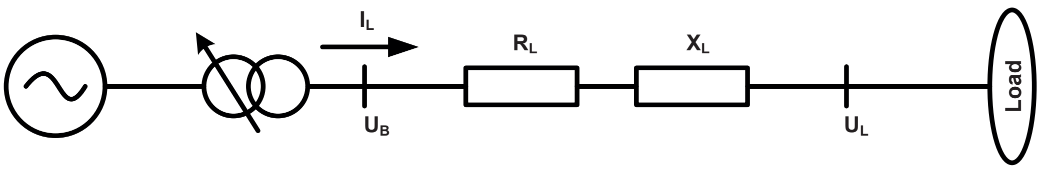


Figure 560: Equivalent electrical circuit for calculating the LDC term

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.

$$Line\ drop\ V\ Ris = U_r[\%] = \frac{\sqrt{3} \cdot I_{CT\_n1} \cdot R}{U_{VT\_n1}} \cdot 100 \quad [\%U_n]$$

$$Line\ drop\ V\ React = U_x[\%] = \frac{\sqrt{3} \cdot I_{CT\_n1} \cdot X}{U_{VT\_n1}} \cdot 100 \quad [\%U_n]$$

(Equation 185)

I_{CT_n1}	Nominal primary current of the CT
U_{VT_n1}	Nominal primary voltage of the VT (phase-to-phase voltage)
R	Resistance of the line, Ω/phase
X	Reactance of the line, Ω/phase

The general LDC equation can be calculated.

$$U_z = \frac{I_{injected}}{I_n} \cdot \frac{\left(U_r[\%]\cos\varphi + U_x[\%]\sin\varphi\right)}{100} \quad [\mathrm{xU_n}]$$

(Equation 186)

$I_{injected}$	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 184*.

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 560* 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 *Chapter 9.5.4.6 Automatic voltage regulation of parallel transformers*.

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.

9.5.4.6 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 184* 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 187* and *Equation 189*) 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 186*) 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 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.

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.

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 TPOSYLTC.

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".

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 561* shows that the circulating current is the reactive component which separates the measured current vector from the expected angle value.

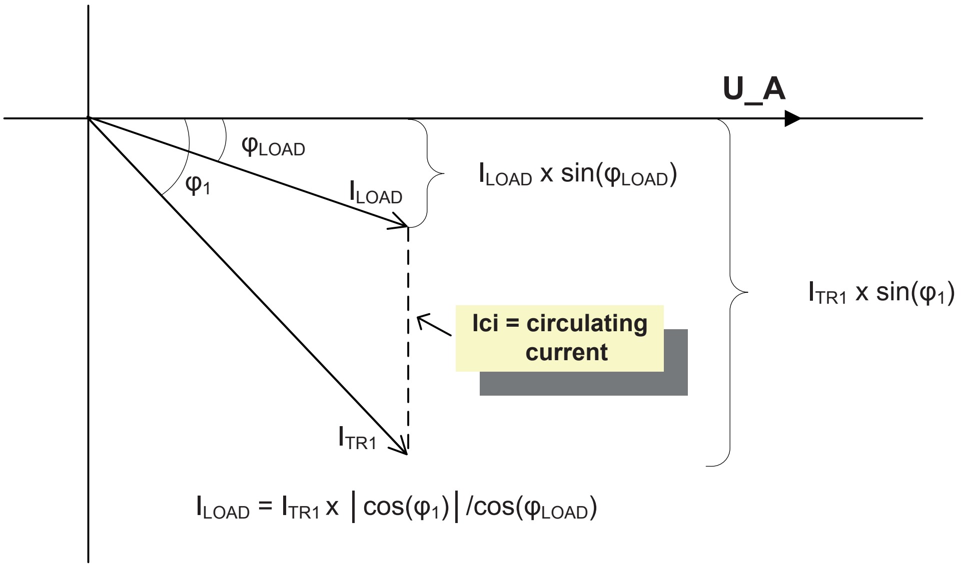


Figure 561: The expected phase angle of the load supplied by the transformers operating in parallel is entered as a setting value ϕ Load

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 187)

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 188)

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.

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.

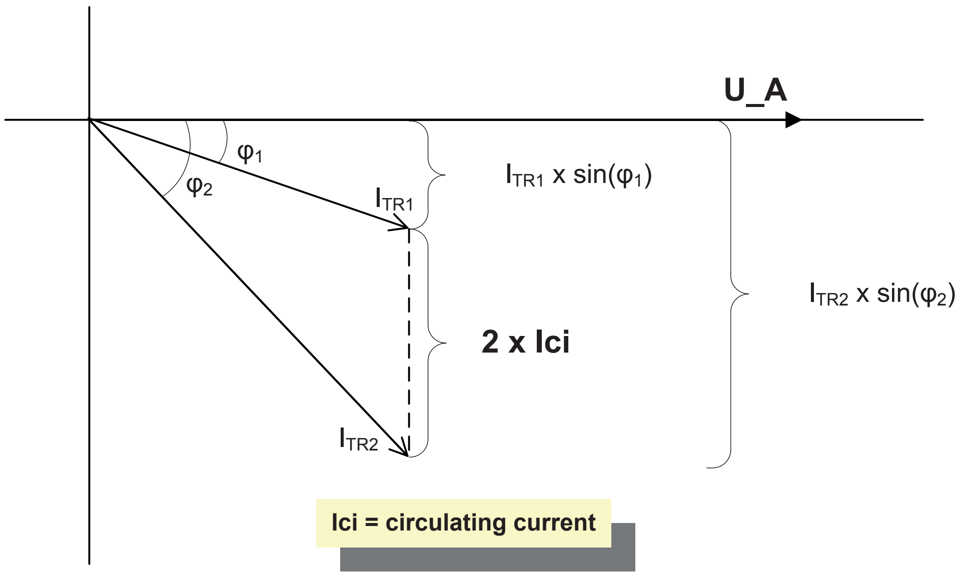


Figure 562: The circulating current between two parallel transformers

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 189)

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

$$U_{ci} = \frac{-I_{ci}}{I_{CT\_n1}} \cdot \frac{\text{Stability}}{100} \cdot U_n$$

(Equation 190)

I_{ci}	Circulating current, primary value
I_{CT_n1}	Nominal primary current of the CT
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 188*. The value of U_{ci}, which can be positive or negative, is considered by adding it to the *Band center voltage* U_s (*Equation 184*). According to *Figure 562* and *Equation 189*, 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 (see *Chapter 9.5.4.1 Voltage and current measurements*). 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.

9.5.4.7 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" mode 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 1014: 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 (*Chapter 9.5.4.9 Blocking scheme*).

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 191)

U_d	$|U_m - U_p|$, differential voltage
U_{BW}	Setting parameter *Band width voltage*

$$t = \frac{T}{2^{(B-1)}}$$

(Equation 192)

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 559*.

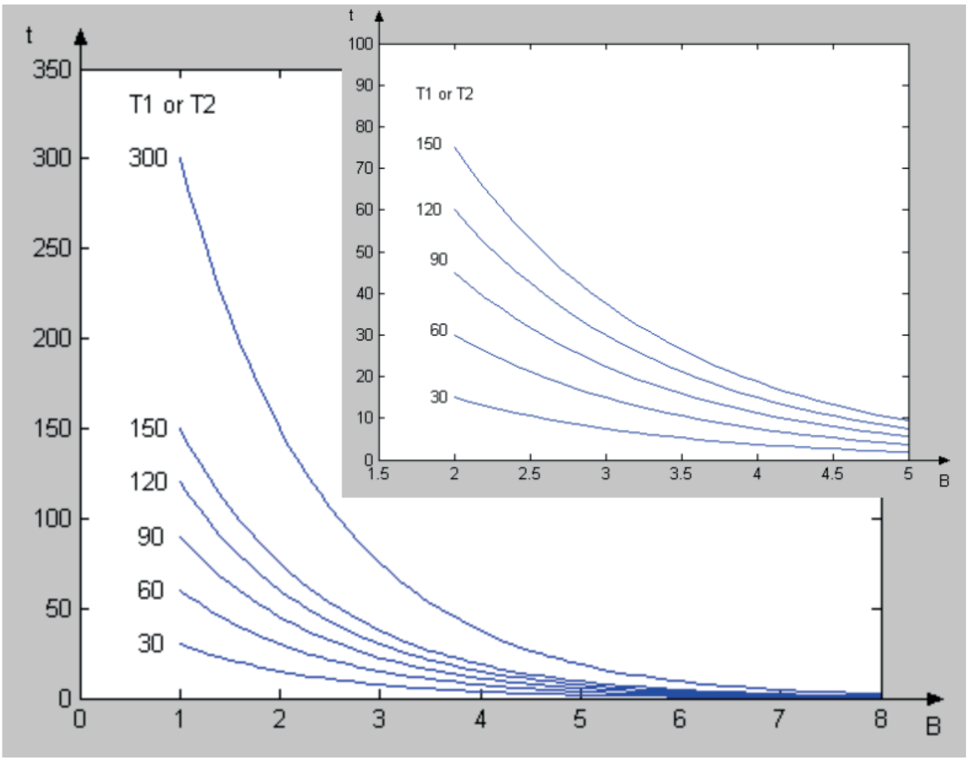


Figure 563: Inverse time characteristic for different values on T1 or T2 (The smaller figure is a zoom-in of the larger one)

9.5.4.8 Pulse control

The tap changer generates an active operating signal when the tap-changing process is active. This signal is used for alarming purposes and must be connected to the TCO input. If the signal is active (=TRUE) for more than 15 seconds after the control pulse has been deactivated, an alarm is generated (*Chapter 9.5.4.10 Alarm indication*). 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 (*Chapter 9.5.4.10 Alarm indication*). Thus, the controller cannot send new pulses to the tap changer when this is already operating because tap changers are typically immune to new pulses when they operate. Furthermore, because the pulses are omitted, the tap changer pulse counter of the controller is not incremented.

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 sent when the tap changer is in operation, the tap changer operating signal can be connected to the `LTC_BLOCK` input. In this case, external blocking is achieved when an automatic pulse is sent to the operating tap changer. By default, the external `LTC_BLOCK` has no effect when the active operation mode is set to "Manual" or "Parallel manual".

The status of the `TCO` input can be read from the `TCO` input data.

9.5.4.9 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. The BLK_STATUS monitored data 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 started due to a timer elapse or a local command. This is to avoid unnecessary event sending.

The BLK_STATUS monitored data is also packed. It contains information about the blocking status as bit-coded output. The block status output does not indicate the actual blocking but indicates if the coming command is successful. The actual blocking is indicated by studying the corresponding monitored data (BLK_I_LOD, BLK_U_UN, RNBK_U_OV, BLK_LTCBLOCK, BLK_I_CIR, BLK_RAISE and BLK_LOWER) values. *Table 1015* illustrates the meaning of different monitored data values. For example, the block status value 9 indicates that there are conditional circulating current and load current blockings (8 + 1 = 9) indicated. By default, the status is “0”.

Table 1015: Bit-coded block status and the meaning of different bits

Bit	Active value	Blocking reason
6 (msb)	64	Lowest position reached
5	32	Highest position reached
4	16	External LTC_BLOCK
3	8	High circuit current
2	4	Overvoltage - Runback raise voltage
1	2	Undervoltage - Block lower voltage
0 (lsb)	1	Overcurrent - Load current

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 given.

Table 1016: 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

Table continues on the next page

Acting operation mode	Command	Load current	Block lowering voltage	Runback raising voltage	High circulating current	External Block	Extreme positions
Auto follower	Raise	X	X			X	X
	Lower	X	X			X	X
Auto single, Auto master, NRP, MCC	Raise	X	X		X	X	X
	Lower	X	X		X [1]	X	X [2]

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 default blocking schema explained in the table operates as such. However, there are also other alternatives that cause different operation when compared to that table.

Table 1017: 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 1018*. Other operation modes follow the default schema.

[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] 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.

Table 1018: 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 1019: 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 1020: 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 1016*) 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 1016*). 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 1016*). However, in the automatic operation mode, the overvoltage situation triggers the fast lowering feature. More information can be found in *Chapter 9.5.4.4 Manual voltage regulation* . 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 1016*). 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 1016*). 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 1016*). It depends on the comparison between the *Raise block tap* and *Lower block tap* settings, which direction is blocked (*Chapter 9.5.4.4 Manual voltage regulation*). This blocking affects both the automatic and manual operation modes.

However, as shown in *Table 1016*, 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 559*). 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 *Chapter 9.5.4.8 Pulse control*)
- 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.

9.5.4.10 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 559*) 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*.

9.5.5 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).

Configuration example for the Manual and Auto single modes

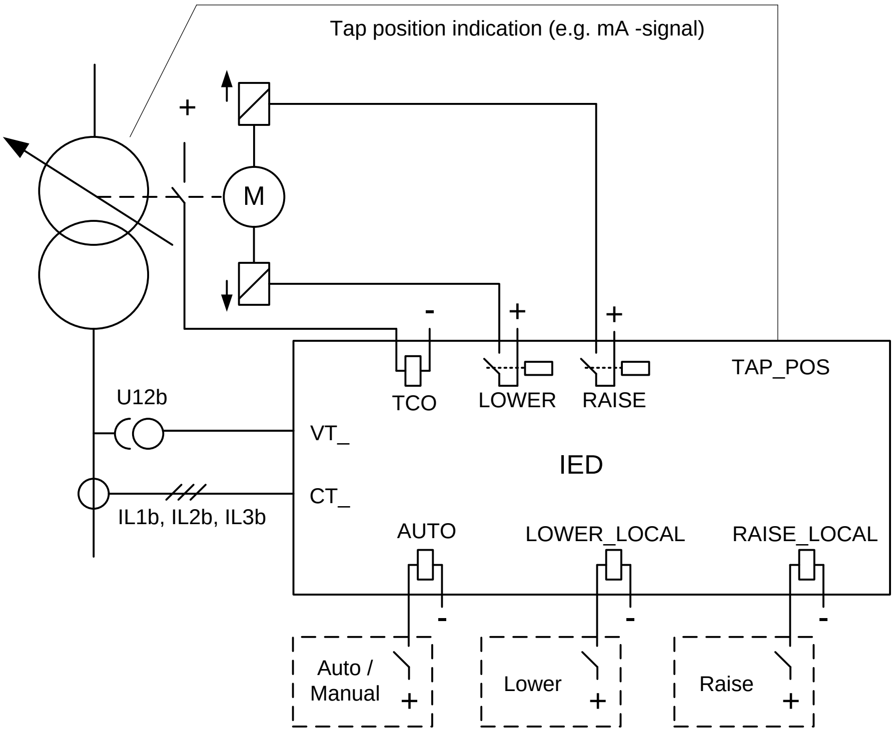


Figure 564: Basic connection diagram for the voltage regulator

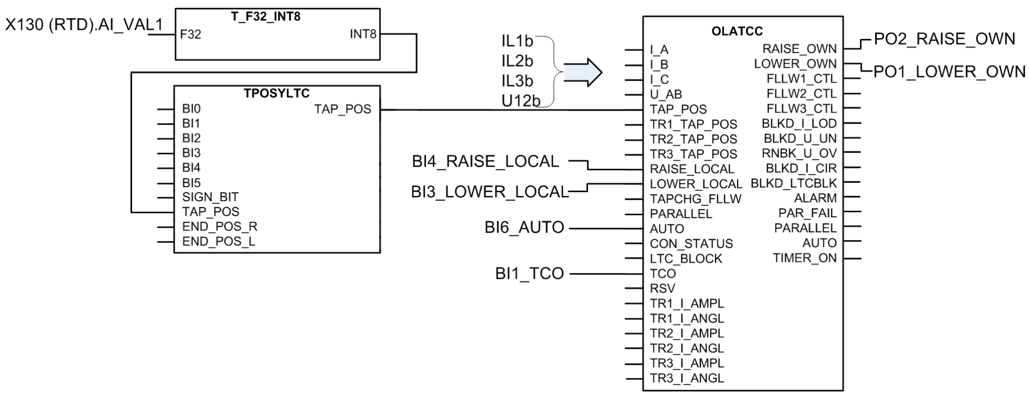


Figure 565: Configuration example for the Manual and Auto single modes

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 signal is first scaled with the X130 (RTD) function. The scaled value is then converted to integer value with T_F32_INT8 function. That integer value is connected to the `TAP_POS` input of the TPOSYLTC function. The tap position value is automatically transferred from TPOSYLTC to OLATCC without 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").

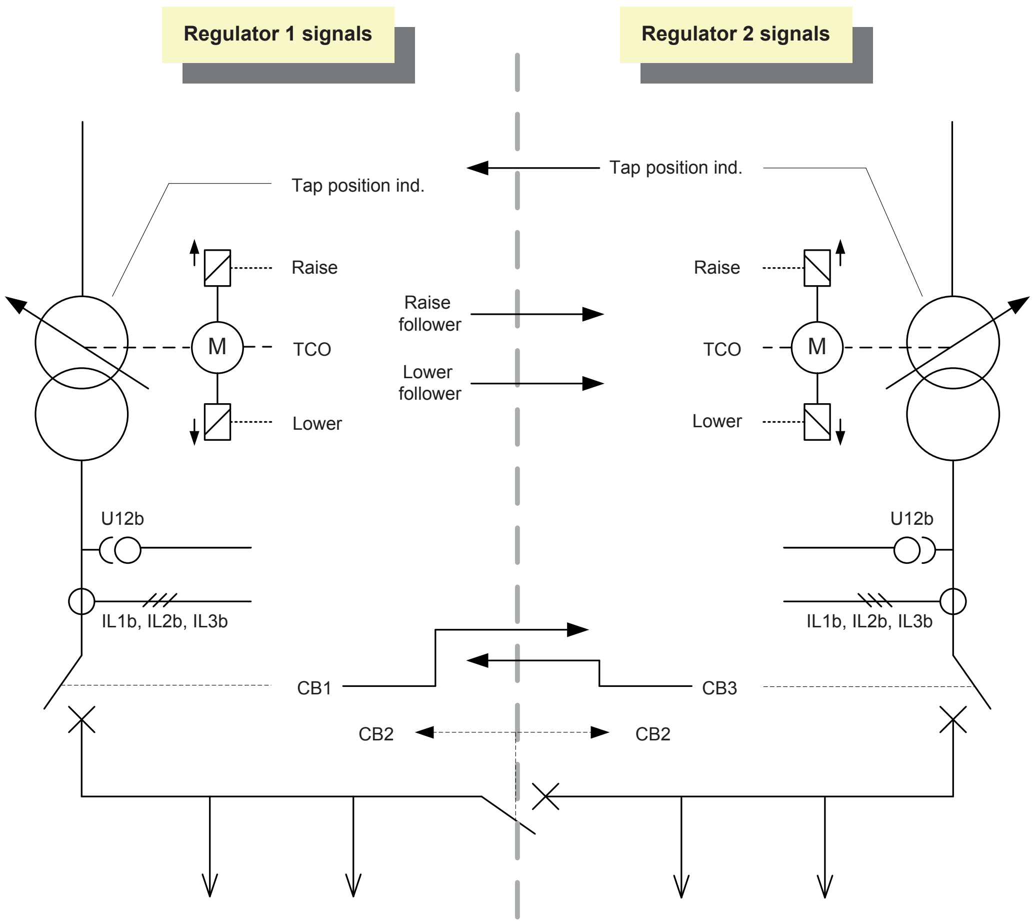


Figure 566: An example of the configuration for the Auto parallel (Master/Follower) mode (the position of the follower known by the master)

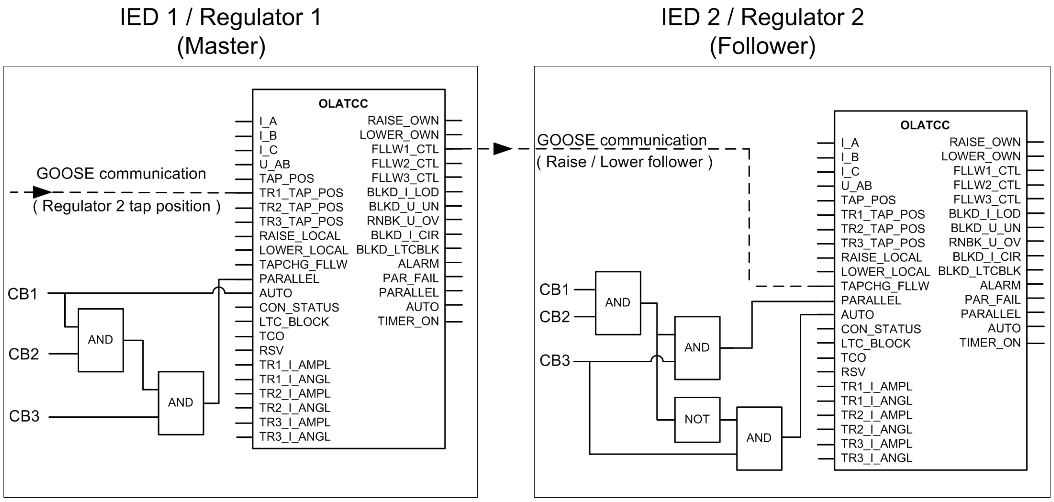


Figure 567: Simplified regulator 1&2 configurations of the Master/Follower example

Table 1021: 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.

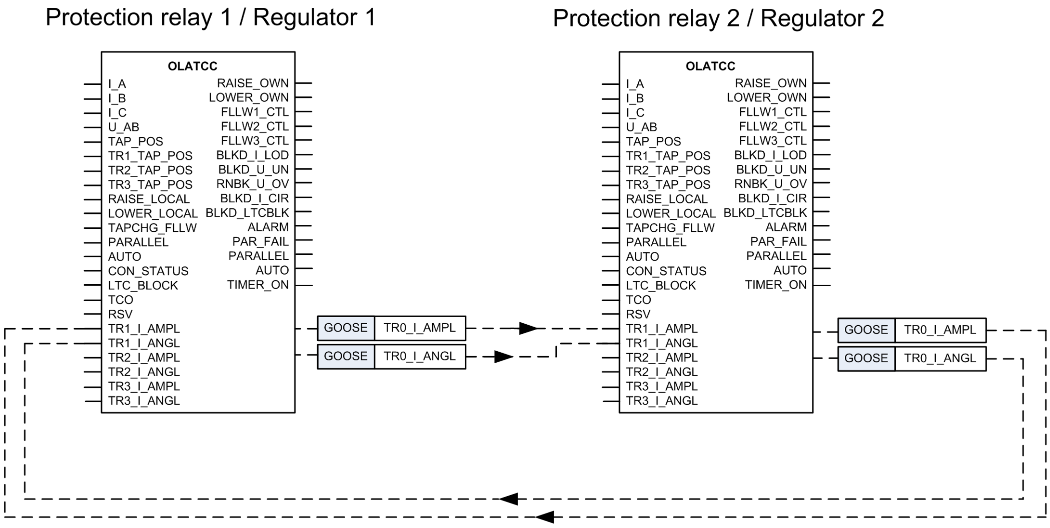


Figure 568: Two parallel transformers and the horizontal connection via GOOSE to transfer current and the phase angle information when the MCC principle is used

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.

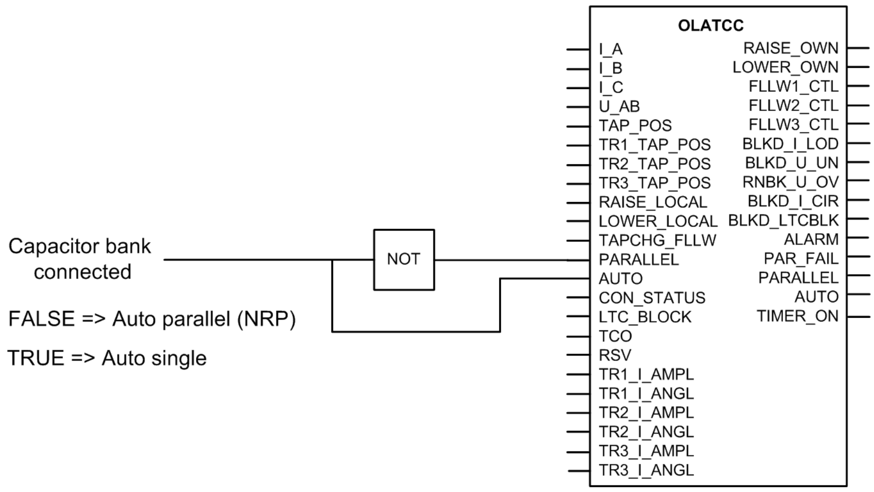


Figure 569: Changing the operation mode of OLATCC automatically when the capacitor bank is connected

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 1022: 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.

Table continues on the next page

Parallel operation modes	Description
	+ 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)

9.5.6 Signals

Table 1023: OLATCC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
U_AB	SIGNAL	0	Phase-to-phase voltage AB
TAP_POS	INT8	0	Integer value representing tap changer position of own transformer
TR1_TAP_POS	INT32	0	Integer value representing tap changer position of transformer 1
TR2_TAP_POS	INT32	0	Integer value representing tap changer position of transformer 2

Table continues on the next page

Name	Type	Default	Description
TR3_TAP_POS	INT32	0	Integer value representing tap changer position of transformer 3
RAISE_LOCAL	BOOLEAN	0=False	Raise command input from configuration
LOWER_LOCAL	BOOLEAN	0=False	Lower command input from configuration
TAPCHG_FLLW	Enum	0=False	Change follower tap position (stop, lower, higher)
PARALLEL	BOOLEAN	0=False	Parallel or single operation
AUTO	BOOLEAN	0=False	Auto/Manual indication
CON_STATUS	BOOLEAN	0=False	Network connection status of the (own) transformer
LTC_BLOCK	BOOLEAN	0=False	External signal for blocking
TCO	BOOLEAN	0=False	Tap changer operating input
RSV	BOOLEAN	0=False	Reduce set voltage active
TR1_I_AMPL	FLOAT32	0.00	Received current magnitude from transformer 1
TR1_I_ANGL	FLOAT32	0.00	Received current angle from transformer 1
TR2_I_AMPL	FLOAT32	0.00	Received current magnitude from transformer 2
TR2_I_ANGL	FLOAT32	0.00	Received current angle from transformer 2
TR3_I_AMPL	FLOAT32	0.00	Received current magnitude from transformer 3
TR3_I_ANGL	FLOAT32	0.00	Received current angle from transformer 3

Table 1024: OLATCC Output signals

Name	Type	Description
RAISE_OWN	BOOLEAN	Raise command for own transformer
LOWER_OWN	BOOLEAN	Lower command for own transformer
FLLW1_CTL	INT32	Lower/Raise command for follower transformer 1 in the Master/Follower operation mode
FLLW2_CTL	INT32	Lower/Raise command for follower transformer 2 in the Master/Follower operation mode
FLLW3_CTL	INT32	Lower/Raise command for follower transformer 3 in the Master/Follower operation mode
ALARM	BOOLEAN	Alarm status
PAR_FAIL	BOOLEAN	Parallel failure detected
PARALLEL	BOOLEAN	Parallel or single operation
AUTO	BOOLEAN	Auto/Manual indication
BLKD_I_LOD	BOOLEAN	Indication of over current blocking
BLKD_U_UN	BOOLEAN	Indication of under voltage blocking
RNBK_U_OV	BOOLEAN	Indication of raise voltage runback
BLKD_I_CIR	BOOLEAN	Indication of high circulating current blocking
BLKD_LTCBLK	BOOLEAN	Indication of external blocking

9.5.7 Settings

Table 1025: OLATCC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Auto parallel mode	2=Auto master 3=Auto follower 5=NRP 7=MCC			2=Auto master	Parallel mode selection
Band center voltage	0.000...2.000	xUn	0.001	1.000	Band center voltage Us
Line drop V Ris	0.0...25.0	%	0.1	0.0	Resistive line-drop compensation factor

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Line drop V React	0.0...25.0	%	0.1	0.0	Reactive line-drop compensation factor
Band reduction	0.00...9.00	%Un	0.01	0.00	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 only with the negative reactance principle
Control delay time 1	1000...300000	ms	100	60000	Control delay time for the first control pulse
Control delay time 2	1000...300000	ms	100	30000	Control delay time for the following control pulses

Table 1026: OLATCC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Manual 2=Auto single 3=Auto parallel 4=Input control 5=Command			5=Command	The operation mode
Custom Man blocking	1=Custom disabled 2=OC 3=UV 4=OC, UV 5=EXT 6=OC, EXT 7=UV, EXT 8=OC, UV, EXT			2=OC	Customized manual blocking
Parallel trafos	0...10		1	0	Number of parallel transformers in addition to own transformer
Delay characteristic	0=Inverse time 1=Definite time			1=Definite time	Selection of delay characteristic
Band width voltage	1.20...18.00	%Un	0.01	3.00	Allowed deviation of the control voltage
Load current limit	0.10...5.00	xIn	0.01	2.00	Load current blocking limit
Block lower voltage	0.10...1.20	xUn	0.01	0.70	Voltage limit, where further voltage lowering commands are blocked
Runback raise V	0.80...2.40	xUn	0.01	1.25	Voltage limit, where fast lower commands takes place
Cir current limit	0.10...5.00	xIn	0.01	0.15	Blocking limit for high circulating current

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
LDC limit	0.00...2.00	xUn	0.01	0.10	Maximum limit for line drop compensation term
Lower block tap	-36...36		1	0	Tap changer limit position which gives lowest voltage on the regulated side
Raise block tap	-36...36		1	17	Tap changer limit position which gives highest voltage on the regulated side
LTC pulse time	500...10000	ms	100	1500	Output pulse duration, common for raise and lower pulses
LDC enable	0=False 1=True			1=True	Selection for line drop compensation

Table 1027: OLATCC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
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
Follower delay time	6...20	s	1	6	Time delay between successive follower commands by a master
Alarms enabled	0=False 1=True			1=True	Alarm selection
Rv Pwr flow allowed	0=False 1=True			0=False	Reverse power flow allowed

9.5.8 Monitored data

Table 1028: OLATCC Monitored data

Name	Type	Values (Range)	Unit	Description
TR0_I_AMPL	FLOAT32	0.00...15000.00	A	Transmitted current magnitude
TR0_I_ANGL	FLOAT32	-180.00...180.00	deg	Transmitted current angle
U_MEAS	FLOAT32	0.00...5.00	xUn	Phase-to-phase voltage, average filtered
ANGL_UA_IA	FLOAT32	-180...180	deg	Measured angle value between

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
				phase A voltage and current
TIMER_STS	Enum	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
OPR_MODE_STS	Enum	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
U_CTL	FLOAT32	0.000...3.000	xUn	Control voltage, Up, target voltage level
UD_CTL	FLOAT32	-2.000...2.000	xUn	Voltage difference between Measured voltage - Control Voltage: Um - Up
I_CIR	FLOAT32	-10.00...10.00	xIn	Calculated circulating current - calculated in operation modes NRP and MCC
LDC	FLOAT32	-2.00...2.00	xUn	Calculated line drop compensation
BLK_STATUS	INT32	0...127		Bit-coded output showing the blocking status for the next operation
ALARM_REAS	Enum	0=No alarm		Status and reason for alarm

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		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		
OP_TM_NUM_H	INT32	0...2147483647		Number of controls for own tap changer during last hour
FAIL_FLLW	Enum	0=No failed followers 1=Follower 1 2=Follower 2 3=Followers 1+2 4=Follower 3 5=Followers 1+3 6=Followers 2+3 7=Followers 1+2+3		Failed followers
PAR_UNIT_MCC	Enum	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	INT32	0...2147483647		Total number of raise and lower commands given in the manual and automatic modes
OLATCC	Enum	1=on 2=blocked		Status

Name	Type	Values (Range)	Unit	Description
		3=test 4=test/blocked 5=off		

9.5.9 Technical data

Table 1029: OLATCC Technical data

Characteristic	Value
Operation accuracy [1]	Depending on the frequency of the measured current: f_n ±2 Hz
	Differential voltage U_d = ±0.5% of the measured value or ±0.005 × U_n (in measured voltages <2.0 × U_n) Operation value = ±1.5% of the U_d for Us = 1.0 × U_n
Operate time accuracy in definite time mode [2]	+4.0%/-0% of the set value
Operate time accuracy in inverse time mode [2]	+8.5%/-0% of the set value (at theoretical B in range of 1.1…5.0) Also note fixed minimum operate time (IDMT) 1 s.
Reset ratio for control operation Reset ratio for analogue based blockings (except run back raise voltage blocking)	Typically 0.80 (1.20) Typically 0.96 (1.04)

9.5.10 Technical revision history

Table 1030: OLATTC Technical revision history

Technical revision	Change
B	Added new output `TIMER_ON` (new 61850 data for that). ACT interface changes by interchanging already existing data between monitored data and output interface. *Operation mode* default to be changed to 4=Input control (previously it was Manual).
C	Internal improvement.
D	Added input `TAP_POS`. Added command mode for *Operation mode* setting.

[1] Default setting values used
[2] Voltage before deviation = set *Band center voltage*

10 Power quality measurement functions

10.1 Current total demand distortion CMHAI

10.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current total demand distortion	CMHAI	PQM3I	PQM3I

10.1.2 Function block

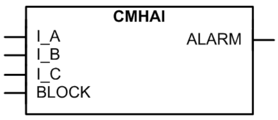


Figure 570: Function block

10.1.3 Functionality

The current total demand distortion function CMHAI is used for monitoring the current total demand distortion TDD.

10.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of CMHAI can be described with a module diagram. All the modules in the diagram are explained in the next sections.

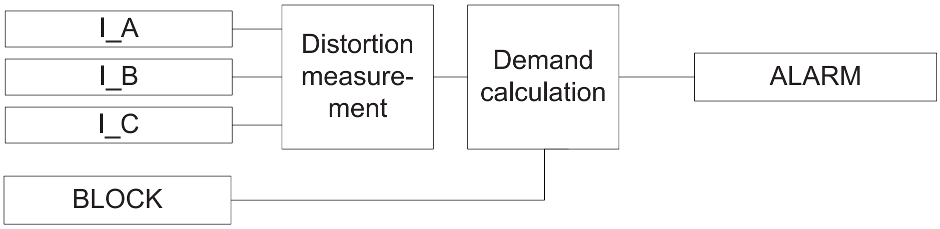


Figure 571: Functional module diagram

Distortion measurement

The distortion measurement module measures harmonics up to the 11th harmonic. The total demand distortion TDD is calculated from the measured harmonic components with the formula

$$TDD = \frac{\sqrt{\sum_{k=2}^{N} I_k^2}}{I_{max\_demand}}$$

(Equation 193)

I_k	k^{th} harmonic component
I_{max_demand}	The maximum demand current measured by CMMXU

If CMMXU is not available in the configuration or the measured maximum demand current is less than the *Initial Dmd current* setting, *Initial Dmd current* is used for I_{max_demand}.

Demand calculation

The demand value for TDD is calculated separately for each phase. If any of the calculated total demand distortion values is above the set alarm limit *TDD alarm limit*, the ALARM output is activated.

The demand calculation window is set with the *Demand interval* setting. It has seven window lengths from "1 minute" to "180 minutes". The window type can be set with the *Demand window* setting. The available options are "Sliding" and "Non-sliding".

The activation of the BLOCK input blocks the ALARM output.

10.1.5 Application

In standards, the power quality is defined through the characteristics of the supply voltage. Transients, short-duration and long-duration voltage variations, unbalance and waveform distortions are the key characteristics describing power quality. Power quality is, however, a customer-driven issue. It could be said that any power problem concerning voltage or current that results in a failure or misoperation of 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. The switch mode power supplies in a number of single-phase electronic equipment, such as personal computers, printers and copiers, have a very high third-harmonic content in the current. Three-phase electronic power converters, that is, dc/ac drives, however, do not generate third-harmonic currents. Still, they can be significant sources of harmonics.

Power quality monitoring is an essential service that utilities can provide for their industrial and key customers. Not only can a monitoring system provide information about system disturbances and their possible causes, it can also detect problem conditions throughout the system before they 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 customer facilities. Thus, power quality monitoring is not only an effective customer service strategy but also a way to protect a utility's reputation for quality power and service.

CMHAI provides a method for monitoring the power quality by means of the current waveform distortion. CMHAI provides a short-term 3-second average and a long-term demand for TDD.

10.1.6 Signals

Table 1031: CMHAI Input signals

Name	Type	Default	Description
I_A	Signal	0	Phase A current
I_B	Signal	0	Phase B current
I_C	Signal	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 1032: CMHAI Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm signal for TDD

10.1.7 Settings

Table 1033: CMHAI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Demand interval	0=1 minute 1=5 minutes 2=10 minutes 3=15 minutes 4=30 minutes 5=60 minutes			2=10 minutes	Time interval for demand calculation

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	6=180 minutes				
Demand window	1=Sliding 2=Non-sliding			1=Sliding	Demand calculation window type
TDD alarm limit	1.0...100.0	%	0.1	50.0	TDD alarm limit

Table 1034: CMHAI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Initial Dmd current	0.10...1.00	xIn	0.01	1.00	Initial demand current

10.1.8 Monitored data

Table 1035: CMHAI Monitored data

Name	Type	Values (Range)	Unit	Description
Max demand TDD IL1	FLOAT32	0.00...500.00	%	Maximum demand TDD for phase A
Max demand TDD IL2	FLOAT32	0.00...500.00	%	Maximum demand TDD for phase B
Max demand TDD IL3	FLOAT32	0.00...500.00	%	Maximum demand TDD for phase C
Time max dmd TDD IL1	Timestamp			Time of maximum demand TDD phase A
Time max dmd TDD IL2	Timestamp			Time of maximum demand TDD phase B
Time max dmd TDD IL3	Timestamp			Time of maximum demand TDD phase C
3SMHTDD_A	FLOAT32	0.00...500.00	%	3 second mean value of TDD for phase A
DMD_TDD_A	FLOAT32	0.00...500.00	%	Demand value for TDD for phase A
3SMHTDD_B	FLOAT32	0.00...500.00	%	3 second mean value of TDD for phase B
DMD_TDD_B	FLOAT32	0.00...500.00	%	Demand value for TDD for phase B

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
3SMHTDD_C	FLOAT32	0.00...500.00	%	3 second mean value of TDD for phase C
DMD_TDD_C	FLOAT32	0.00...500.00	%	Demand value for TDD for phase C

10.2 Voltage total harmonic distortion VMHAI

10.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage total harmonic distortion	VMHAI	PQM3U	PQM3V

10.2.2 Function block

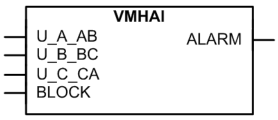


Figure 572: Function block

10.2.3 Functionality

The voltage total harmonic distortion function VMHAI is used for monitoring the voltage total harmonic distortion THD.

10.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of VMHAI can be described with a module diagram. All the modules in the diagram are explained in the next sections.

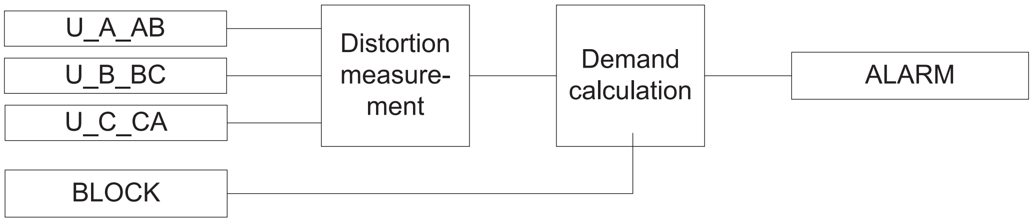


Figure 573: Functional module diagram

Distortion measurement

The distortion measurement module measures harmonics up to the 11th harmonic. The total harmonic distortion THD for voltage is calculated from the measured harmonic components with the formula

$$THD = \frac{\sqrt{\sum_{k=2}^{N} U_k^2}}{U_1}$$

(Equation 194)

U_k	k^{th} harmonic component
U_1	the voltage fundamental component amplitude

Demand calculation

The demand value for THD is calculated separately for each phase. If any of the calculated demand THD values is above the set alarm limit *THD alarm limit*, the ALARM output is activated.

The demand calculation window is set with the *Demand interval* setting. It has seven window lengths from "1 minute" to "180 minutes". The window type can be set with the *Demand window* setting. The available options are "Sliding" and "Non-sliding".

The activation of the BLOCK input blocks the ALARM output.

10.2.5 Application

VMHAI provides a method for monitoring the power quality by means of the voltage waveform distortion. VMHAI provides a short-term three-second average and long-term demand for THD.

10.2.6 Signals

Table 1036: VMHAI Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 1037: VMHAI Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm signal for THD

10.2.7 Settings

Table 1038: VMHAI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Demand interval	0=1 minute 1=5 minutes 2=10 minutes 3=15 minutes 4=30 minutes 5=60 minutes 6=180 minutes			2=10 minutes	Time interval for demand calculation
Demand window	1=Sliding 2=Non-sliding			1=Sliding	Demand calculation window type
THD alarm limit	1.0...100.0	%	0.1	50.0	THD alarm limit

10.2.8 Monitored data

Table 1039: VMHAI Monitored data

Name	Type	Values (Range)	Unit	Description
Max demand THD UL1	FLOAT32	0.00...500.00	%	Maximum demand THD for phase A
Max demand THD UL2	FLOAT32	0.00...500.00	%	Maximum demand THD for phase B
Max demand THD UL3	FLOAT32	0.00...500.00	%	Maximum demand THD for phase C
Time max dmd THD UL1	Timestamp			Time of maximum demand THD phase A
Time max dmd THD UL2	Timestamp			Time of maximum demand THD phase B
Time max dmd THD UL3	Timestamp			Time of maximum demand THD phase C
3SMHTHD_A	FLOAT32	0.00...500.00	%	3 second mean value of THD for phase A
DMD_THD_A	FLOAT32	0.00...500.00	%	Demand value for THD for phase A
3SMHTHD_B	FLOAT32	0.00...500.00	%	3 second mean value of THD for phase B
DMD_THD_B	FLOAT32	0.00...500.00	%	Demand value for THD for phase B
3SMHTHD_C	FLOAT32	0.00...500.00	%	3 second mean value of THD for phase C
DMD_THD_C	FLOAT32	0.00...500.00	%	Demand value for THD for phase C

10.2.9 Technical revision history

Table 1040: VMHAI Technical revision history

Technical revision	Change
B	Internal improvement.
C	Internal improvement.

10.3 Voltage variation PHQVVR

10.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage variation	PHQVVR	PQMU	PQMV

10.3.2 Function block

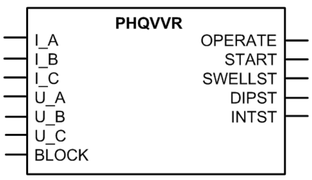


Figure 574: Function block

10.3.3 Functionality

The voltage variation 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 voltage variation to be implemented using the RMS value of the voltage. IEEE standard 1159-1995 provides recommendations for monitoring the electric power quality of the single-phase and polyphase ac power systems.

PHQVVR contains a blocking functionality. It is possible to block a set of function outputs or the function itself.

10.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHQVVR can be described with a module diagram. All the modules in the diagram are explained in the next sections.

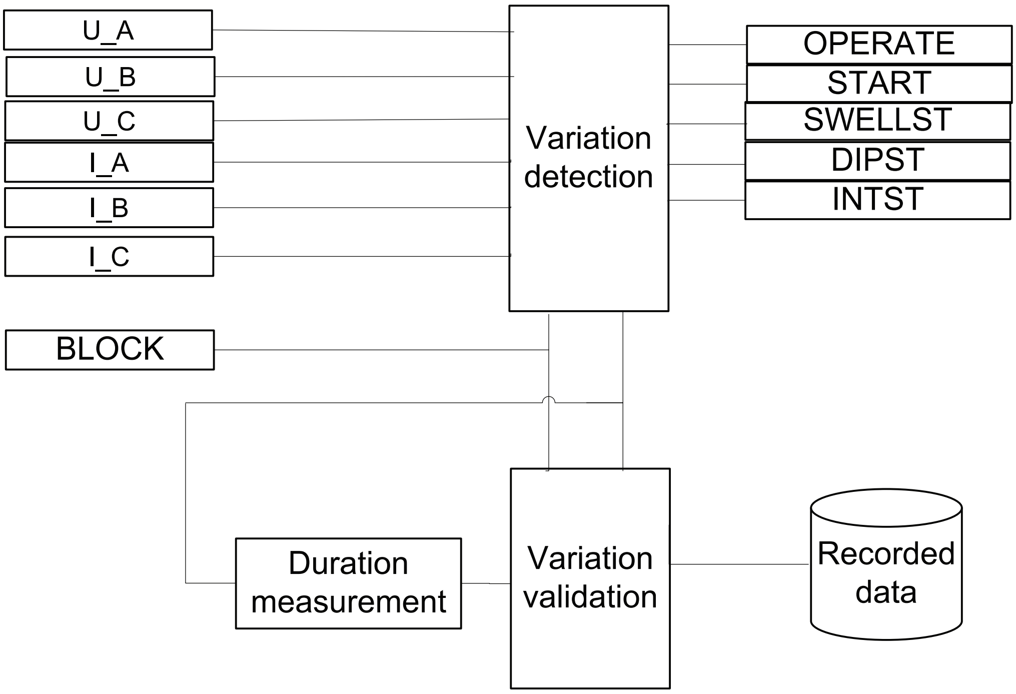


Figure 575: Functional module diagram

10.3.4.1 Phase mode setting

PHQVVR is designed for both single-phase and polyphase ac power systems, and selection can be made with the *Phase mode* setting, which can be set either to the "Single Phase" or "Three Phase" mode. The default setting is "Single Phase".

The basic difference between these alternatives depends on how many phases are needed to have the voltage variation activated. When the *Phase mode* setting is "Single Phase", the activation is straightforward. There is no dependence between the phases for variation start. The START output and the corresponding phase start are activated when the limit is exceeded or undershot. The corresponding phase start deactivation takes place when the limit (includes small hysteresis) is undershot or exceeded. The START output is deactivated when there are no more active phases.

However, when *Phase mode* is "Three Phase", all the monitored phase signal magnitudes, defined with *Phase supervision*, have to fall below or rise above the limit setting to activate the START output and the corresponding phase output, that is, all the monitored phases have to be activated. Accordingly, the deactivation occurs when the activation requirement is not fulfilled, that is, one or more monitored phase signal magnitudes return beyond their limits. Phases do not need to be activated by the same variation type to activate the START output. Another consequence is that if only one or two phases are monitored, it is sufficient that these monitored phases activate the START output.

10.3.4.2 Variation detection

The module compares the measured voltage against the limit settings. If 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, that is, when there is a voltage different from the nominal voltage, the *Reference voltage* setting is set to this voltage.

The *Variation enable* setting is used for enabling or disabling the variation types. By default, the setting value is "Swell+dip+Int" and all the alternative variation types are indicated. For example, for setting "Swell+dip", the interruption detection is not active and only swell or dip events are indicated.

In a case where *Phase mode* is "Single Phase" and the dip functionality is available, the output DIPST is activated when the measured TRMS value drops below the *Voltage dip set 3* setting in one phase and also remains above the *Voltage Int set* setting. If the voltage drops below the *Voltage Int set* setting, the output INTST is activated. INTST is deactivated when the voltage value rises above the setting *Voltage Int set*. When the same measured TRMS magnitude rises above the setting *Voltage swell set 3*, the SWELLST output is activated.

There are three setting value limits for dip (*Voltage dip set 1..3*) and swell activation (*Voltage swell set 1..3*) and one setting value limit for interruption.

If *Phase mode* is "Three Phase", the DIPST and INTST outputs are activated when the voltage levels of all monitored phases, defined with the parameter *Phase supervision*, drop below the *Voltage Int set* setting value. An example for the detection principle of voltage interruption for "Three Phase" when *Phase supervision* is "Ph A + B + C", and also the corresponding start signals when *Phase mode* is "Single Phase", are as shown in the example for the detection of a three-phase interruption.

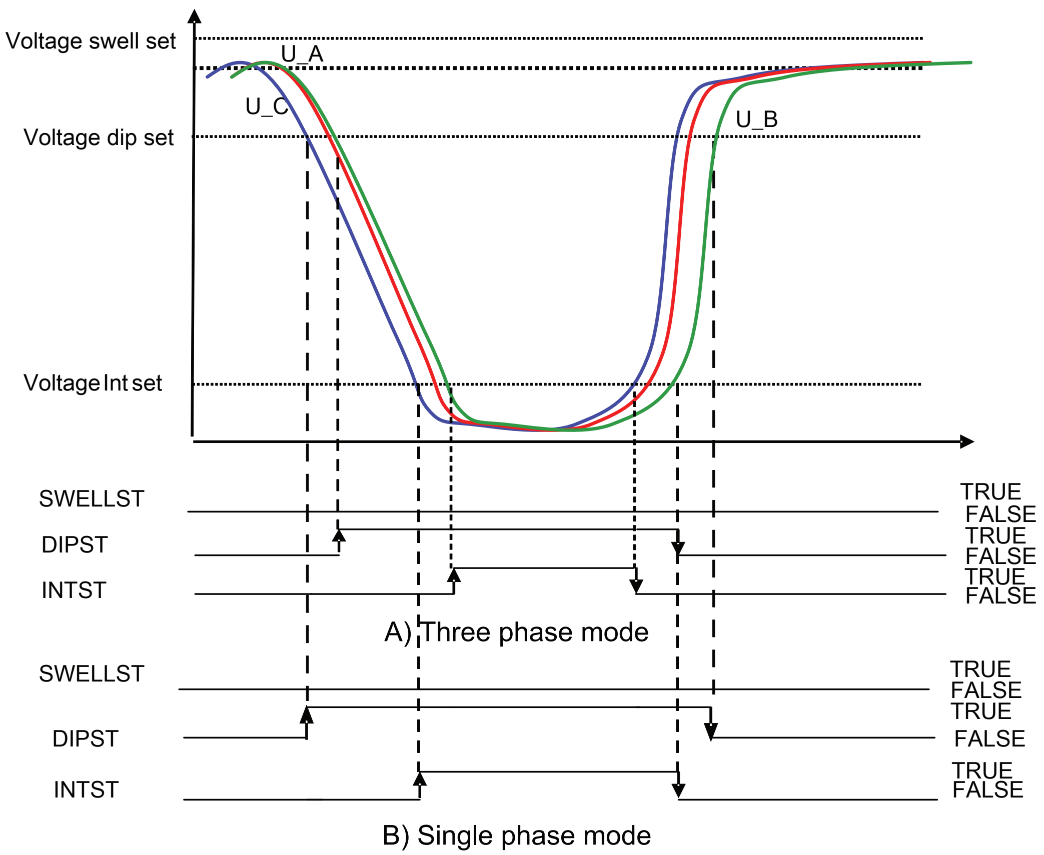


Figure 576: Detection of three-phase voltage interruption

The module measures voltage variation magnitude on each phase separately, that is, there are phase-segregated outputs ST_A, ST_B and ST_C for voltage variation indication. The configuration parameter *Phase supervision* 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 a voltage interruption in that phase.

The maximum magnitude and depth are defined as percentage values calculated from the difference between the reference and the measured voltage. For example, a dip to 70 percent means that the minimum voltage dip magnitude variation is 70 percent of the reference voltage amplitude.

The activation of the BLOCK input resets the function and outputs.

10.3.4.3 Variation validation

The validation criterion for voltage variation is that the measured total variation duration is between the set minimum and maximum durations (Either one of *VVa dip time 1*, *VVa swell time 1* or *VVa Int time 1*, depending on the variation type, and *VVa Dur Max*). The maximum variation duration setting is the same for all variation types.

Figure 577 shows voltage dip operational regions. In *Figure 576*, only one voltage dip/swell/Int set is drawn, whereas in this figure there are three sub-limits for the dip operation. When *Voltage dip set 3* is undershot, the corresponding ST_x and also the DIPST outputs are activated. When the TRMS voltage magnitude remains between *Voltage dip set 2* and *Voltage dip set 1* for a period longer than *VVa dip time 2* (shorter time than *VVa dip time 3*), a momentary dip event is detected. Furthermore, if the signal magnitude stays between the limits longer than *VVa dip time 3* (shorter time than *VVa Dur max*), a temporary dip event is detected. If the voltage remains below *Voltage dip set 1* for a period longer than *VVa dip time 1* but a shorter time than *VVa dip time 2*, an instantaneous dip event is detected.

For an event detection, the OPERATE output is always activated for one task cycle. The corresponding counter and only one of them (INSTDIPCNT, MOMDIPCNT or TEMPDIPCNT) is increased by one. If the dip limit undershooting duration is shorter than *VVa dip time 1*, *VVa swell time 1* or *VVa Int time 1*, the event is not detected at all, and if the duration is longer than *VVa Dur Max*, MAXDURDIPCNT is increased by one but no event detection resulting in the activation of the OPERATE output and recording data update takes place. These counters are available through the monitored data view on the LHMI or through tools via communications. There are no phase-segregated counters but all the variation detections are registered to a common time/magnitude-classified counter type. Consequently, a simultaneous multiphase event, that is, the variation-type event detection time moment is exactly the same for two or more phases, is counted only once also for single-phase power systems.

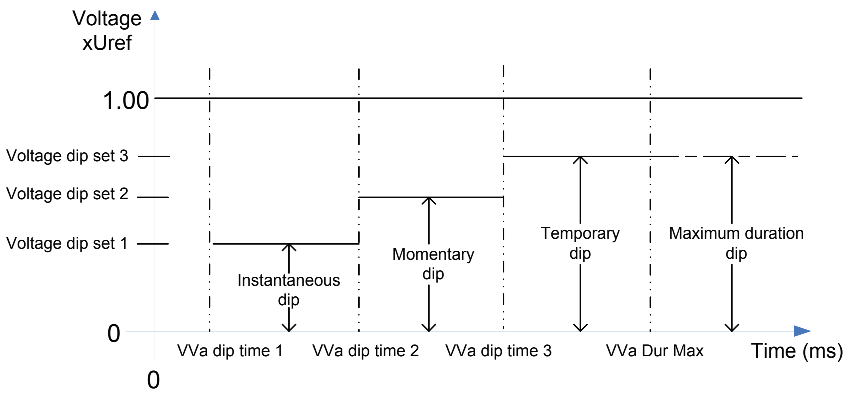


Figure 577: Voltage dip operational regions

In *Figure 578*, the corresponding limits regarding the swell operation are provided with the inherent magnitude limit order difference. The swell functionality principle is the same as for dips, but the different limits for the signal magnitude and times and the inherent operating zone change (here, *Voltage swell set x* > 1.0 xUn) are applied.

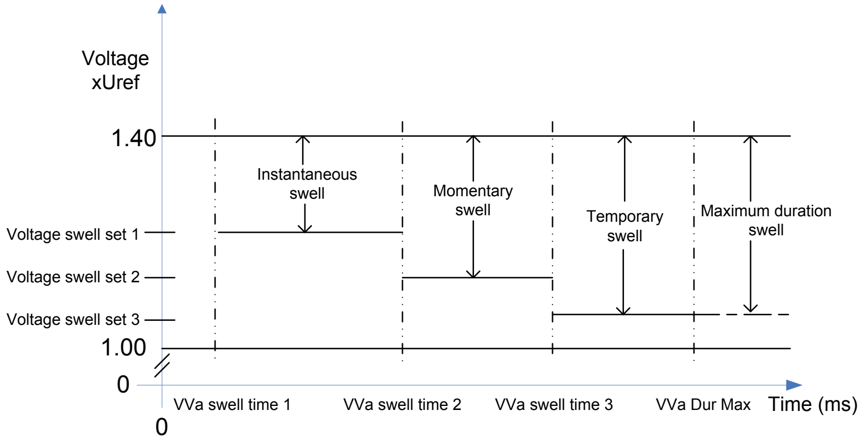


Figure 578: Voltage swell operational regions

For interruption, as shown in *Figure 579*, there is only one magnitude limit but four duration limits for interruption classification. Now the event and counter type depends only on variation duration time.

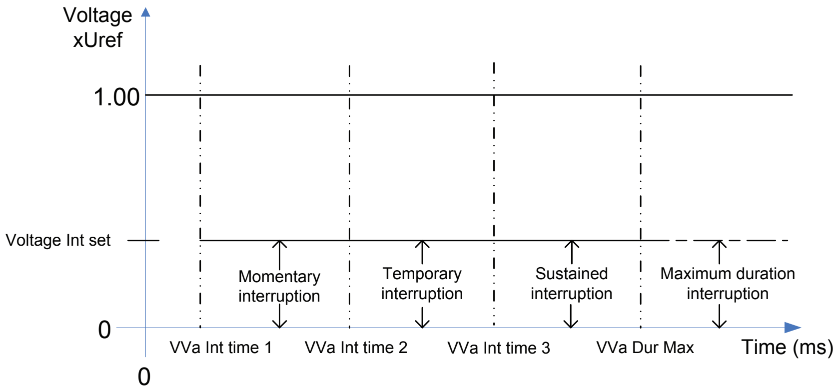


Figure 579: Interruption operating regions

Generally, no event detection is done if both the magnitude and duration requirements are not fulfilled. For example, the dip event does not indicate if the TRMS voltage magnitude remains between *Voltage dip set 3* and *Voltage dip set 2* for a period shorter than *VVa dip time 3* before rising back above *Voltage dip set 3*.

The event indication ends and possible detection is done when the TRMS voltage returns above (for dip and interruption) or below (for swell) the activation-starting limit. For example, after an instantaneous dip, the event indication when the voltage magnitude exceeds *Voltage dip set 1* is not detected (and recorded) immediately but only if no longer dip indication for the same dip variation takes place and maximum duration time for dip variation does not exceed before the signal magnitude rises above *Voltage dip set 3*. There is a small hysteresis for all these limits to avoid the oscillation of the output activation. No drop-off approach is applied here due to the hysteresis.

Consequently, only one event detection and recording of the same variation type can take place for one voltage variation, so the longest indicated variation of each variation type is detected. Furthermore, it is possible that another instantaneous dip event replaces the one already indicated if the magnitude again undershoots *Voltage dip set 1* for the set time after the first detection and the signal magnitude or time requirement is again fulfilled. Another possibility is that if the time condition is not fulfilled for an instantaneous dip detection but the signal rises above *Voltage dip set 1*, the already elapsed time is included in the momentary dip timer. Especially the interruption time is included in the dip time. If the signal does not exceed *Voltage dip set 2* before the timer *VVa dip time 2* has elapsed when the momentary dip timer is also started after the magnitude undershooting *Voltage dip set 2*, the momentary dip event instead is detected. Consequently, the same dip occurrence with a changing variation depth can result in several dip event indications but only one detection. For example, if the magnitude has undershot *Voltage dip set 1* but remained above *Voltage Intr set* for a shorter time than the value of *VVa dip time 1* but the signal rises between *Voltage dip set 1* and *Voltage dip set 2* so that the total duration of the dip activation is longer than *VVa dip time 2* and the maximum time is not overshot, this is detected as a momentary dip even though a short instantaneous dip period has been included. In text, the terms "deeper" and "higher" are used for referring to dip or interruption.

Although examples are given for dip events, the same rules can be applied to the swell and interruption functionality too. For swell indication, "deeper" means that the signal rises even more and "higher" means that the signal magnitude becomes lower respectively.

The adjustable voltage thresholds adhere to the relationships:

VVa dip time 1 ≤ *VVa dip time 2* ≤ *VVa dip time 3*.

VVa swell time 1 ≤ *VVa swell time 2* ≤ *VVa swell time 3*.

VVa Int time 1 ≤ *VVa Int time 2* ≤ *VVa Int time 3*.

There is a validation functionality built-in function that checks the relationship adherence so that if *VVa x time 1* is set higher than *VVa x time 2* or *VVa x time 3*, *VVa x time 2* and *VVa x time 3* are set equal to the new *VVa x time 1*. If *VVa x time 2* is set higher than *VVa x time 3*, *VVa x time 3* is set to the new *VVa x time 2*. If *VVa x time 2* is set lower than *VVa x time 1*, the entered *VVa x time 2* is rejected. If *VVa x time 3* is set lower than *VVa x time 2*, the entered *VVa x time 3* is rejected.

10.3.4.4 Duration measurement

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 580*. 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.

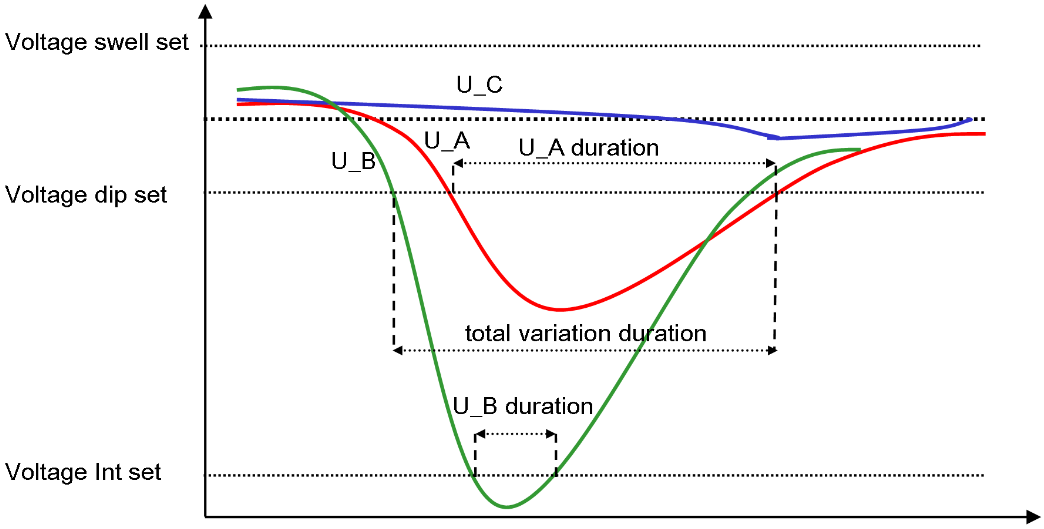


Figure 580: Single-phase interruption for the Phase mode value "Single Phase"

10.3.4.5 Three/single-phase selection variation examples

The provided rules always apply for single-phase (*Phase Mode* is "Single Phase") power systems. However, for three-phase power systems (where *Phase Mode* is "Three Phase"), it is required that all the phases have to be activated before the activation of the `START` output. Interruption event indication requires all three phases to undershoot *Voltage Int set* simultaneously, as shown in *Figure 576*. When the requirement for interruption for "Three Phase" is no longer fulfilled, variation is indicated as a dip as long as all phases are active.

In case of a single-phase interruption of *Figure 580*, when there is a dip indicated in another phase but the third phase is not active, there is no variation indication start when *Phase Mode* is "Three Phase". In this case, only the *Phase Mode* value "Single Phase" results in the `ST_B` interruption and the `ST_A` dip.

It is also possible that there are simultaneously a dip in one phase and a swell in other phases. The functionality of the corresponding event indication with one inactive phase is shown in *Figure 581*. Here, the "Swell + dip" variation type of *Phase mode* is "Single Phase". For the selection "Three Phase" of *Phase mode*, no event indication or any activation takes place due to a non-active phase.

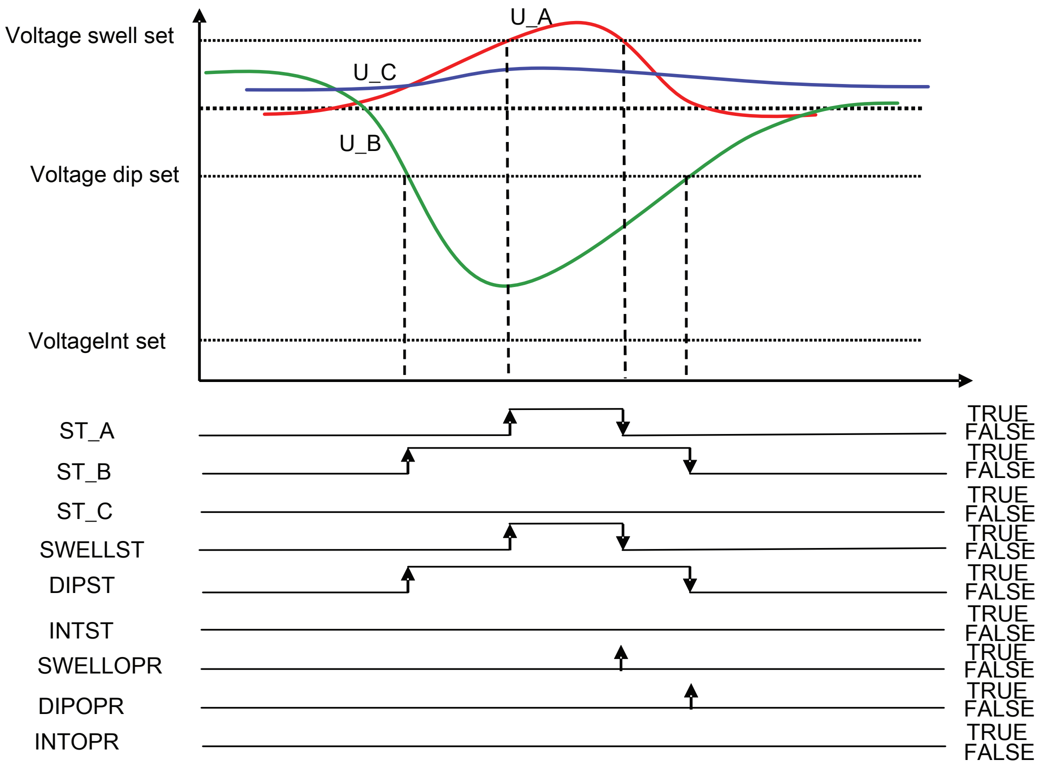


Figure 581: Concurrent dip and swell when Phase mode is "Single Phase"

In *Figure 582*, one phase is in dip and two phases have a swell indication. For the *Phase Mode* value "Three Phase", the activation occurs only when all the phases are active. Furthermore, both swell and dip variation event detections take place simultaneously. In case of a concurrent voltage dip and voltage swell, both SWELLCNT and DIPCNT are incremented by one.

Also *Figure 582* shows that for the *Phase Mode* value "Three Phase", two different time moment variation event swell detections take place and, consequently, DIPCNT is incremented by one but SWELLCNT is totally incremented by two. Both in *Figure 581* and *Figure 582* it is assumed that variation durations are sufficient for detections to take place.

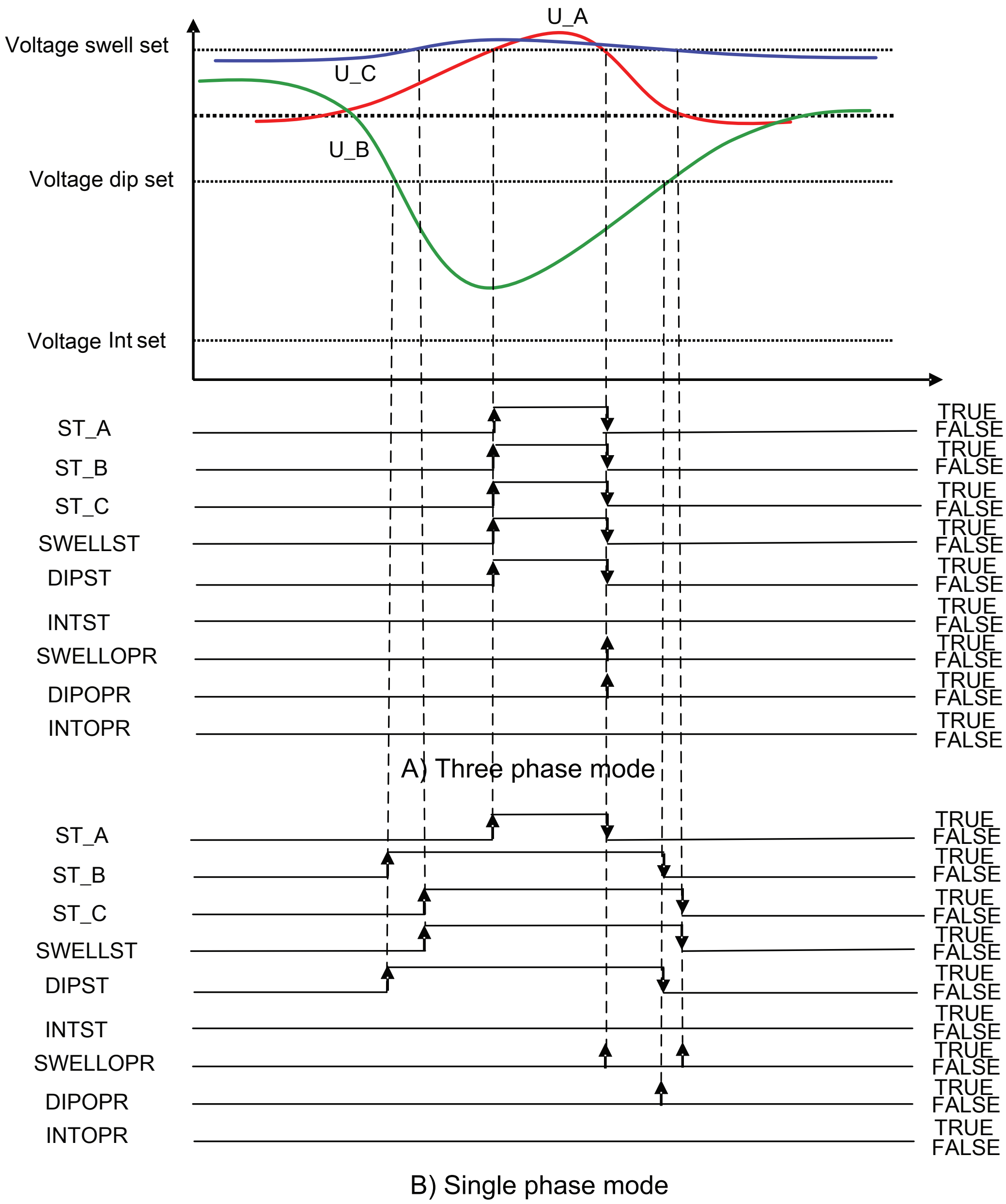


Figure 582: Concurrent dip and two-phase swell

10.3.5 Recorded data

Besides counter increments, the information required for a later fault analysis is stored after a valid voltage variation is detected.

Recorded data information

When voltage variation starts, the phase current magnitudes preceding the activation moment are stored. Also, the initial voltage magnitudes are temporarily stored at the variation starting 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, as shown in *Figure 583*. The function tracks each variation-active voltage phase, and the minimum or maximum magnitude corresponding to swell or dip/interruption during variation is temporarily stored. If the minimum or maximum is found in tracking and a new magnitude is stored, also the inactive phase voltages are stored at the same moment, that is, the inactive phases are not magnitude-tracked. The time instant (time stamp) at which the minimum or maximum magnitude is measured is also temporarily stored for each voltage phase where variation is active. Finally, variation detection triggers the recorded data update when the variation activation ends and the maximum duration time is not exceeded.

The data objects to be recorded for PHQVVR are given in *Table 1041*. There are totally three data banks, and the information given in the table refers to one data bank content.

The three sets of recorded data available are saved in data banks 1-3. The data bank 1 holds always the most recent recorded data, and the older data sets are moved to the next 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 newest data are placed into bank 1 and the data in bank 3 are overwritten by the data from bank 2.

Figure 583 shows a valid recorded voltage interruption and two dips for the *Phase mode* value "Single Phase". The first dip event duration is based on the `U_A` duration, while the second dip is based on the time difference between the dip stop and start times. The first detected event is an interruption based on the `U_B` duration given in *Figure 583*. It is shown also with dotted arrows how voltage time stamps are taken before the final time stamp for recording, which is shown as a solid arrow. Here, the `U_B` timestamp is not taken when the `U_A` activation starts.

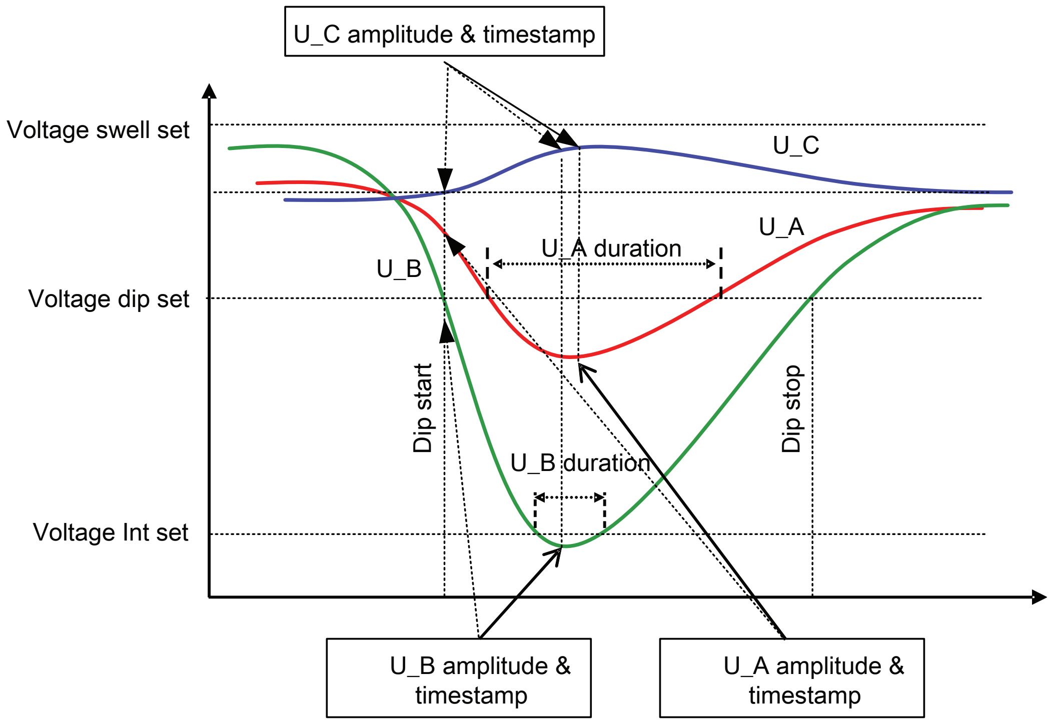


Figure 583: Valid recorded voltage interruption and two dips

Table 1041: PHQVVR recording data bank parameters

Parameter description	Parameter name
Event detection triggering time stamp	Time
Variation type	Variation type
Variation magnitude Ph A	Variation Ph A
Variation magnitude Ph A time stamp (maximum/minimum magnitude measuring time moment during variation)	Var Ph A rec time
Variation magnitude Ph B	Variation Ph B
Variation magnitude Ph B time stamp (maximum/minimum magnitude measuring time moment during variation)	Var Ph B rec time
Variation magnitude Ph C	Variation Ph C
Variation magnitude Ph C time stamp (maximum/minimum magnitude measuring time moment during variation)	Var Ph C rec time
Variation duration Ph A	Variation Dur Ph A
Variation Ph A start time stamp (phase A variation start time moment)	Var Dur Ph A time
Variation duration Ph B	Variation Dur Ph B
Variation Ph B start time stamp (phase B variation start time moment)	Var Dur Ph B time
Variation duration Ph C	Variation Dur Ph C
Variation Ph C start time stamp (phase C variation start time moment)	Var Dur Ph C time
Current magnitude Ph A preceding variation	Var current Ph A
Current magnitude Ph B preceding variation	Var current Ph B
Current magnitude Ph C preceding variation	Var current Ph C

Table 1042: Enumeration values for the recorded data parameters

Setting name	Enum name	Value
Variation type	Swell	1
Variation type	Dip	2
Variation type	Swell + dip	3
Variation type	Interruption	4
Variation type	Swell + Int	5
Variation type	Dip + Int	6
Variation type	Swell+dip+Int	7

10.3.6 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 drop 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.

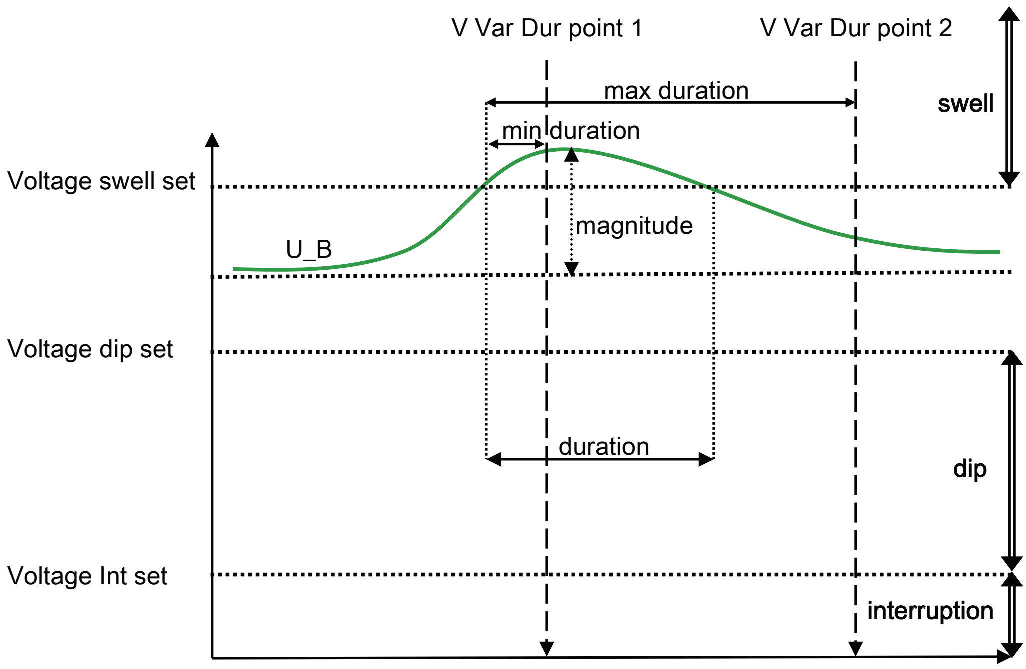


Figure 584: Duration and voltage magnitude limits for swell, dip and interruption measurement

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. Furthermore, IEEE Std 1159-1995 gives the recommended practice for monitoring the electric power quality.

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. The measurement mode is always TRMS.

10.3.7 Signals

Table 1043: PHQVVR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current magnitude
I_B	SIGNAL	0	Phase B current magnitude
I_C	SIGNAL	0	Phase C current magnitude
U_A	SIGNAL	0	Phase-to-earth voltage A
U_B	SIGNAL	0	Phase-to-earth voltage B
U_C	SIGNAL	0	Phase-to-earth voltage C
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 1044: PHQVVR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Voltage variation detected
START	BOOLEAN	Voltage variation present
SWELLST	BOOLEAN	Voltage swell active
DIPST	BOOLEAN	Voltage dip active
INTST	BOOLEAN	Voltage interruption active

10.3.8 Settings

Table 1045: PHQVVR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Reference voltage	10.0...200.0	%Un	0.1	57.7	Reference supply voltage in %
Voltage dip set 1	10.0...100.0	%	0.1	80.0	Dip limit 1 in % of reference voltage
VVa dip time 1	0.5...54.0	cycles	0.1	3.0	Voltage variation dip duration 1
Voltage dip set 2	10.0...100.0	%	0.1	80.0	Dip limit 2 in % of reference voltage
VVa dip time 2	10.0...180.0	cycles	0.1	30.0	Voltage variation dip duration 2
Voltage dip set 3	10.0...100.0	%	0.1	80.0	Dip limit 3 in % of reference voltage
VVa dip time 3	2000...60000	ms	10	3000	Voltage variation dip duration 3
Voltage swell set 1	100.0...140.0	%	0.1	120.0	Swell limit 1 in % of reference voltage
VVa swell time 1	0.5...54.0	cycles	0.1	0.5	Voltage variation swell duration 1
Voltage swell set 2	100.0...140.0	%	0.1	120.0	Swell limit 2 in % of reference voltage
VVa swell time 2	10.0...80.0	cycles	0.1	10.0	Voltage variation swell duration 2
Voltage swell set 3	100.0...140.0	%	0.1	120.0	Swell limit 3 in % of reference voltage
VVa swell time 3	2000...60000	ms	10	2000	Voltage variation swell duration 3
Voltage Int set	0.0...100.0	%	0.1	10.0	Interruption limit in % of reference voltage
VVa Int time 1	0.5...30.0	cycles	0.1	3.0	Voltage variation Int duration 1
VVa Int time 2	10.0...180.0	cycles	0.1	30.0	Voltage variation Int duration 2
VVa Int time 3	2000...60000	ms	10	3000	Voltage variation interruption duration 3
VVa Dur Max	100...3600000	ms	100	60000	Maximum voltage variation duration

Table 1046: PHQVVR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Variation enable	1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int			7=Swell+dip+Int	Enable variation type

Table 1047: PHQVVR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Phase supervision	1=Ph A			7=Ph A + B + C	Monitored voltage phase

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Ph B 3=Ph A + B 4=Ph C 5=Ph A + C 6=Ph B + C 7=Ph A + B + C				
Phase mode	1=Three Phase 2=Single Phase			2=Single Phase	Three/Single phase mode

10.3.9 Monitored data

Table 1048: PHQVVR Monitored data

Name	Type	Values (Range)	Unit	Description
ST_A	BOOLEAN	0=False 1=True		Start Phase A (Voltage Variation Event in progress)
ST_B	BOOLEAN	0=False 1=True		Start Phase B (Voltage Variation Event in progress)
ST_C	BOOLEAN	0=False 1=True		Start Phase C (Voltage Variation Event in progress)
INSTSWELLCNT	INT32	0...2147483647		Instantaneous swell operation counter
MOMSWELLCNT	INT32	0...2147483647		Momentary swell operation counter
TEMPSWELLCNT	INT32	0...2147483647		Temporary swell operation counter
MAXDURSWELLCNT	INT32	0...2147483647		Maximum duration swell operation counter
INSTDIPCNT	INT32	0...2147483647		Instantaneous dip operation counter
MOMDIPCNT	INT32	0...2147483647		Momentary dip operation counter
TEMPDIPCNT	INT32	0...2147483647		Temporary dip operation counter
MAXDURDIPCNT	INT32	0...2147483647		Maximum duration dip operation counter
MOMINTCNT	INT32	0...2147483647		Momentary interruption operation counter
TEMPINTCNT	INT32	0...2147483647		Temporary interruption operation counter

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
SUSTINTCNT	INT32	0...2147483647		Sustained interruption operation counter
MAXDURINTCNT	INT32	0...2147483647		Maximum duration interruption operation counter
PHQVVR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
Time	Timestamp			Time
Variation type	Enum	0=No variation 1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int		Variation type
Variation Ph A	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase C
Var Ph C rec time	Timestamp			Variation magnitude Phase C time stamp
Variation Dur Ph A	FLOAT32	0.000...3600.000	s	Variation duration Phase A
Var Dur Ph A time	Timestamp			Variation Ph A start time stamp

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Variation Dur Ph B	FLOAT32	0.000...3600.000	s	Variation duration Phase B
Var Dur Ph B time	Timestamp			Variation Ph B start time stamp
Variation Dur Ph C	FLOAT32	0.000...3600.000	s	Variation duration Phase C
Var Dur Ph C time	Timestamp			Variation Ph C start time stamp
Var current Ph A	FLOAT32	0.00...60.00	xIn	Current magnitude Phase A preceding variation
Var current Ph B	FLOAT32	0.00...60.00	xIn	Current magnitude Phase B preceding variation
Var current Ph C	FLOAT32	0.00...60.00	xIn	Current magnitude Phase C preceding variation
Time	Timestamp			Time
Variation type	Enum	0=No variation 1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int		Variation type
Variation Ph A	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase C

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Var Ph C rec time	Timestamp			Variation magnitude Phase C time stamp
Variation Dur Ph A	FLOAT32	0.000...3600.000	s	Variation duration Phase A
Var Dur Ph A time	Timestamp			Variation Ph A start time stamp
Variation Dur Ph B	FLOAT32	0.000...3600.000	s	Variation duration Phase B
Var Dur Ph B time	Timestamp			Variation Ph B start time stamp
Variation Dur Ph C	FLOAT32	0.000...3600.000	s	Variation duration Phase C
Var Dur Ph C time	Timestamp			Variation Ph C start time stamp
Var current Ph A	FLOAT32	0.00...60.00	xIn	Current magnitude Phase A preceding variation
Var current Ph B	FLOAT32	0.00...60.00	xIn	Current magnitude Phase B preceding variation
Var current Ph C	FLOAT32	0.00...60.00	xIn	Current magnitude Phase C preceding variation
Time	Timestamp			Time
Variation type	Enum	0=No variation 1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int		Variation type
Variation Ph A	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase B

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase C
Var Ph C rec time	Timestamp			Variation magnitude Phase C time stamp
Variation Dur Ph A	FLOAT32	0.000...3600.000	s	Variation duration Phase A
Var Dur Ph A time	Timestamp			Variation Ph A start time stamp
Variation Dur Ph B	FLOAT32	0.000...3600.000	s	Variation duration Phase B
Var Dur Ph B time	Timestamp			Variation Ph B start time stamp
Variation Dur Ph C	FLOAT32	0.000...3600.000	s	Variation duration Phase C
Var Dur Ph C time	Timestamp			Variation Ph C start time stamp
Var current Ph A	FLOAT32	0.00...60.00	xIn	Current magnitude Phase A preceding variation
Var current Ph B	FLOAT32	0.00...60.00	xIn	Current magnitude Phase B preceding variation
Var current Ph C	FLOAT32	0.00...60.00	xIn	Current magnitude Phase C preceding variation

10.3.10 Technical data

Table 1049: 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)

10.4 Voltage unbalance VSQVUB

10.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage unbalance	VSQVUB	PQUUB	PQVUB

10.4.2 Function block

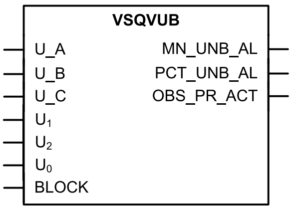


Figure 585: Function block

10.4.3 Functionality

The voltage unbalance function VSQVUB monitors voltage unbalance conditions in power transmission and distribution networks. It can be applied to identify a network and load unbalance that can 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 and ratio of maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of the phase voltage magnitude.

VSQVUB provides statistics which can be used to verify the compliance of the power quality with the European standard EN 50160 (2000). The statistics over selected period include a freely selectable percentile for unbalance. VSQVUB also includes an alarm functionality providing a maximum unbalance value and the date and time of occurrence.

VSQVUB contains a blocking functionality. It is possible to block a set of function outputs or the function itself.

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 VSQVUB can be described with a module diagram. All the modules in the diagram are explained in the next sections.

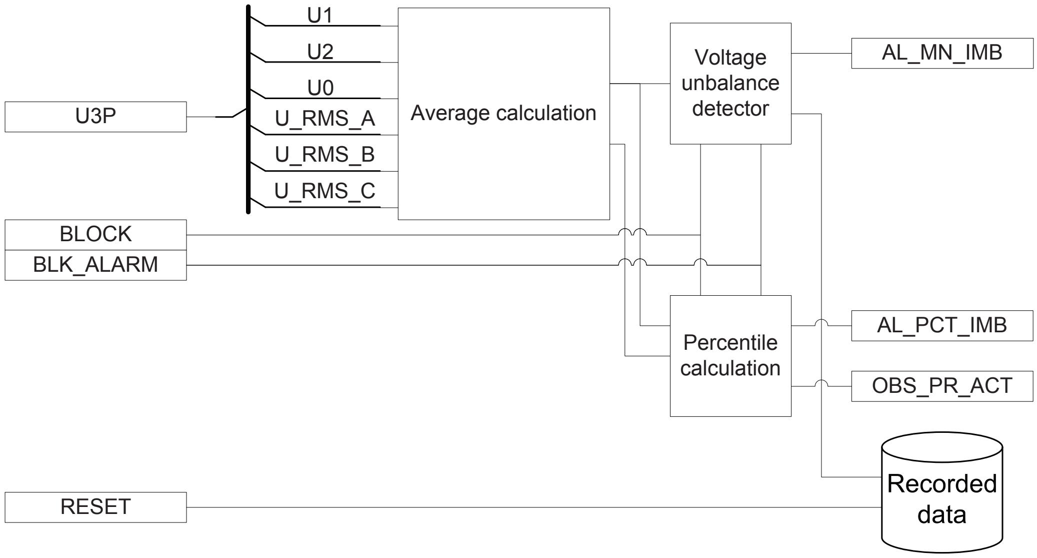


Figure 586: Functional module diagram

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 ten-minute average is used for percentile calculation for a longer period.

The Average calculation module uses five different methods for the average calculation. The required method can be selected with the *Unb detection method* parameter.

When the "Neg Seq" mode is selected with *Unb detection method*, the voltage unbalance is calculated based on the negative-sequence voltage magnitude. Similarly, when the "Zero Seq" 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 ten-minute value are available in the Monitored data view through the outputs 3S_MN_UNB and 10MN_MN_UNB.

For VT connection = "Delta", the calculated zero-sequence voltage is always zero, hence, the setting *Unb detection method* = "Zero Seq" is not applicable in this VT configuration.

Voltage unbalance detector

The three-second average value is calculated and compared to the set value *Unbalance start val*. If the voltage unbalance exceeds this limit, the MN_UNB_AL output is activated.

The activation of the BLOCK input blocks MN_UNB_AL output.

Percentile calculation

The Percentile calculation module performs the statistics calculation for the level of voltage unbalance value for a settable duration. The operation of the Percentile calculation module can be described with a module diagram.

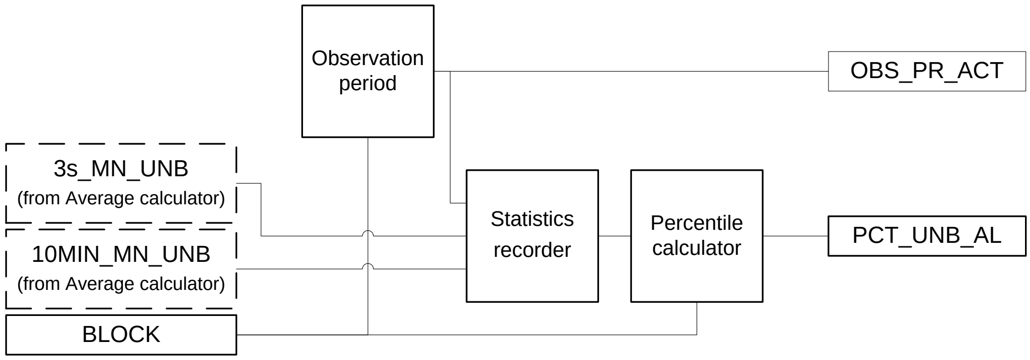


Figure 587: Percentile calculation

Observation period

The Observation period module calculates the length of the observation time for the Statistics recorder sub-module as well as determines the possible start of a new one. A new period can be started by timed activation using calendar time settings *Obs period Str year*, *Obs period Str month*, *Obs period Str day* and *Obs period Str hour*.

The observation period start time settings *Obs period Str year*, *Obs period Str month*, *Obs period Str day* and *Obs period Str hour* are used to set the calendar time in UTC. These settings have to be adjusted according to the local time and local daylight saving time.

A preferable way of continuous statistics recordings can be selected over a longer period (months, years). With the *Trigger mode* setting, the way the next possible observation time is activated after the former one has finished can be selected.

Table 1050: Trigger mode observation times

Trigger mode	Observation time
Single	Only one period of observation time is activated.
Periodic	The time gap between the two trigger signals is seven days.
Continuous	The next period starts right after the previous observation period is completed.

The length of the period is determined by the settings *Obs period selection* and *User Def Obs period*. The `OBS_PR_ACT` output is an indication signal which exhibits rising edge (TRUE) when the observation period starts and falling edge (FALSE) when the observation period ends.

If the *Percentile unbalance*, *Trigger mode* or *Obs period duration* settings change when `OBS_PR_ACT` is active, `OBS_PR_ACT` deactivates immediately.

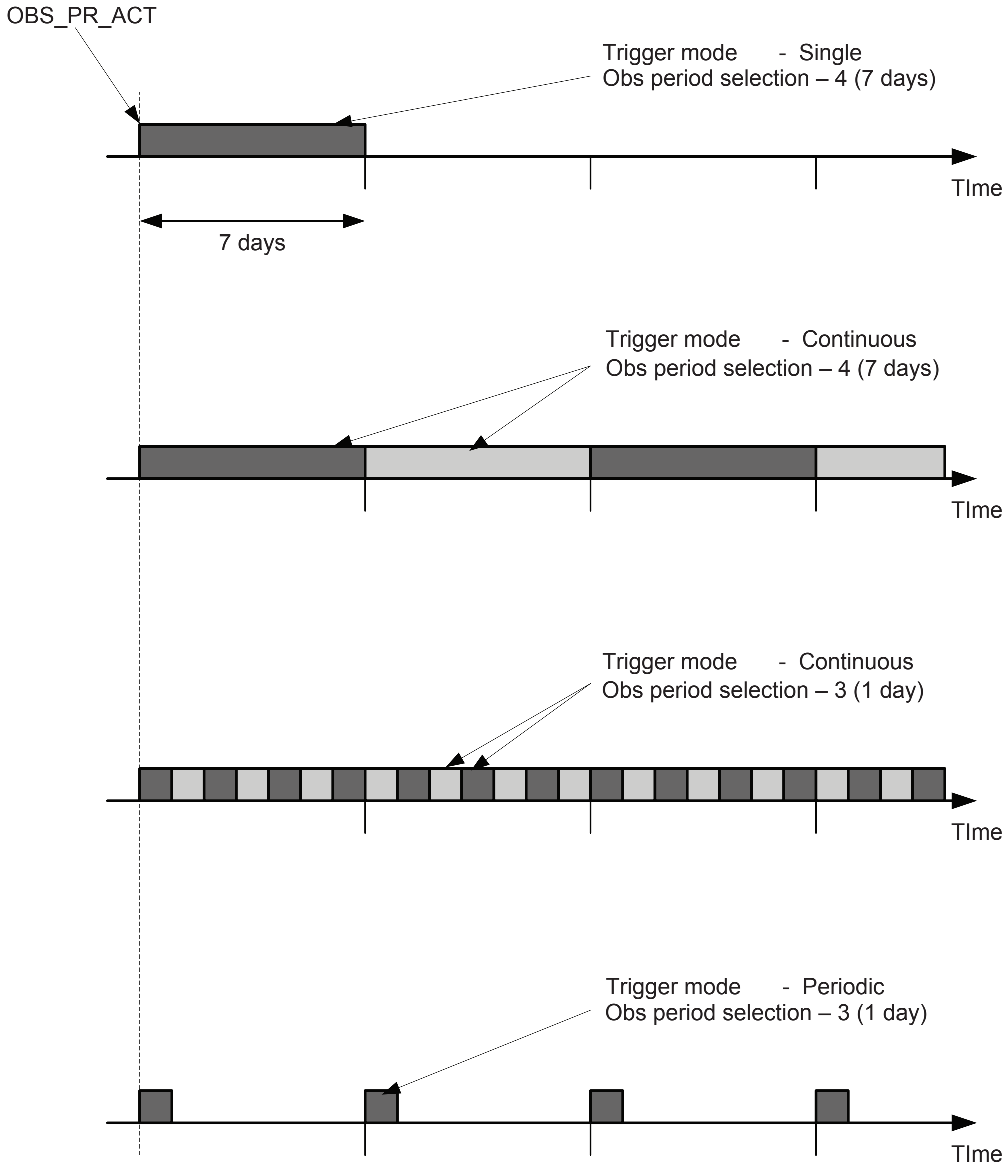


Figure 588: Periods for statistics recorder with different trigger modes and period settings

The BLOCK input blocks the OBS_PR_ACT output, which then disables the maximum value calculation of the Statistics recorder module. If the trigger mode is selected "Periodic" or "Continuous" and the blocking is deactivated before the next observation period is due to start, the scheduled period starts normally.

Statistics recorder

The Statistics recorder module provides readily calculated three-second or ten-minute values of the selected phase to the percentile calculator module based on the length of the active observation period. If the observation period is less than one day, the three-second average values are used. If the observation period is one day or longer, the ten-minute average values are used.

The maximum three-second or ten-minute mean voltage unbalance is recorded during the active observation period. The observation period start time *PR_STR_TIME*, observation period end time *PR_END_TIME*, maximum voltage unbalance value during observation period active, *MAX_UNB_VAL* and time of occurrence *MAX_UNB_TIME* are available through the Monitored data view. These outputs are updated once OBS_PR_ACT deactivates.

Percentile calculator

The purpose of the Percentile calculator module is to find the voltage unbalance level so that during the observation time 95 percent (default value of the *Percentile unbalance* setting) of all the measured voltage unbalance amplitudes are less than or equal to the calculated percentile.

The computed output value PCT_UNB_VAL, below which the percentile of the values lies, is available in the Monitored data view. The PCT_UNB_VAL output value is updated at the end of the observation period.

If the output PCT_UNB_VAL is higher than the defined setting *Unbalance start val* at the end of the observation period, an alarm output PCT_UNB_AL is activated. The PCT_UNB_AL output remains active for the whole period before the next period completes.

The BLOCK input blocks the output PCT_UNB_VAL.

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 to 2 and 2 to 3) when a voltage unbalance is detected. When all three banks have data and a new variation 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.

The recorded data can be reset with the RESET binary input signal by navigating to the HMI reset (**Main menu** > **Clear** > **Reset recorded data** > **VSQVUBx**) or through tools via communications.

When a voltage unbalance is detected in the system, VSQVUB responds with the MN_UNB_AL alarm signal. During the alarm situation, VSQVUB stores the maximum magnitude and the time of occurrence and the duration of alarm MN_UNB_AL. The recorded data is stored when MN_UNB_AL is deactivated.

Table 1051: Recorded data

Parameter	Description
Alarm high mean Dur	Time duration for alarm high mean unbalance
Max unbalance Volt	Maximum three-second voltage
Time Max Unb Volt	Time stamp of voltage unbalance

10.4.5 Application

Voltage unbalance is one of the basic power quality parameters.

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 network impedance and load impedance in each phase are equal. In some cases, the condition of a balance network and load is not met completely, which leads to a current and voltage unbalance in the system. Providing unbalanced supply voltage has a detrimental effect on load 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 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.

Another major application is the long-term power quality monitoring. This can be used to confirm a compliance to the standard power supply quality norms. The function provides a voltage unbalance level which corresponds to the 95 th percentile of the ten minutes' average values of voltage unbalance recorded over a period of up to one week. It means that for 95 percent of time during the observation period the voltage unbalance was less than or equal to the calculated percentile. An alarm can be obtained if this value exceeds the value that can be set.

The function uses five different methods for calculating voltage unbalance.

- 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.

10.4.6 Signals

Table 1052: VSQVUB Input signals

Name	Type	Default	Description
U_A	SIGNAL	0	Phase A voltage
U_B	SIGNAL	0	Phase B voltage
U_C	SIGNAL	0	Phase C voltage
U_1	SIGNAL	0	Positive phase sequence voltage
U_2	SIGNAL	0	Negative phase sequence voltage
U_0	SIGNAL	0	Zero sequence voltage
BLOCK	BOOLEAN	0=False	Block all outputs except measured values

Table 1053: VSQVUB Output signals

Name	Type	Description
MN_UNB_AL	BOOLEAN	Alarm active when 3 sec voltage unbalance exceeds the limit
PCT_UNB_AL	BOOLEAN	Alarm active when percentile unbalance exceeds the limit
OBS_PR_ACT	BOOLEAN	Observation period is active

10.4.7 Settings

Table 1054: VSQVUB Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On/Off
Unb detection method	1=Neg Seq 2=Zero Seq 3=Neg to Pos Seq 4=Zero to Pos Seq 5=Ph vectors Comp			3=Neg to Pos Seq	Set the operation mode for voltage unbalance calculation
Unbalance start Val	1...100	%	1	1	Voltage unbalance start value
Trigger mode	1=Single 2=Periodic 3=Continuous			3=Continuous	Specifies the observation period triggering mode
Percentile unbalance	1...100	%	1	95	The percent to which percentile

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
					value PCT_UNB_VAL is calculated
Obs period selection	1=1 Hour 2=12 Hours 3=1 Day 4=7 Days 5=User defined			5=User defined	Observation period for unbalance calculation
User Def Obs period	1...168	h	1	168	User define observation period for statistic calculation
Obs period Str year	2008...2076			2011	Calendar time for observation period start year in YYYY
Obs period Str month	0=reserved 1=January 2=February 3=March 4=April 5=May 6=June 7=July 8=August 9=September 10=October 11=November 12=December			1=January	Calendar time for observation period start month
Obs period Str day	1...31			1	Calendar time for observation period start day
Obs period Str hour	0...23	h		0	Calendar time for observation period start hour

10.4.8 Monitored data

Table 1055: VSQVUB Monitored data

Name	Type	Values (Range)	Unit	Description
3S_MN_UNB	FLOAT32	0.00...150.00	%	Non sliding 3 second mean value of voltage unbalance
10MIN_MN_UNB	FLOAT32	0.00...150.00	%	Sliding 10 minutes mean value of voltage unbalance
PCT_UNB_VAL	FLOAT32	0.00...150.00	%	Limit below which percentile unbalance of the values lie

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
MAX_UNB_VAL	FLOAT32	0.00...150.00	%	Maximum voltage unbalance measured in the observation period
MAX_UNB_TIME	Timestamp			Time stamp at which maximum voltage unbalance measured in the observation period
PR_STR_TIME	Timestamp			Time stamp of starting of the previous observation period
PR_END_TIME	Timestamp			Time stamp of end of previous observation period
Alarm high mean Dur	FLOAT32	0.000...3600.000	s	Time duration for alarm high mean unbalance
Max unbalance Volt	FLOAT32	0.00...150.00	%	Maximum 3 seconds unbalance voltage
Time Max Unb Volt	Timestamp			Time stamp of maximum voltage unbalance
Alarm high mean Dur	FLOAT32	0.000...3600.000	s	Time duration for alarm high mean unbalance
Max unbalance Volt	FLOAT32	0.00...150.00	%	Maximum 3 seconds unbalance voltage
Time Max Unb Volt	Timestamp			Time stamp of maximum voltage unbalance
Alarm high mean Dur	FLOAT32	0.000...3600.000	s	Time duration for alarm high mean unbalance
Max unbalance Volt	FLOAT32	0.00...150.00	%	Maximum 3 seconds unbalance voltage

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Time Max Unb Volt	Timestamp			Time stamp of maximum voltage unbalance
VSQVUB	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

10.4.9 Technical data

Table 1056: VSQVUB Technical data

Characteristic	Value
Operation accuracy	±1.5 % of the set value or ±0.002 × U_n
Reset ratio	Typically 0.96

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.

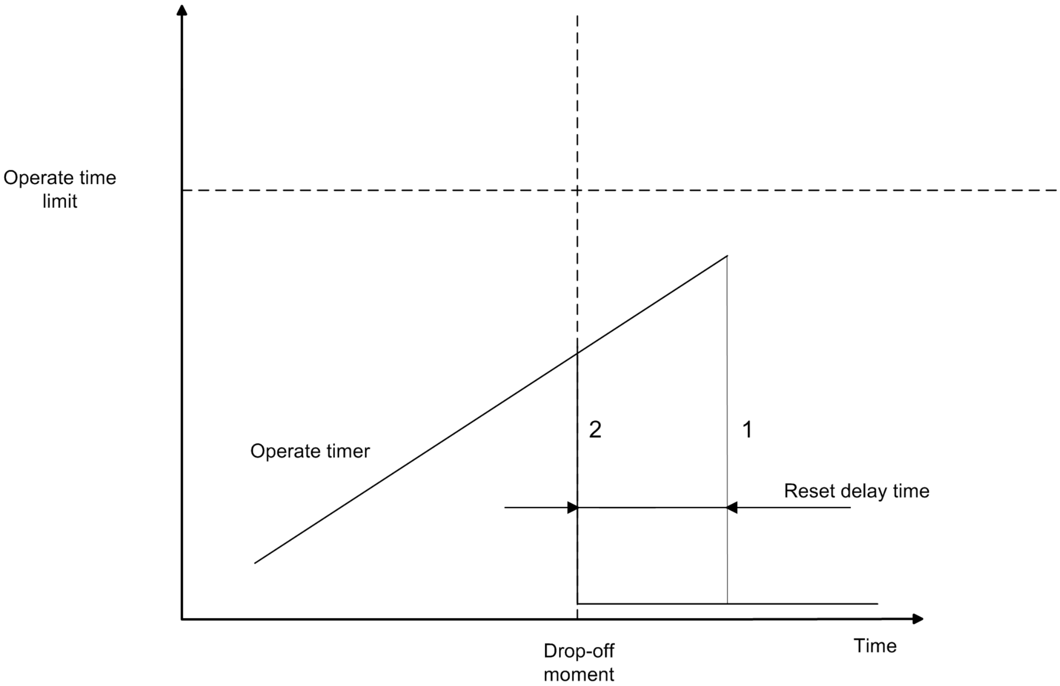


Figure 589: Operation of the counter in drop-off

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.

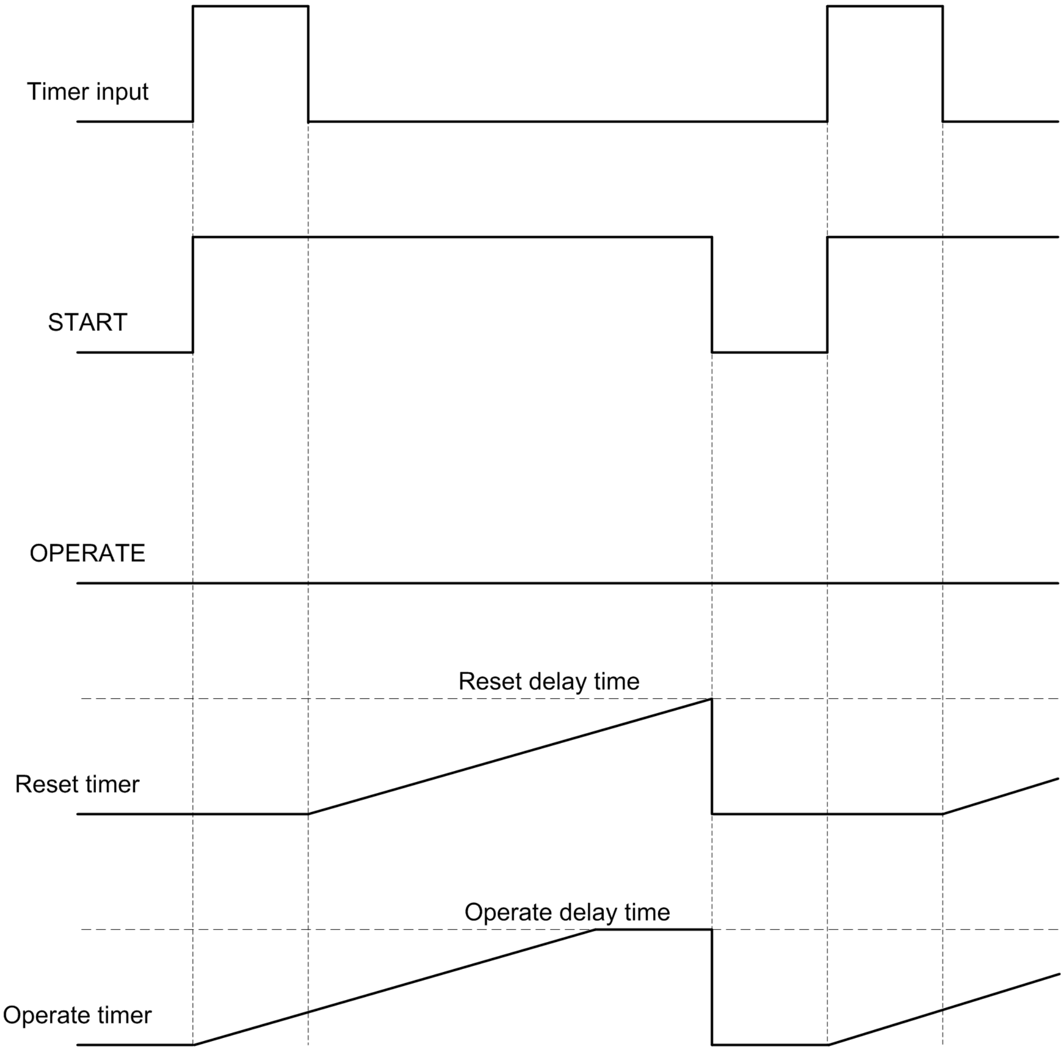


Figure 590: Drop-off period is longer than the set Reset delay time

When the drop-off period is longer than the set *Reset delay time*, as described in *Figure 590*, 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.

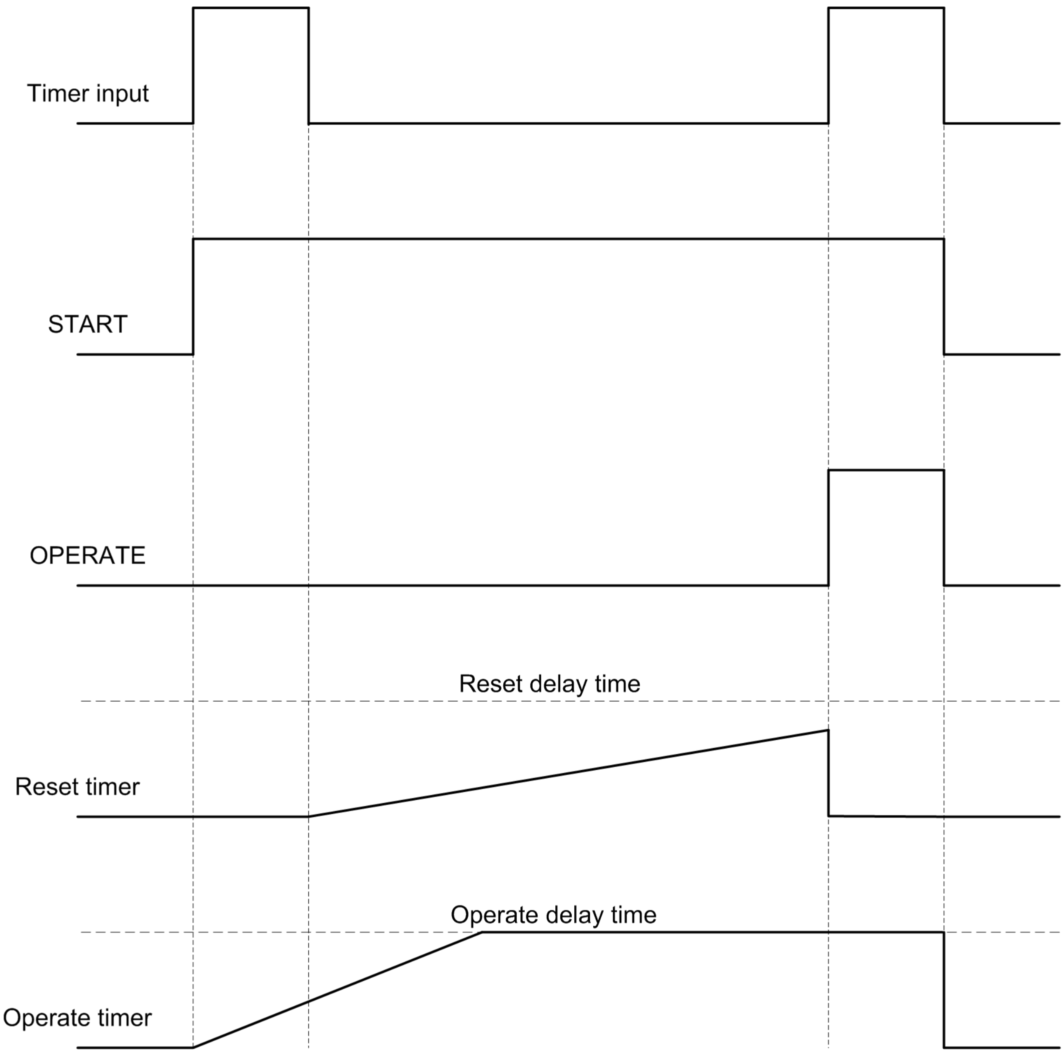


Figure 591: Drop-off period is shorter than the set Reset delay time

When the drop-off period is shorter than the set *Reset delay time*, as described in *Figure 591*, 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.

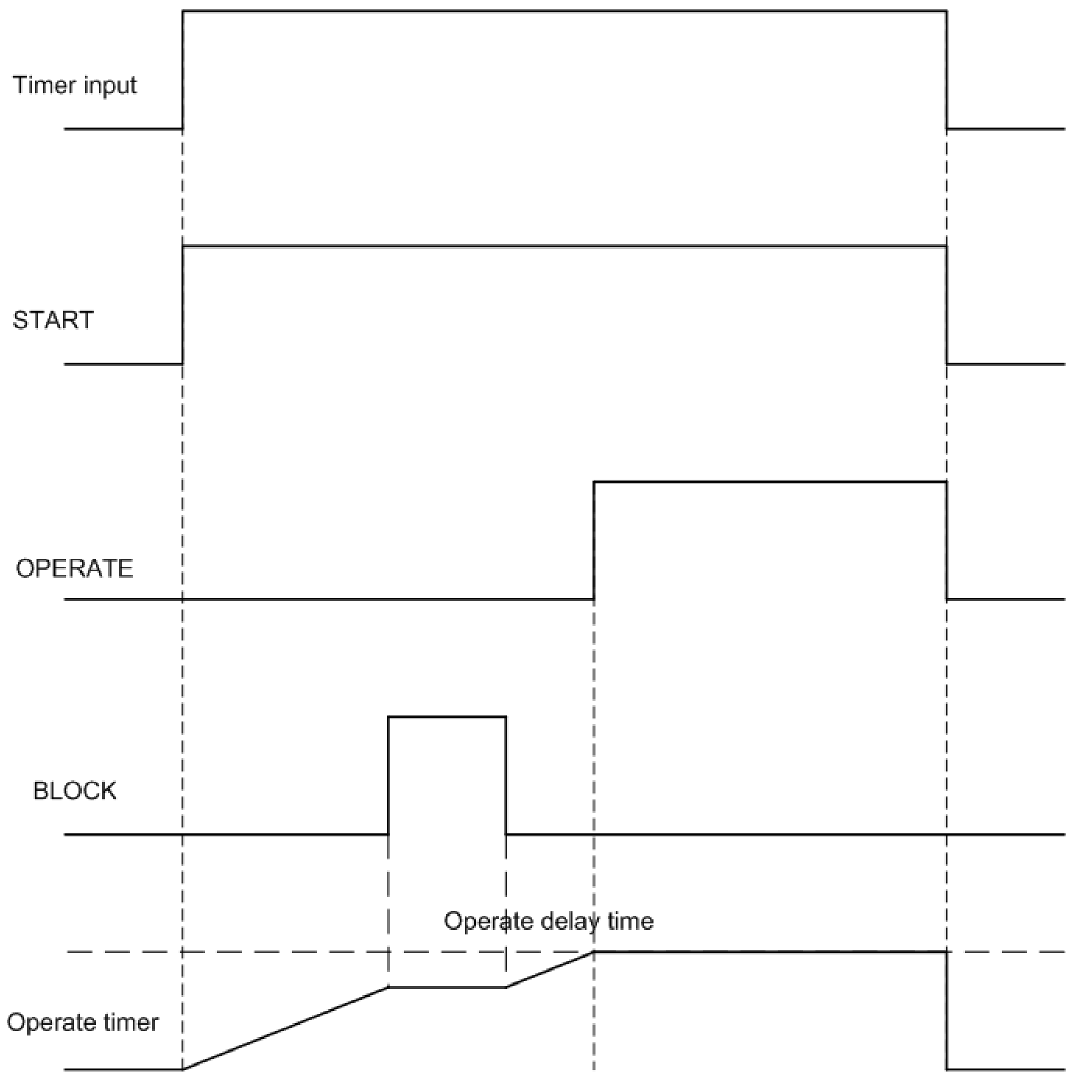


Figure 592: Operating effect of the BLOCK input when the selected blocking mode is "Freeze timer"

If the BLOCK input is activated when the operate timer is running, as described in *Figure 592*, the timer is frozen during the time BLOCK 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 same way as described in *Figure 590*, regardless of the BLOCK input .

The selected blocking mode is "Freeze timer".

11.2 Current based inverse definite minimum time 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.

There are two methods to level out the inverse-time characteristic.

- The *Minimum operate time* setting defines the minimum operating time for the IDMT curve, that is, the operation time is always at least the *Minimum operate time* setting.
- Alternatively, the *IDMT Sat point* is used for giving the leveling-out point as a multiple of the *Start value* setting. (Global setting: **Configuration** > **System** > ***IDMT Sat point***). The default parameter value is 50. This setting affects only the overcurrent and earth-fault IDMT timers.

IDMT operation time at currents over 50 x In is not guaranteed.

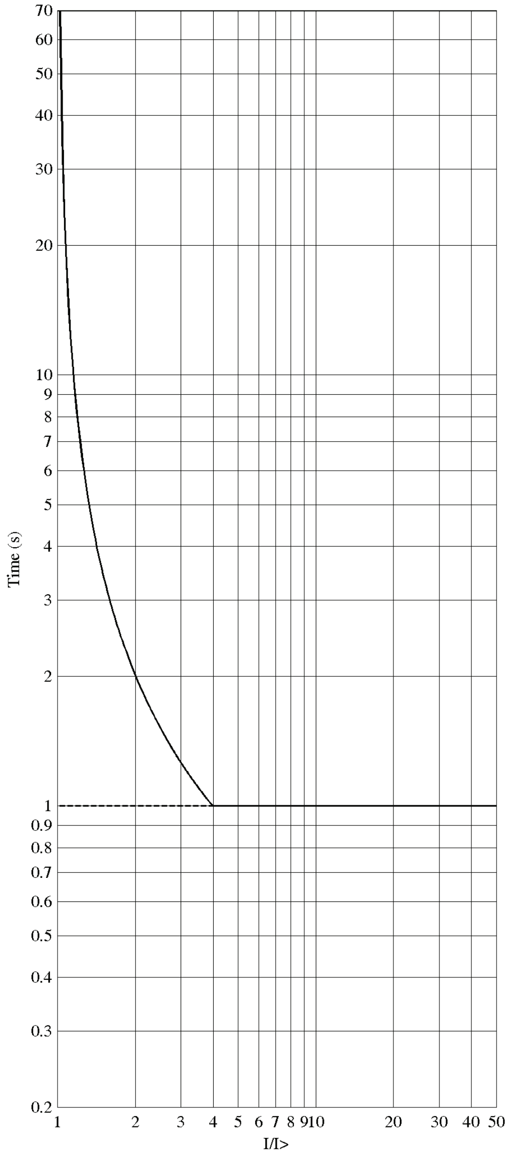


Figure 593: Operation time curve based on the IDMT characteristic leveled out with the Minimum operate time setting is set to 1000 milliseconds (the IDMT Sat point setting is set to maximum).

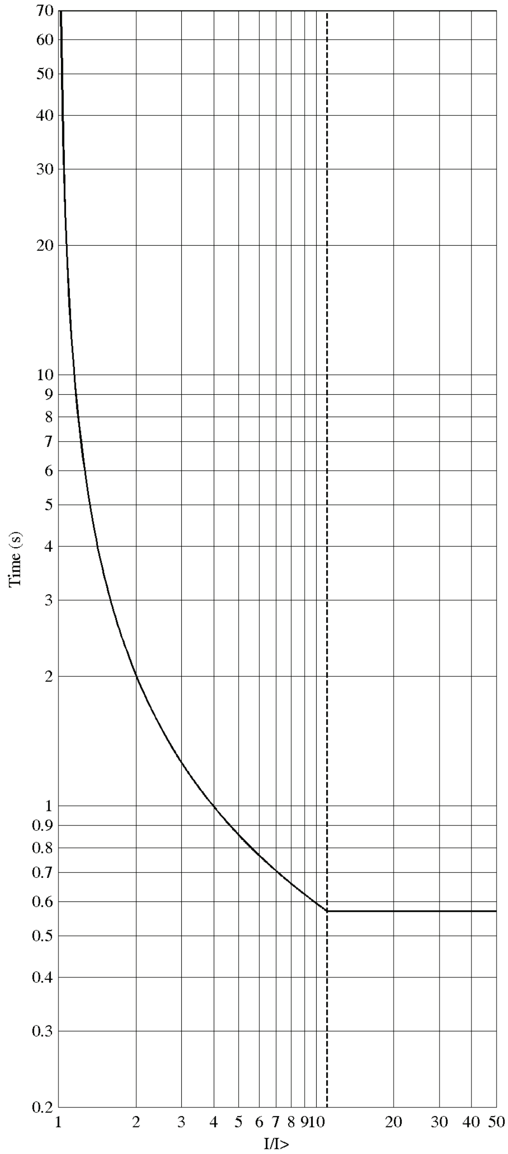


Figure 594: Operation time curve based on the IDMT characteristic leveled out with IDMT Sat point setting value "11" (the Minimum operate time setting is set to minimum).

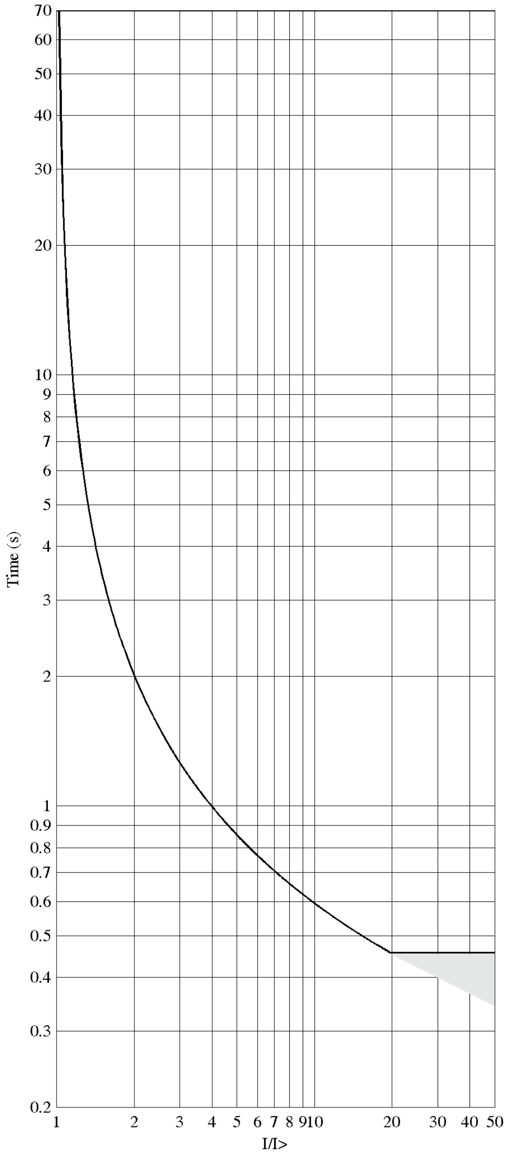


Figure 595: Example of how the inverse time characteristic is leveled out with currents over 50 x In and the Setting Start value setting "2.5 x In". (the IDMT Sat point setting is set to maximum and the Minimum operate time setting is set to minimum).

The grey zone in *Figure 595* shows the behavior of the curve in case the measured current is outside the guaranteed measuring range. Also, the maximum measured current of 50 x In gives the leveling-out point 50/2.5 = 20 x I/I>.

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 195)

t[s]	Operate time in seconds
I	measured current
I>	set *Start value*
k	set *Time multiplier*

Table 1057: 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

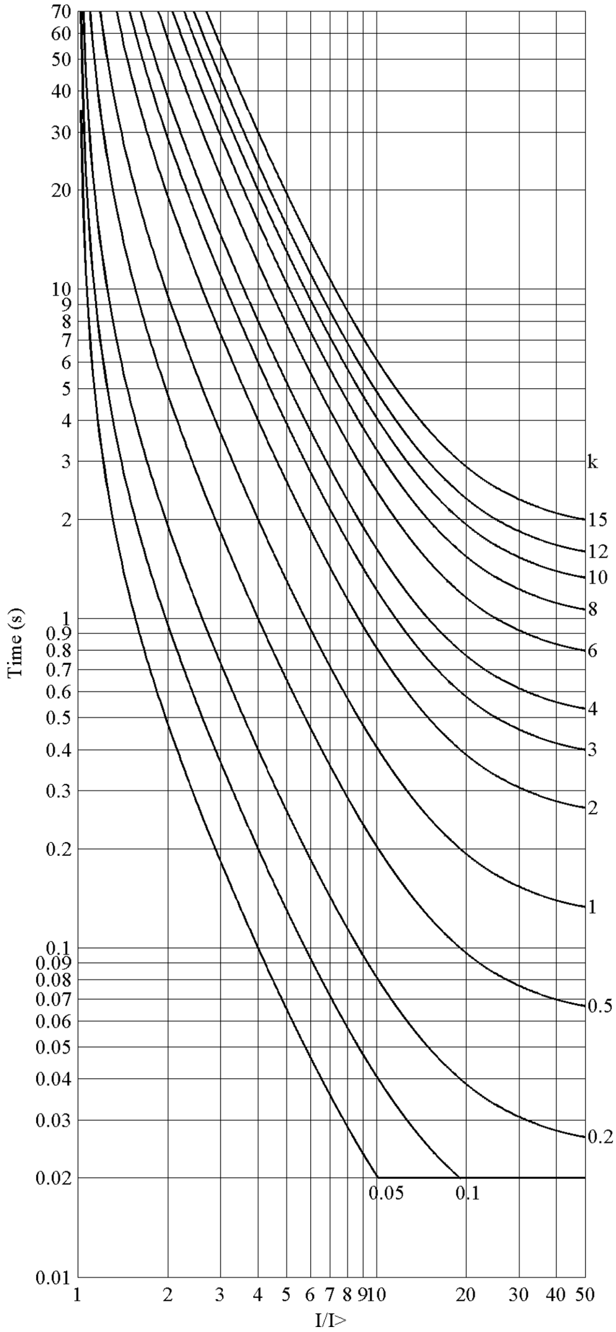


Figure 596: ANSI extremely inverse-time characteristics

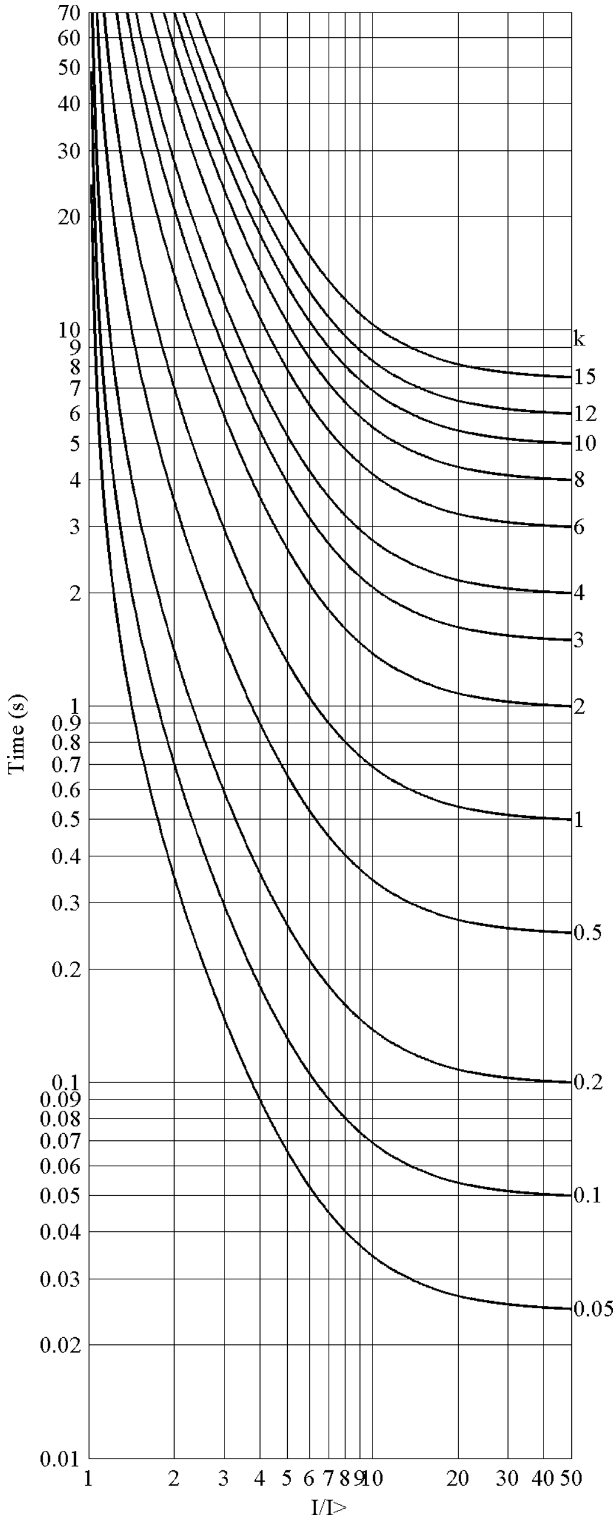


Figure 597: ANSI very inverse-time characteristics

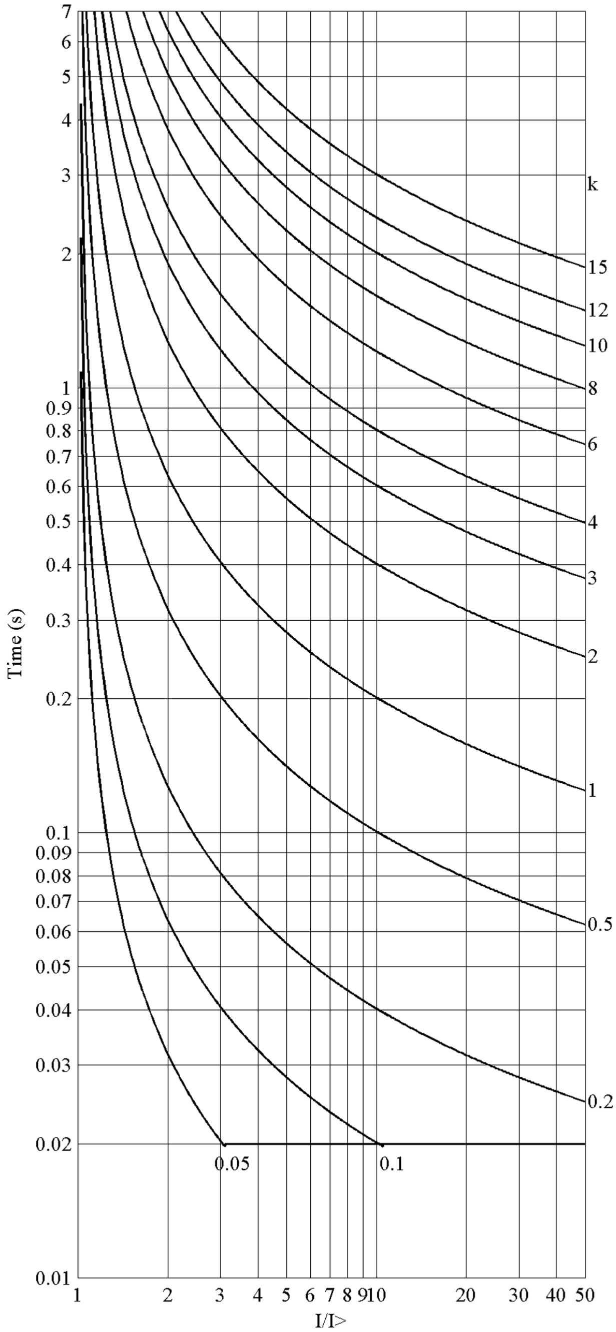


Figure 598: ANSI normal inverse-time characteristics

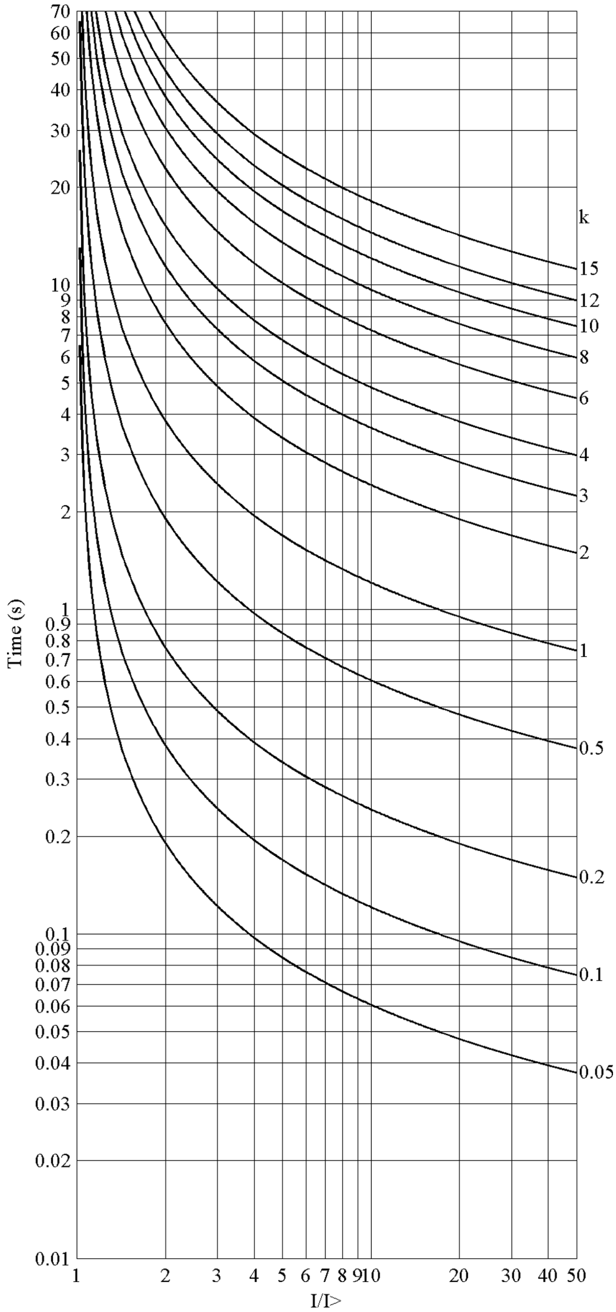


Figure 599: ANSI moderately inverse-time characteristics

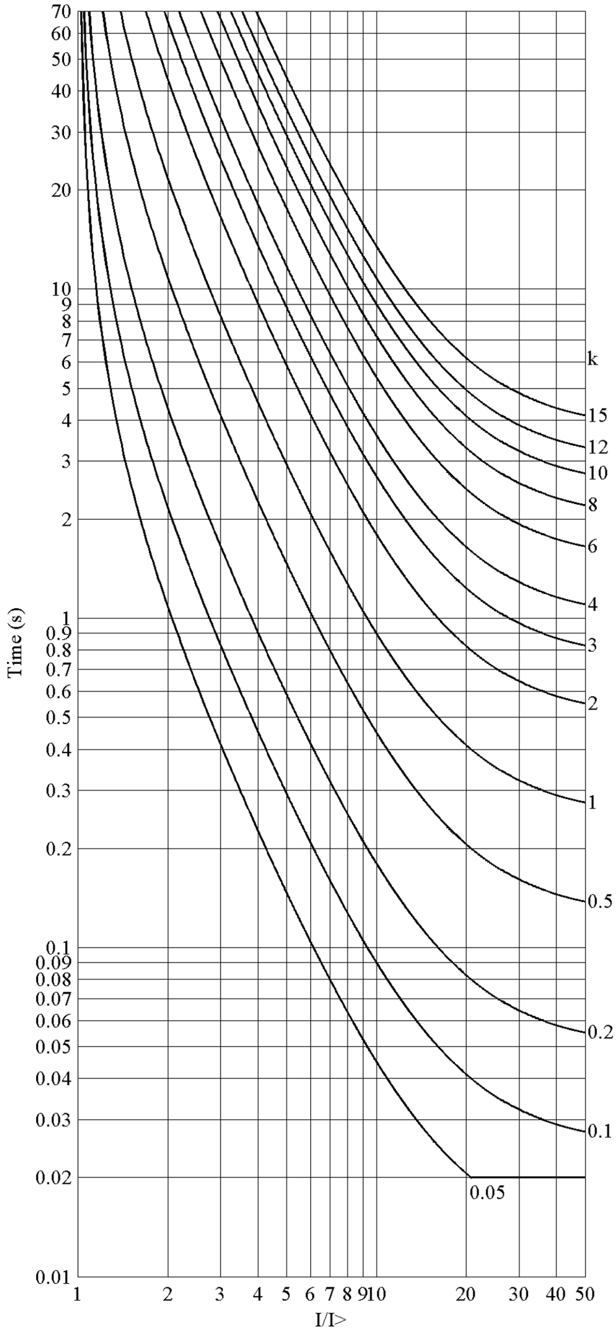


Figure 600: ANSI long-time extremely inverse-time characteristics

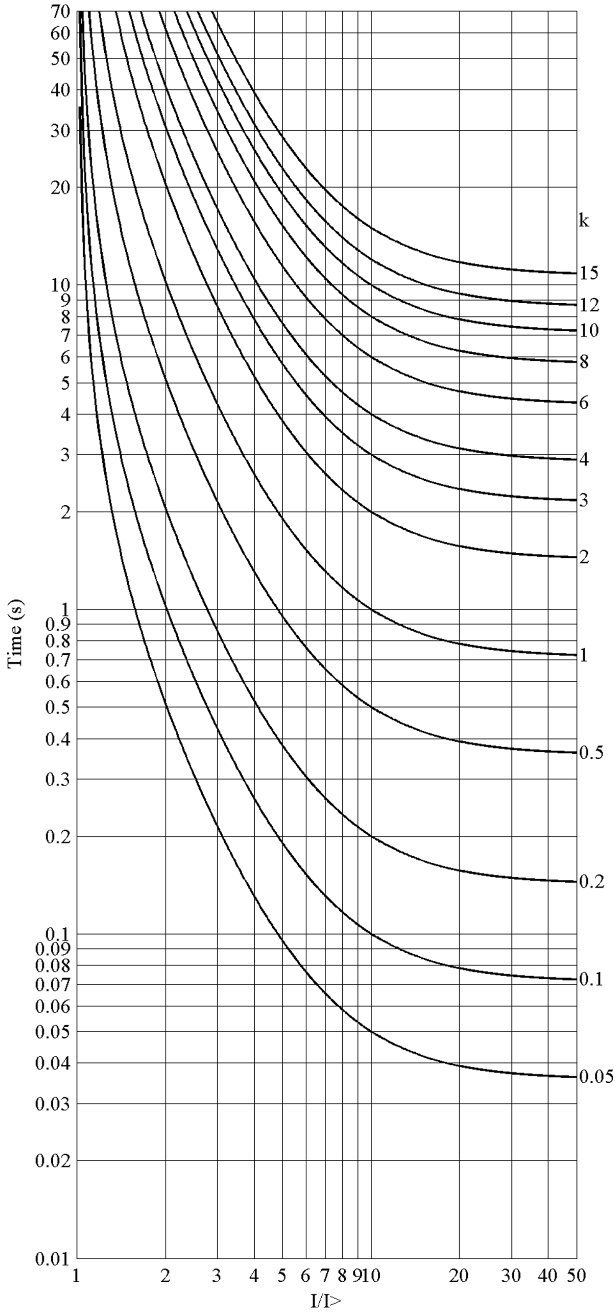


Figure 601: ANSI long-time very inverse-time characteristics

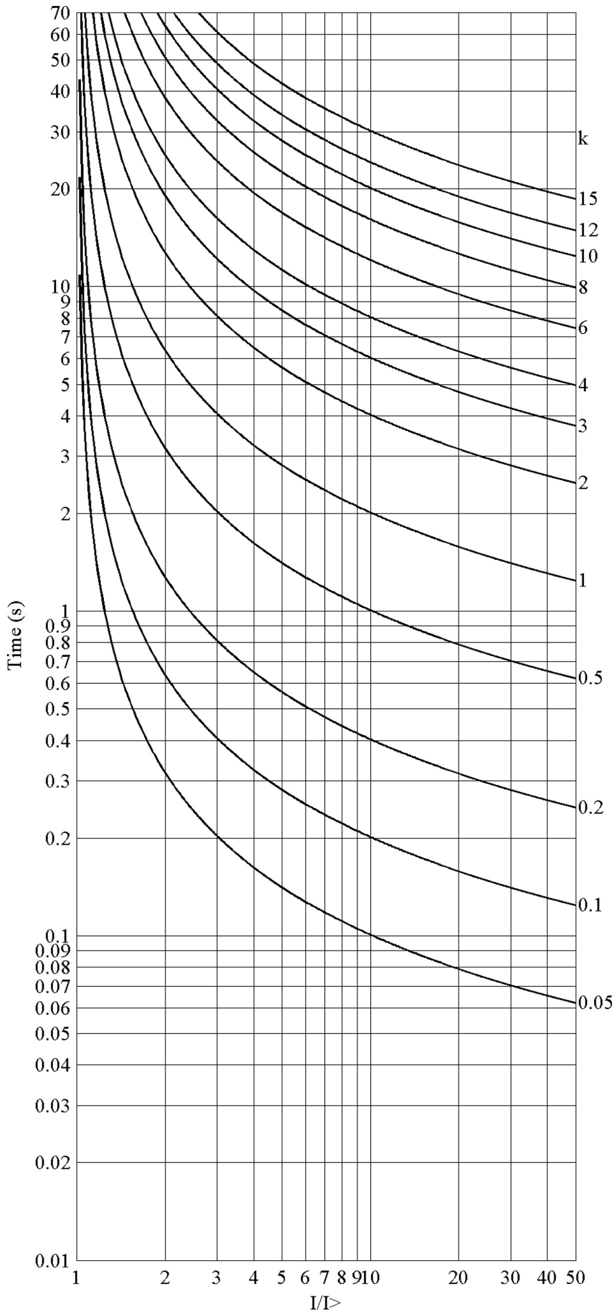


Figure 602: ANSI long-time inverse-time characteristics

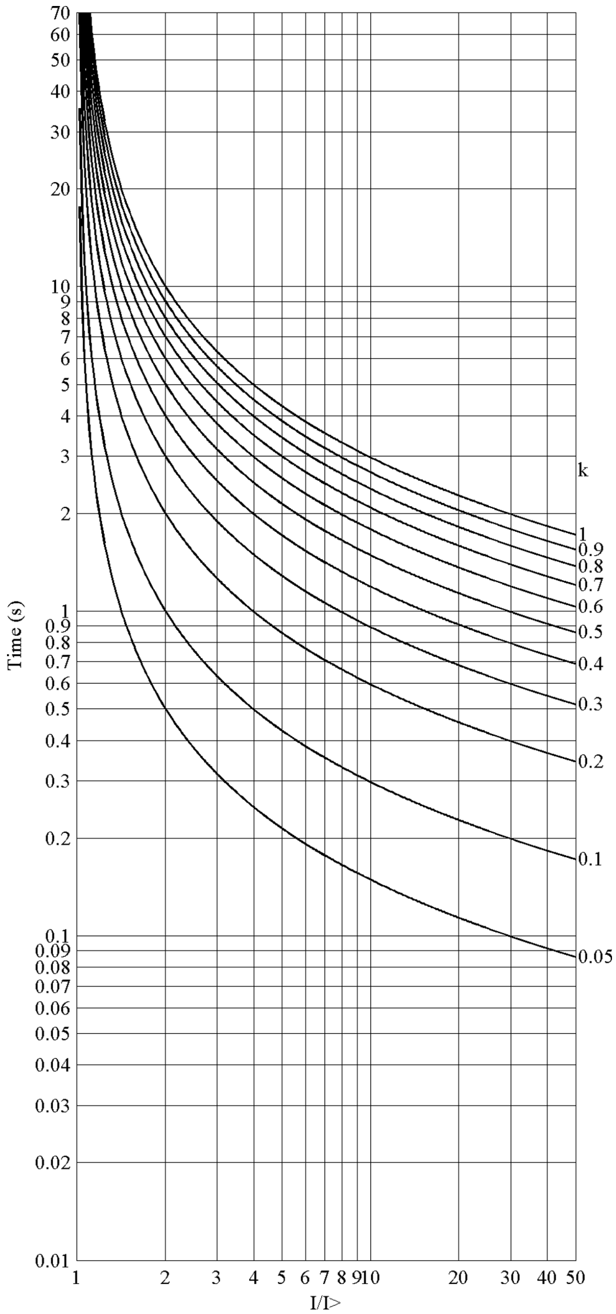


Figure 603: IEC normal inverse-time characteristics

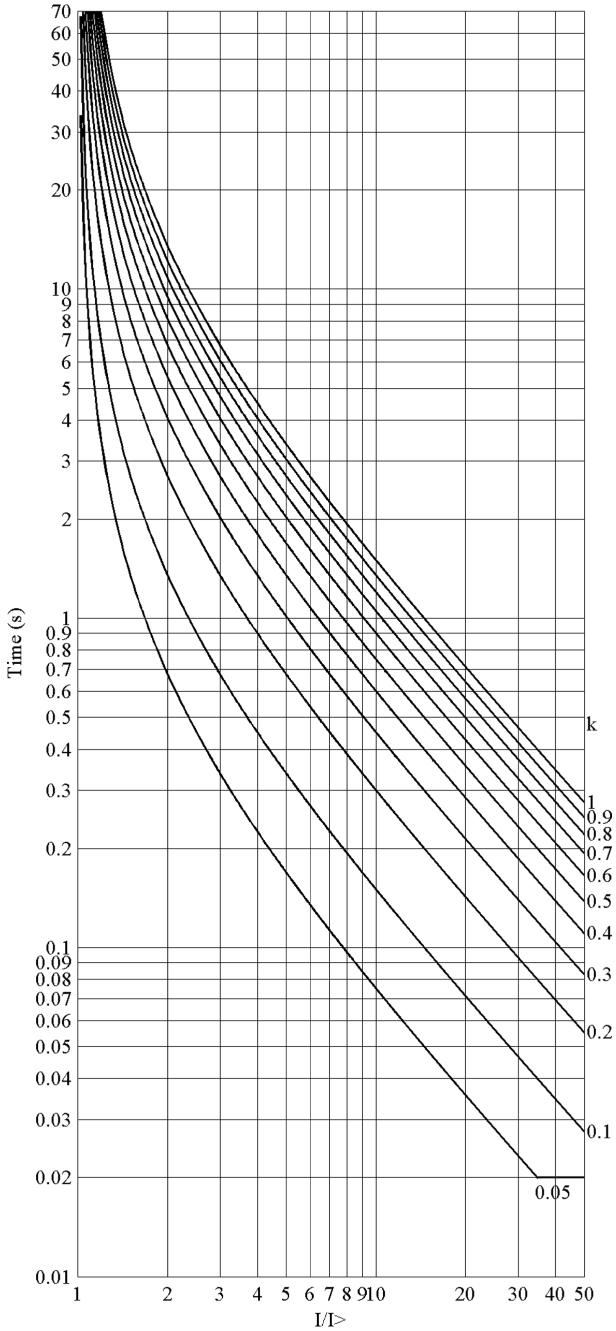


Figure 604: IEC very inverse-time characteristics

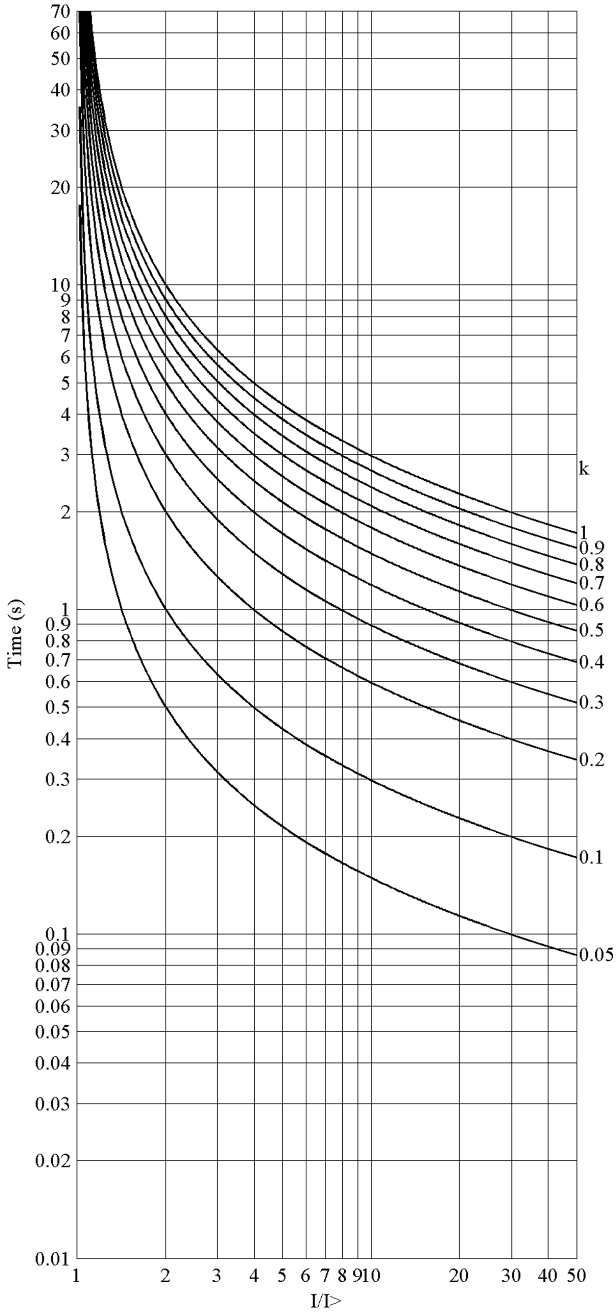


Figure 605: IEC inverse-time characteristics

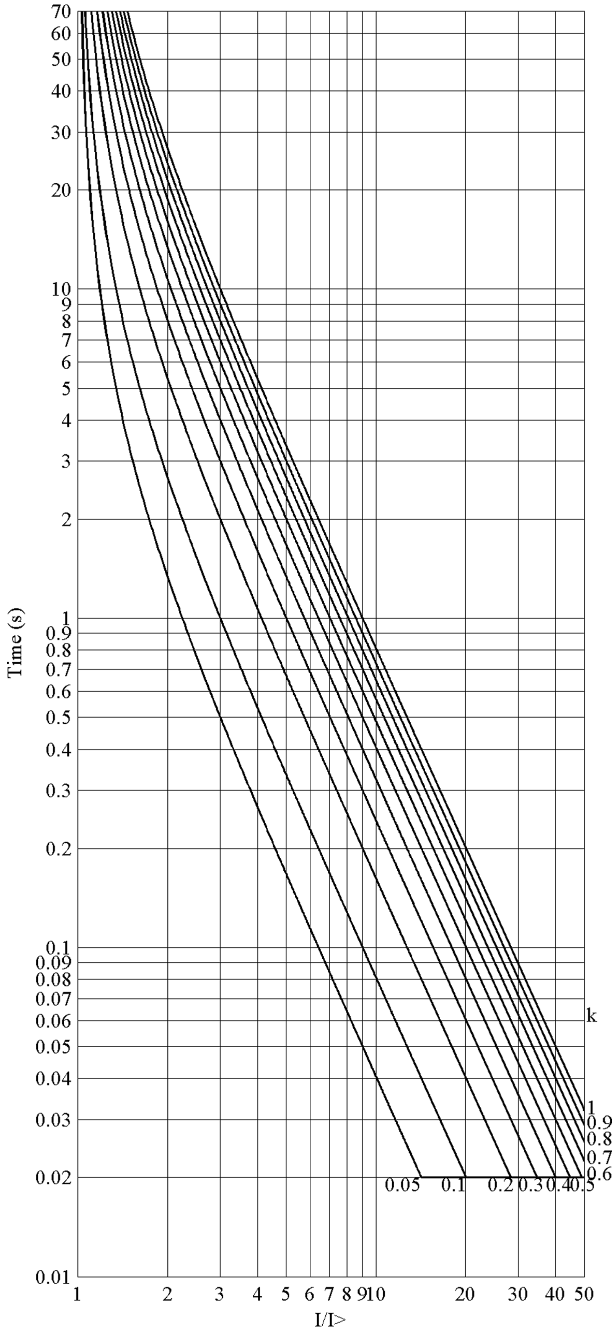


Figure 606: IEC extremely inverse-time characteristics

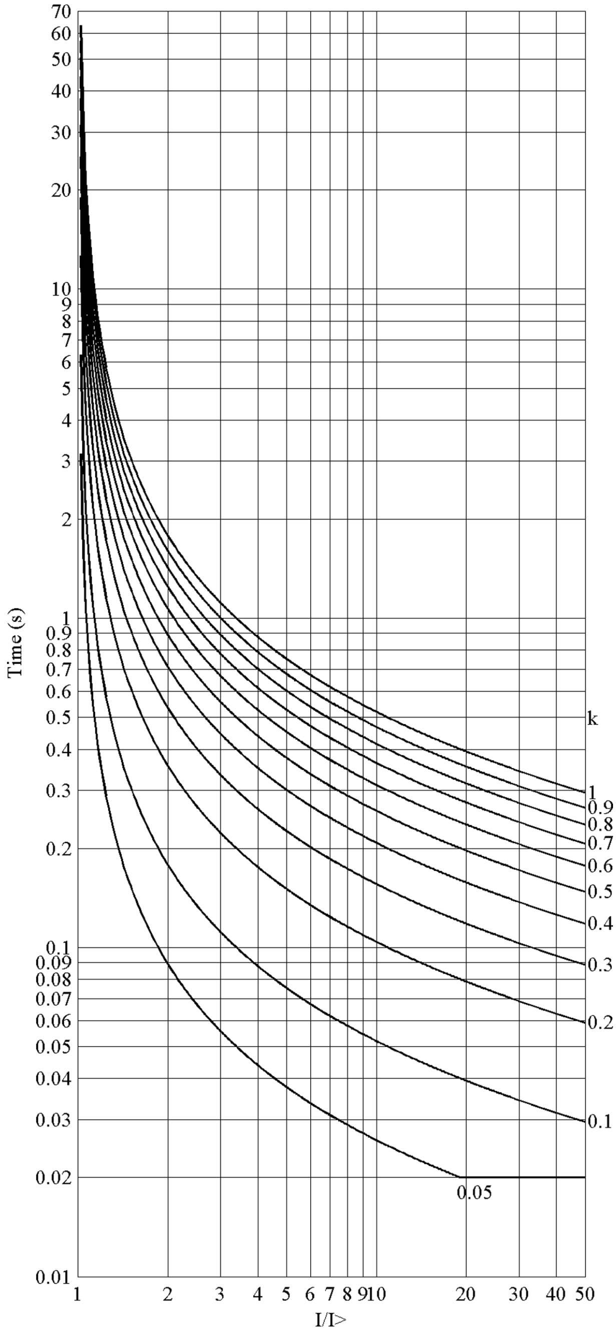


Figure 607: IEC short-time inverse-time characteristics

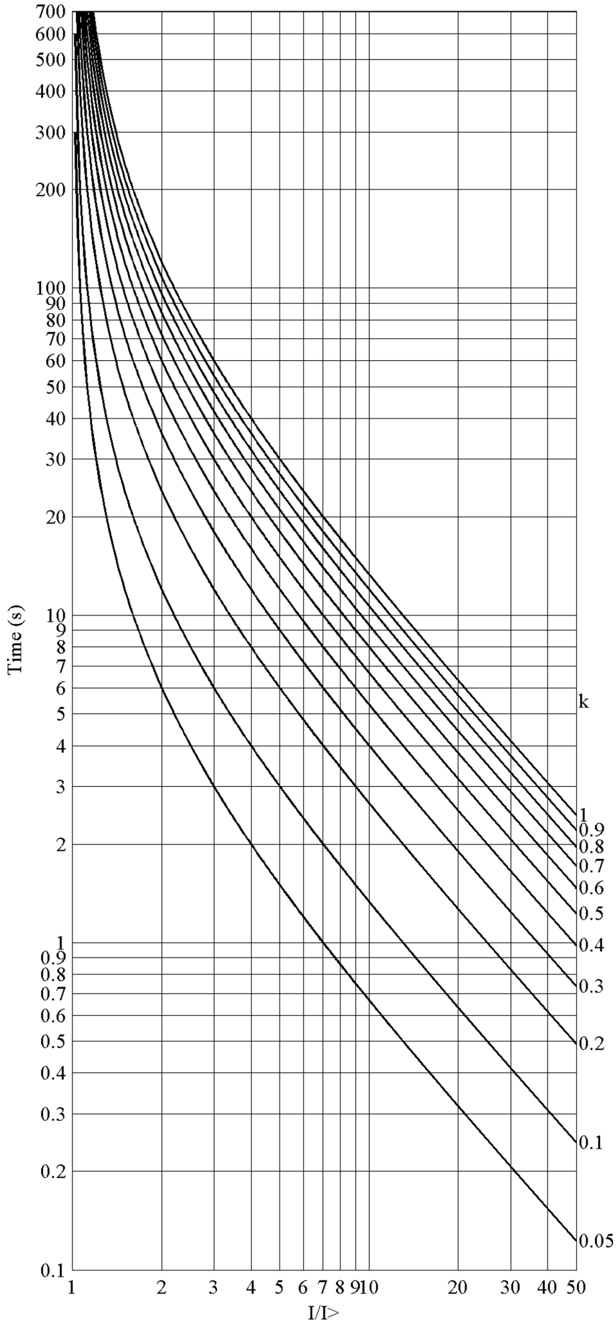


Figure 608: IEC long-time inverse-time characteristics

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 196)

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 197)

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 198)

t[s]	Operate time (in seconds)
k	Set *Time multiplier*
I	Measured current
I>	Set *Start value*

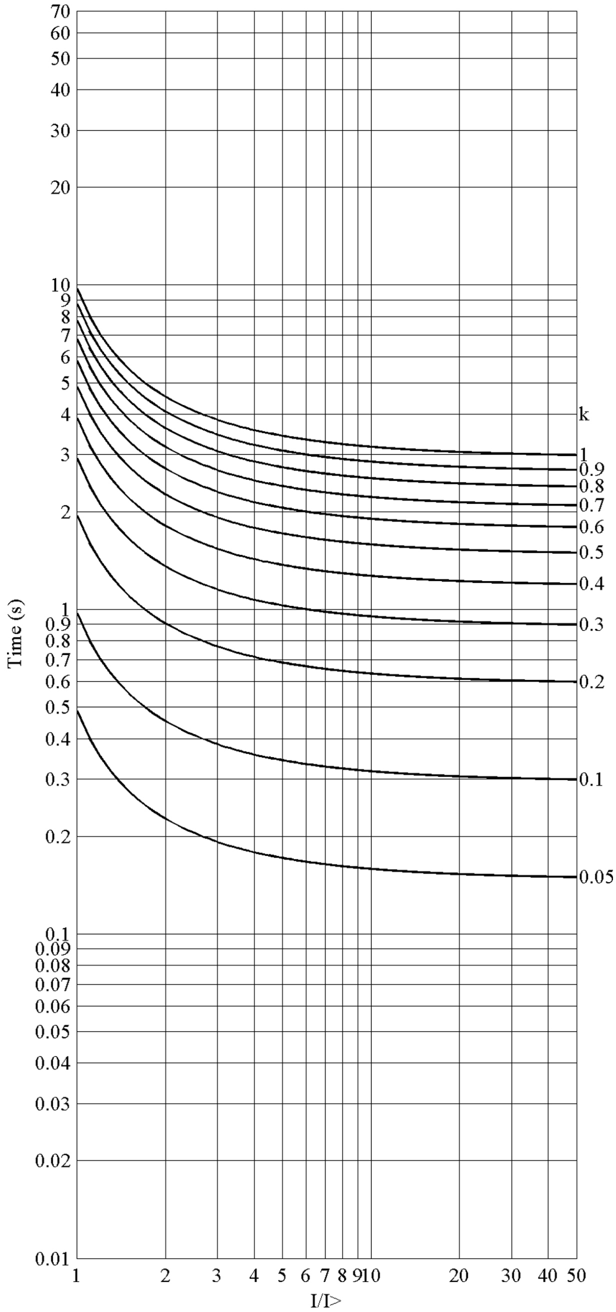


Figure 609: RI-type inverse-time characteristics

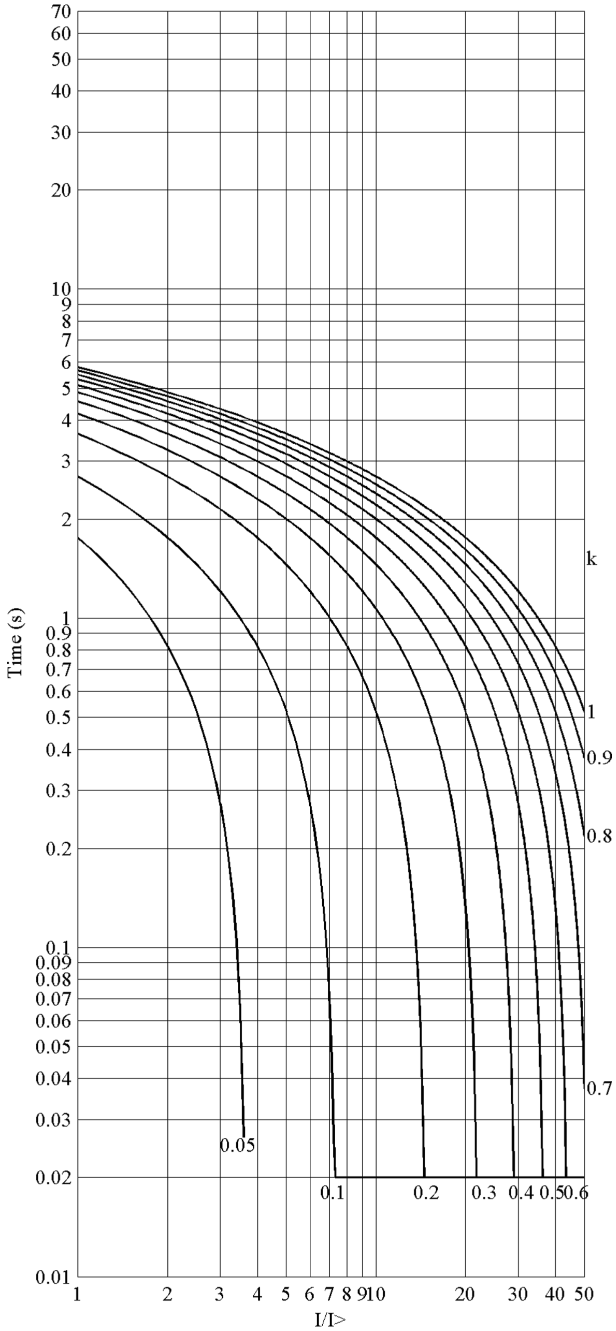


Figure 610: RD-type inverse-time characteristics

11.2.2 Reset in inverse-time modes

The user can select the reset characteristics by using the *Type of reset curve* setting.

Table 1058: 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 199)

t[s]	Reset time (in seconds)
k	set *Time multiplier*
I	Measured current
I>	set *Start value*

Table 1059: 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

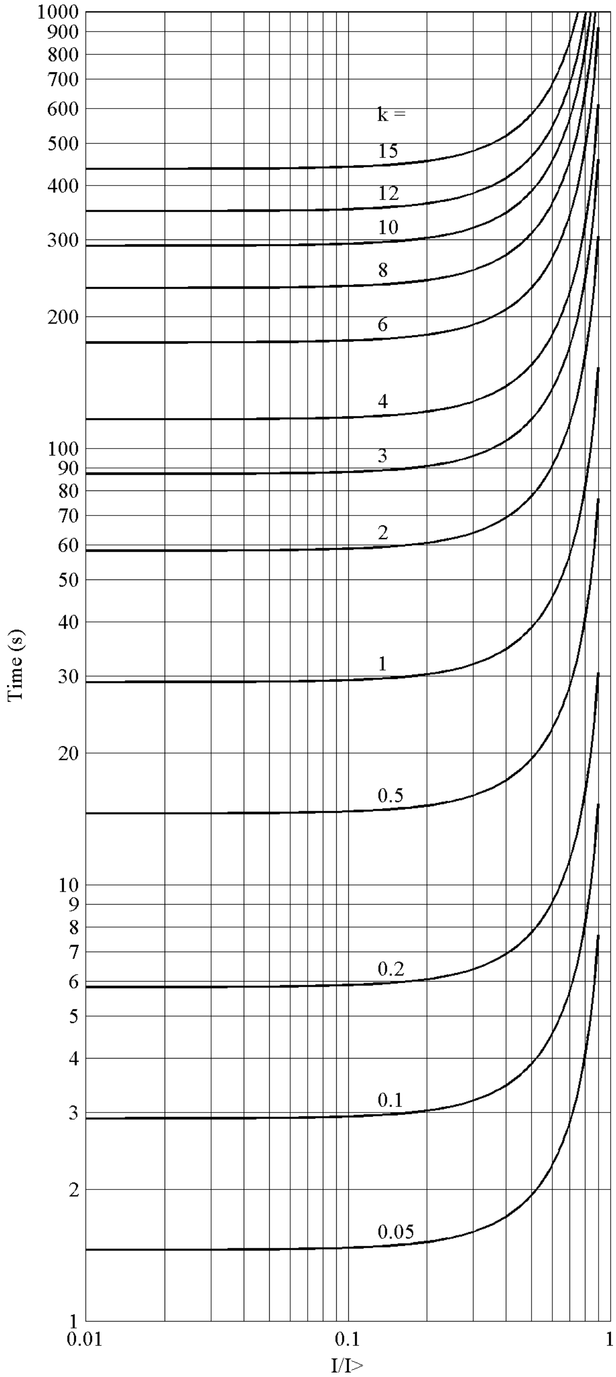


Figure 611: ANSI extremely inverse reset time characteristics

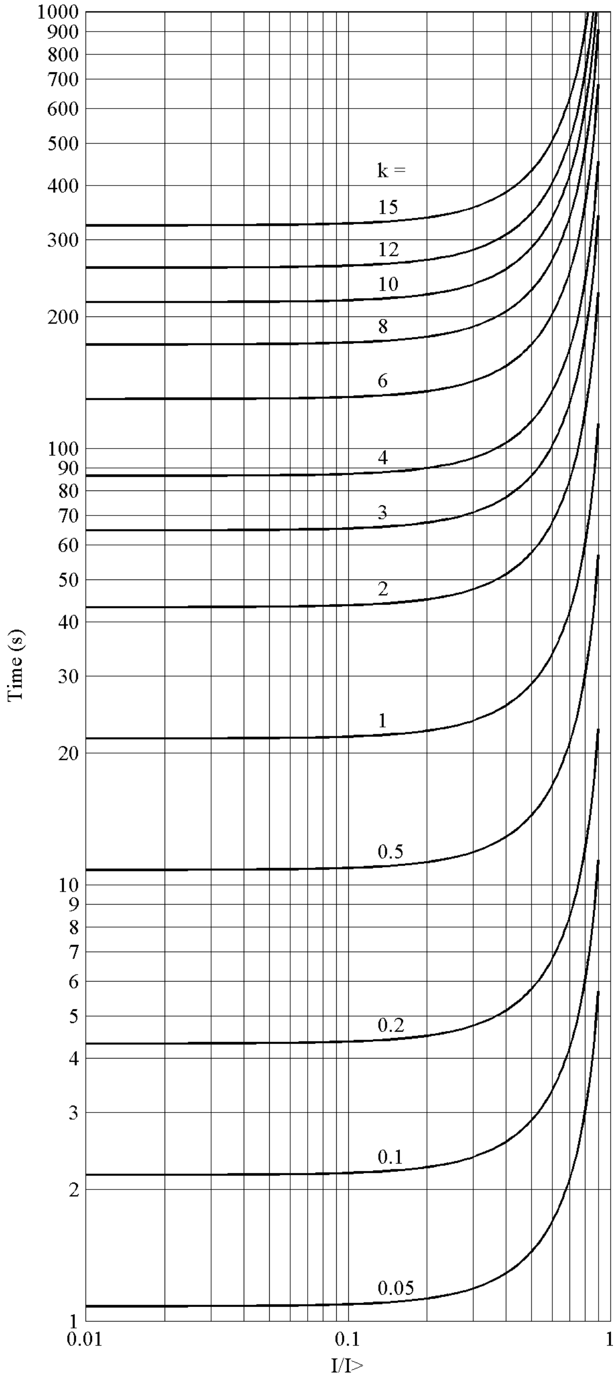


Figure 612: ANSI very inverse reset time characteristics

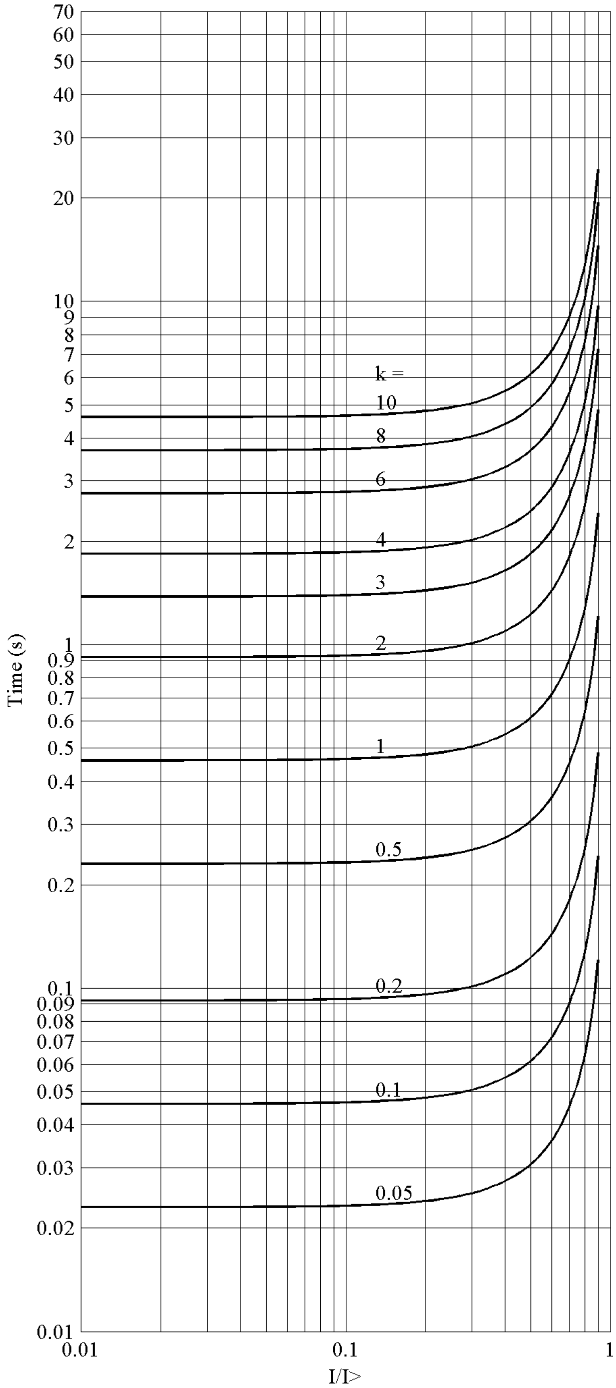


Figure 613: ANSI normal inverse reset time characteristics

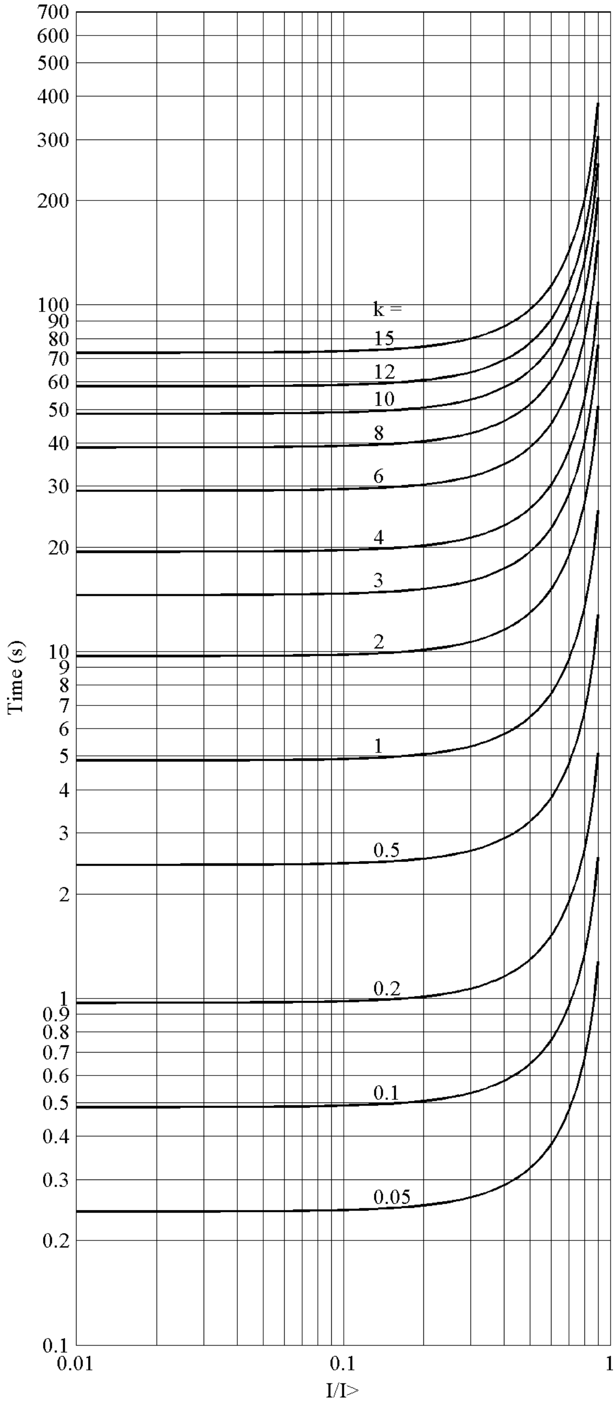


Figure 614: ANSI moderately inverse reset time characteristics

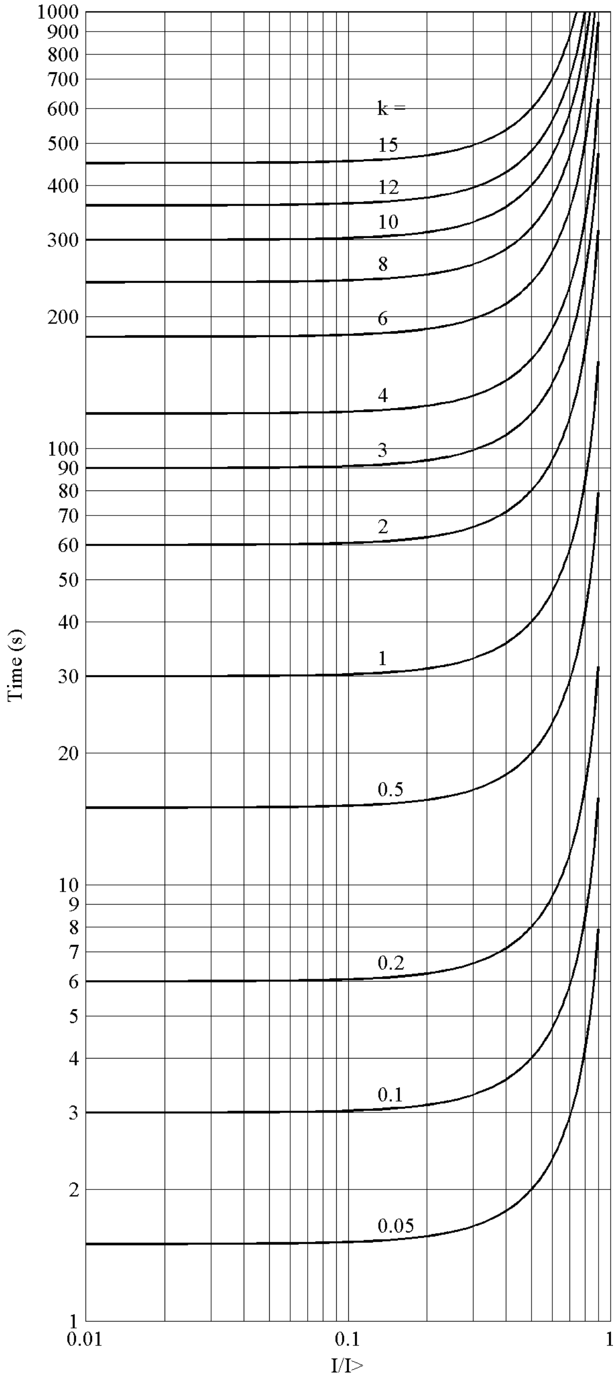


Figure 615: ANSI long-time extremely inverse reset time characteristics

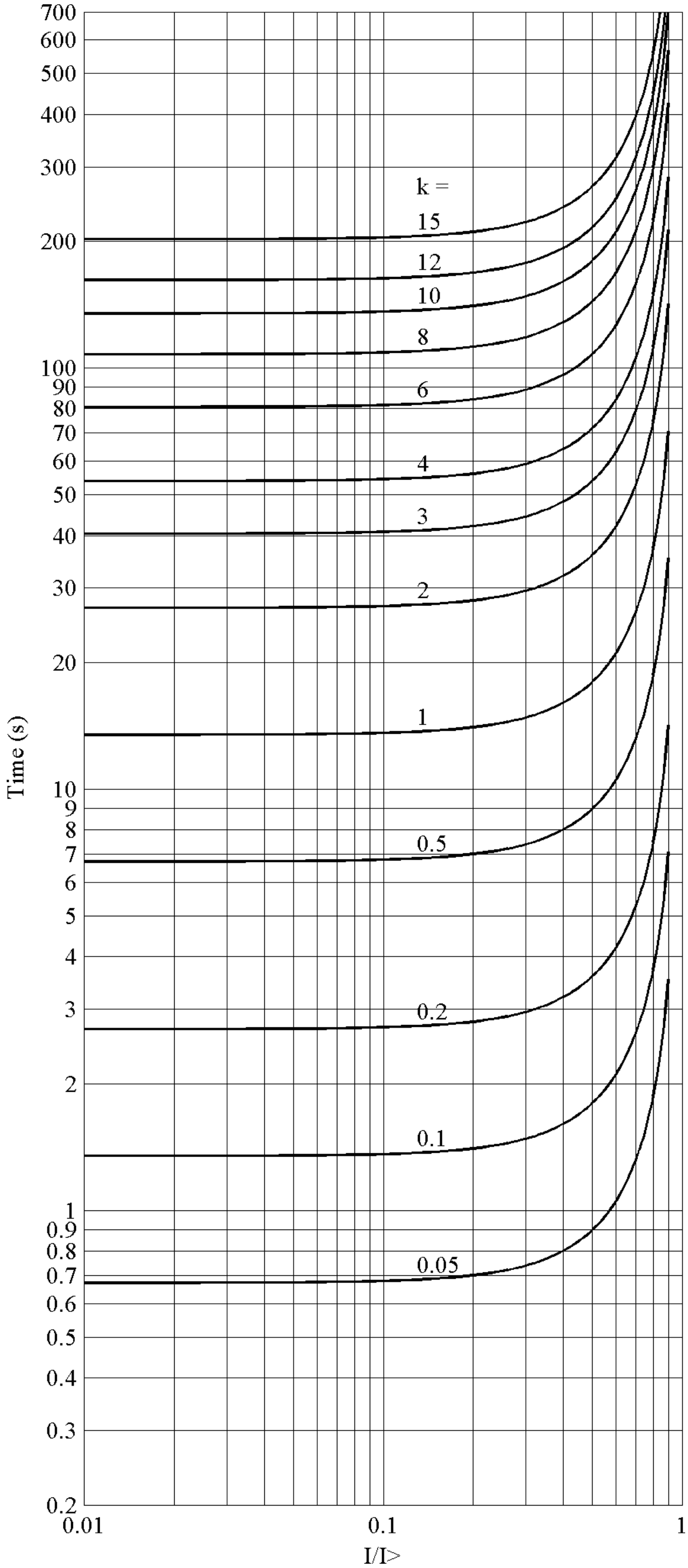


Figure 616: ANSI long-time very inverse reset time characteristics

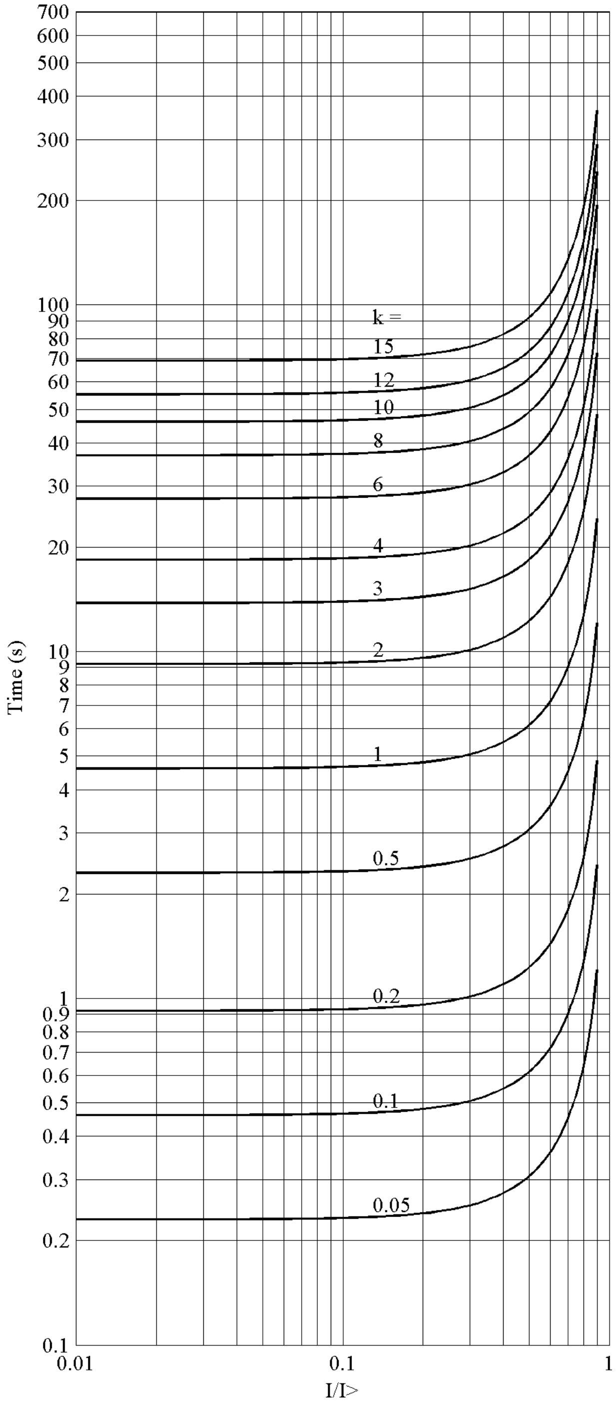


Figure 617: ANSI long-time inverse reset time characteristics

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 200)

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 BLOCK 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 selected blocking mode is "Freeze timer".

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:

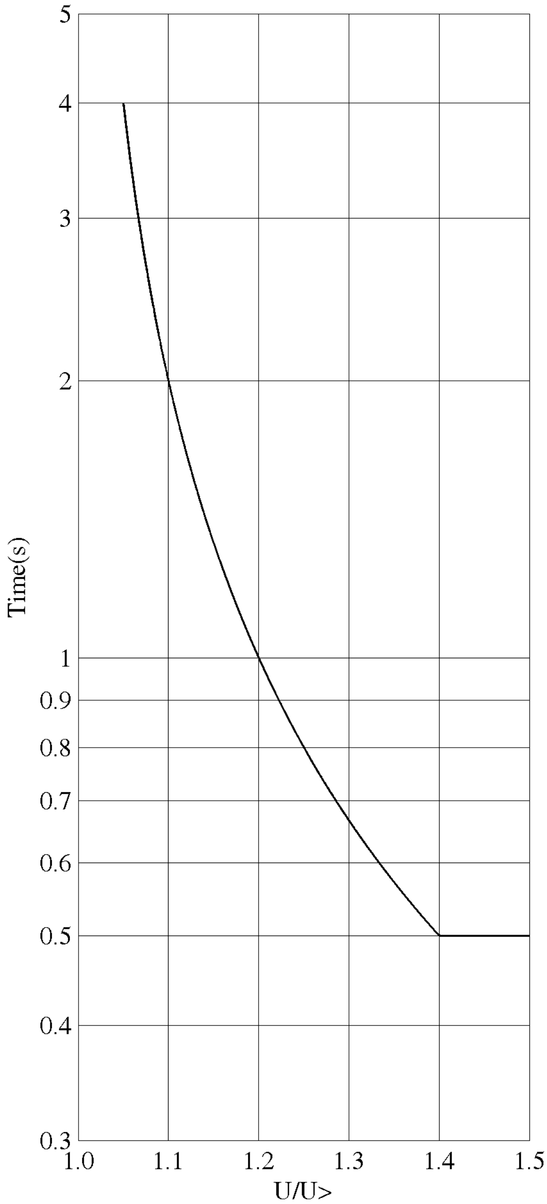


Figure 618: Operate time curve based on IDMT characteristic with Minimum operate time set to 0.5 second

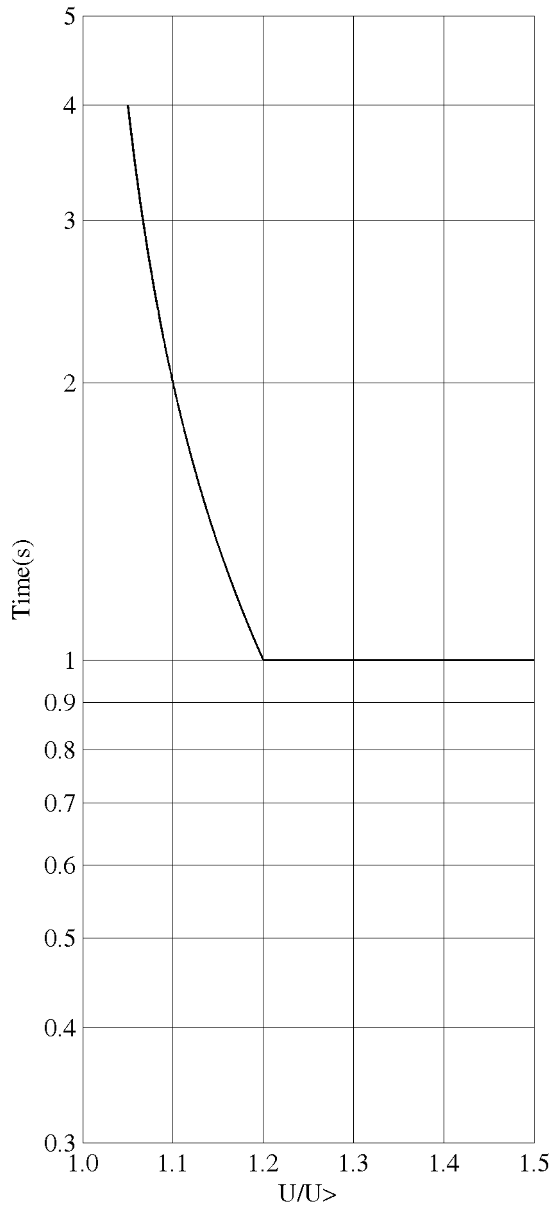


Figure 619: Operate time curve based on IDMT characteristic with Minimum operate time set to 1 second

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 201)

t [s]	operate time in seconds
U	measured voltage
U>	the set value of *Start value*
k	the set value of *Time multiplier*

Table 1060: 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

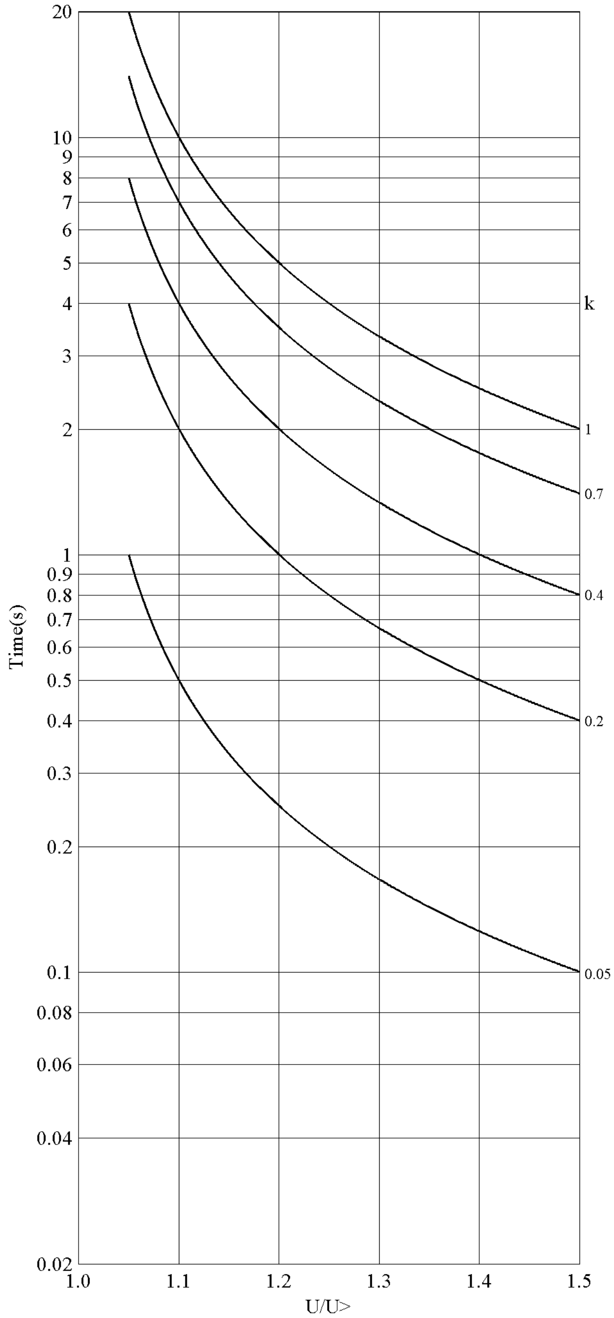


Figure 620: Inverse curve A characteristic of overvoltage protection

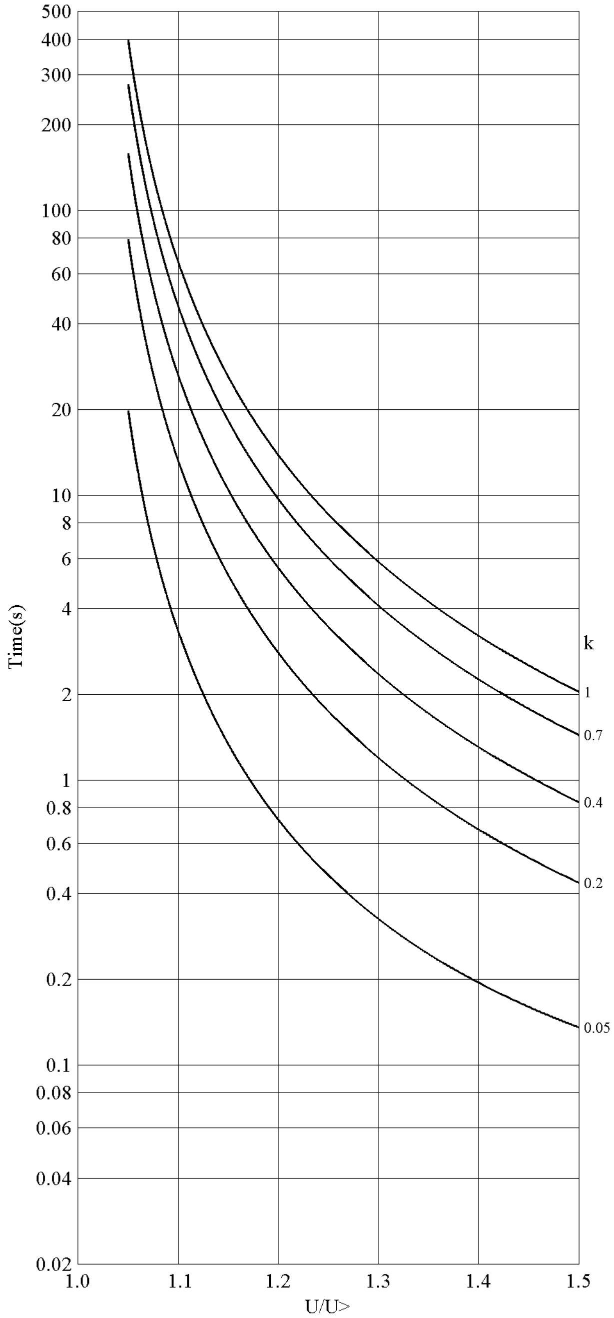


Figure 621: Inverse curve B characteristic of overvoltage protection

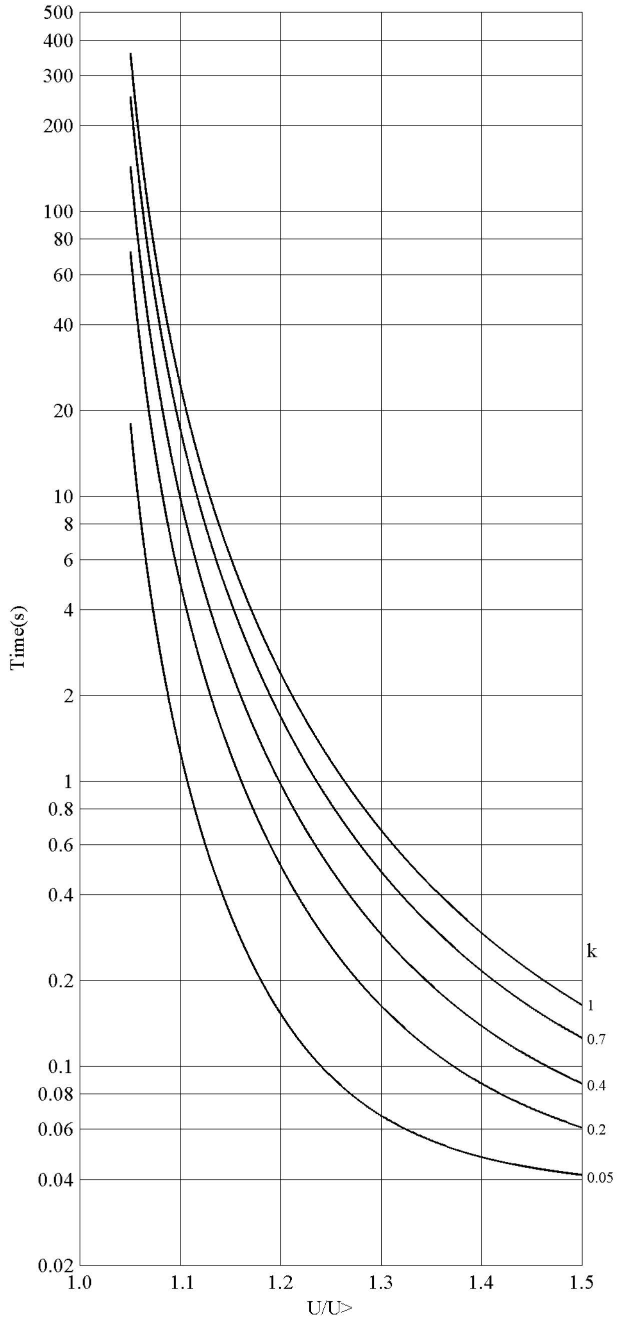


Figure 622: Inverse curve C characteristic of overvoltage protection

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 202)

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 203)

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 1061: 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

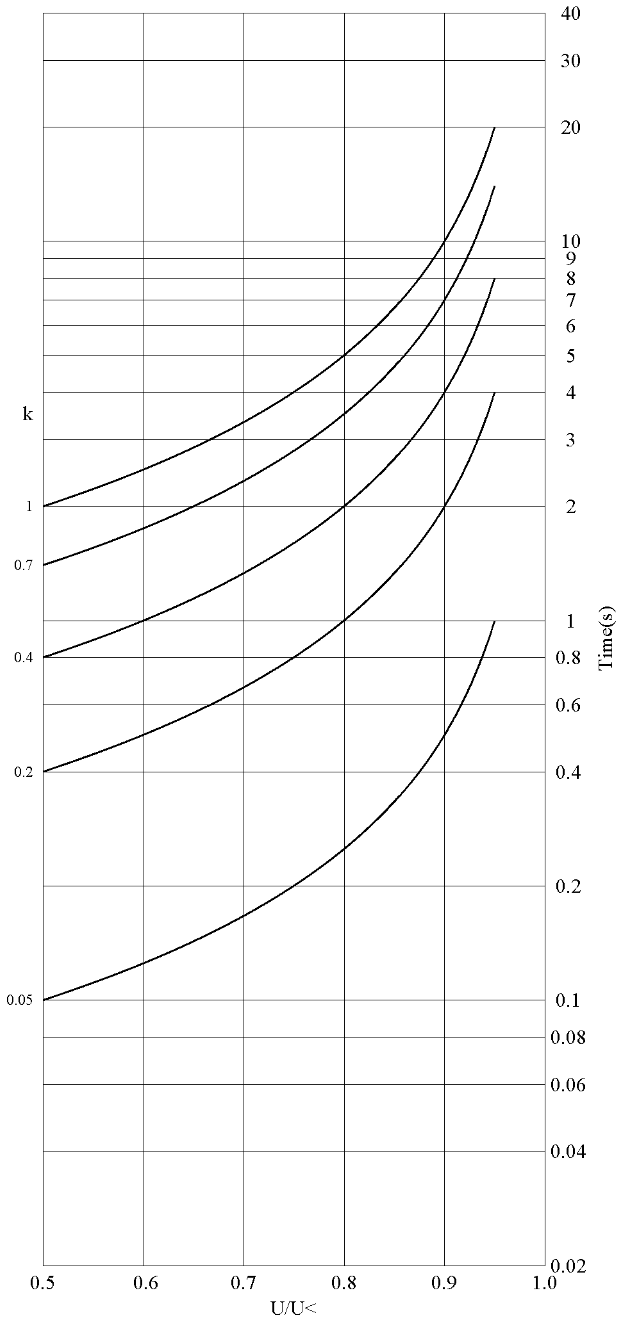


Figure 623: : Inverse curve A characteristic of undervoltage protection

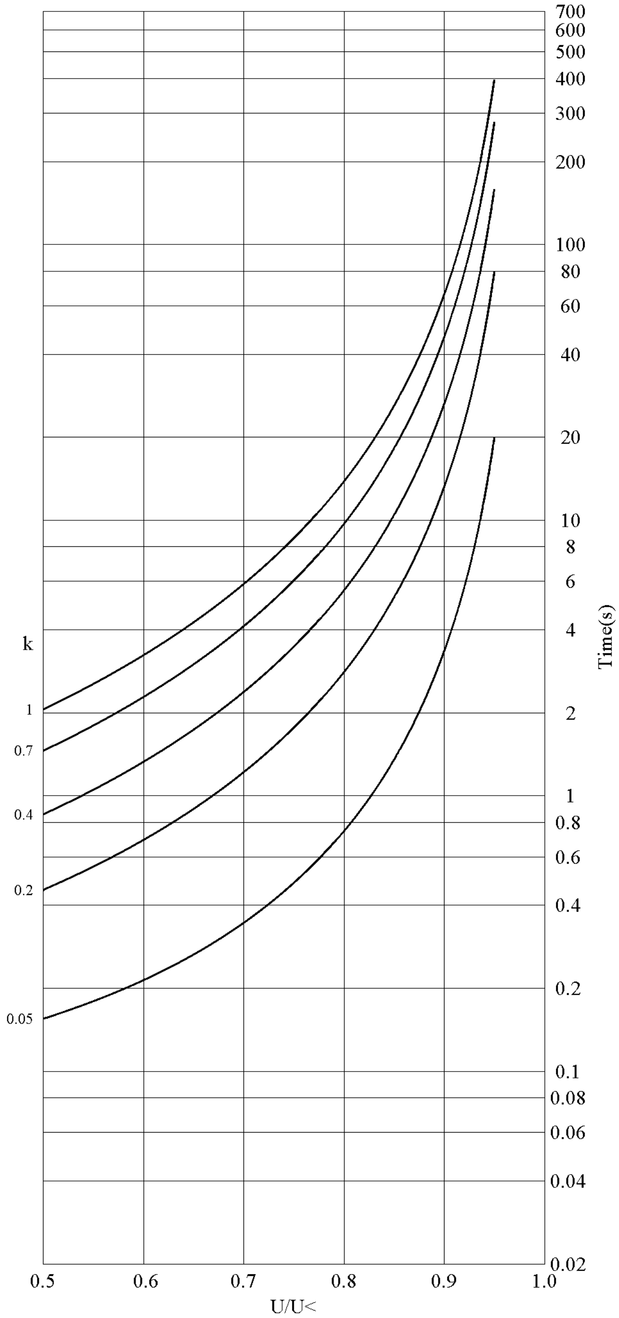


Figure 624: Inverse curve B characteristic of undervoltage protection

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 204)

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 Frequency measurement and protection

All the function blocks that use frequency quantity as their input signal share the common features related to the frequency measurement algorithm. The frequency estimation is done from one phase (phase-to-phase or phase voltage) or from the positive phase sequence (PPS). The voltage groups with three-phase inputs use PPS as the source. The frequency measurement range is 0.6...1.5 × F_n. The df/dt measurement range always starts from 0.6 × F_n. When the frequency exceeds these limits, it is regarded as out of range and a minimum or maximum value is held as the measured value respectively with appropriate quality information. The frequency estimation requires 160 ms to stabilize after a bad quality signal. Therefore, a delay of 160 ms is added to the transition from the bad quality. The bad quality of the signal can be due to restrictions like:

- The source voltage is below 0.02 × U_n at F_n.
- The source voltage waveform is discontinuous.
- The source voltage frequency rate of change exceeds 15 Hz/s (including stepwise frequency changes).

When the bad signal quality is obtained, the nominal or zero (depending on the *Def frequency Sel* setting) frequency value is shown with appropriate quality information in the measurement view. The frequency protection functions are blocked when the quality is bad, thus the timers and the function outputs are reset. When the frequency is out of the function block's setting range but within the measurement range, the protection blocks are running. However, the OPERATE outputs are blocked until the frequency restores to a valid range.

11.5 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 205)

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.

11.6 Calculated measurements

Calculated residual current and voltage

The residual current is calculated from the phase currents according to equation:

$$\overline{Io} = -(\overline{I}_A + \overline{I}_B + \overline{I}_C)$$

(Equation 206)

The residual voltage is calculated from the phase-to-earth voltages when the VT connection is selected as “Wye” with the equation:

$$\overline{Uo} = (\overline{U}_A + \overline{U}_B + \overline{U}_C)/3$$

(Equation 207)

Sequence components

The phase-sequence current components are calculated from the phase currents according to:

$$\overline{I}_0 = (\overline{I}_A + \overline{I}_B + \overline{I}_C)/3$$

(Equation 208)

$$\overline{I}_1 = (\overline{I}_A + a \cdot \overline{I}_B + a^2 \cdot \overline{I}_C)/3$$

(Equation 209)

$$\overline{I}_2 = (\overline{I}_A + a^2 \cdot \overline{I}_B + a \cdot \overline{I}_C)/3$$

(Equation 210)

The phase-sequence voltage components are calculated from the phase-to-earth voltages when *VT connection* is selected as “Wye” with the equations:

$$\overline{U}_0 = (\overline{U}_A + \overline{U}_B + \overline{U}_C)/3$$

(Equation 211)

$$\overline{U}_1 = (\overline{U}_A + a \cdot \overline{U}_B + a^2 \cdot \overline{U}_C)/3$$

(Equation 212)

$$\overline{U}_2 = (\overline{U}_A + a^2 \cdot \overline{U}_B + a \cdot \overline{U}_C)/3$$

(Equation 213)

When *VT connection* is selected as “Delta”, the positive and negative phase sequence voltage components are calculated from the phase-to-phase voltages according to the equations:

$$\overline{U}_1 = (\overline{U}_{AB} - a^2 \cdot \overline{U}_{BC})/3$$

(Equation 214)

$$\overline{U}_2 = (\overline{U}_{AB} - a \cdot \overline{U}_{BC})/3$$

(Equation 215)

The phase-to-earth voltages are calculated from the phase-to-phase voltages when *VT connection* is selected as "Delta" according to the equations.

$$\overline{U}_A = \overline{U}_0 + \left(\overline{U}_{AB} - \overline{U}_{CA}\right)/3$$

(Equation 216)

$$\overline{U}_B = \overline{U}_0 + \left(\overline{U}_{BC} - \overline{U}_{AB}\right)/3$$

(Equation 217)

$$\overline{U}_C = \overline{U}_0 + \left(\overline{U}_{CA} - \overline{U}_{BC}\right)/3$$

(Equation 218)

If the $\overline{U}_0$ channel is not valid, it is assumed to be zero.

The phase-to-phase voltages are calculated from the phase-to-earth voltages when *VT connection* is selected as "Wye" according to the equations.

$$\overline{U}_{AB} = \overline{U}_A - \overline{U}_B$$

(Equation 219)

$$\overline{U}_{BC} = \overline{U}_B - \overline{U}_C$$

(Equation 220)

$$\overline{U}_{CA} = \overline{U}_C - \overline{U}_A$$

(Equation 221)

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 1062: 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

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.

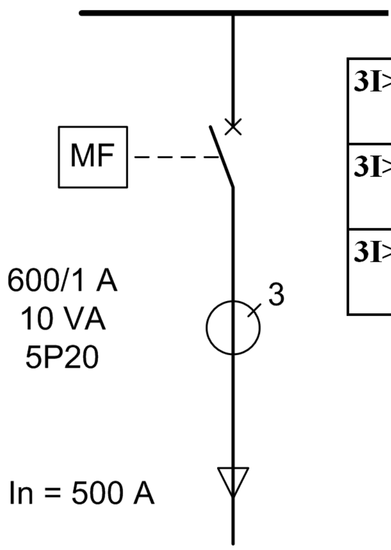
With inverse time mode of operation and when the high-set stages are not used, the AC component of the fault current should not saturate the CT less than 20 times the starting current. Otherwise, the inverse operation time can be further prolonged. Therefore, the accuracy limit factor F_a should be chosen using the formula:

F_a > 20 × *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	2.00 x I_{2n}
	0.75 s	0.75 s
3I>>	1800A	3.00 x I_{2n}
	0.50 s	0.50 s
3I>>>	3500 A	5.83 x I_{2n}
	0.20 s	0.20 s

Figure 625: 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 625*). 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 625*.

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.

13 IED physical connections

13.1 Module slot numbering

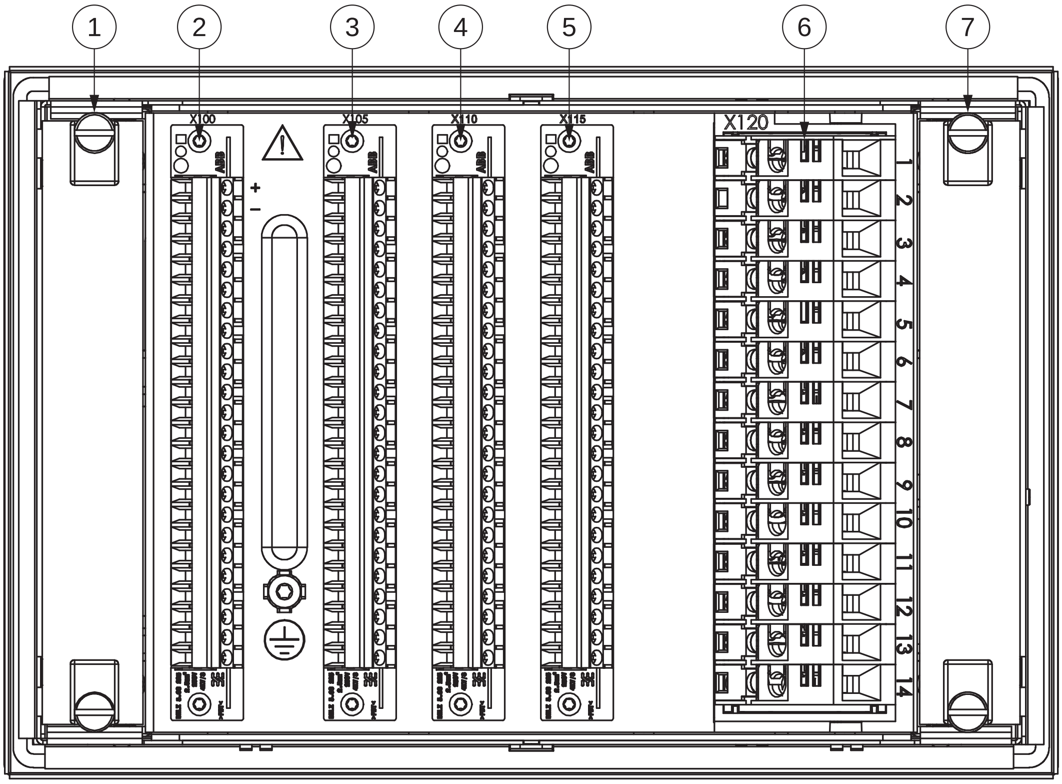


Figure 626: Module slot numbering

1	X000
2	X100
3	X105
4	X110
5	X115
6	X120
7	X130

13.2 Protective earth connections

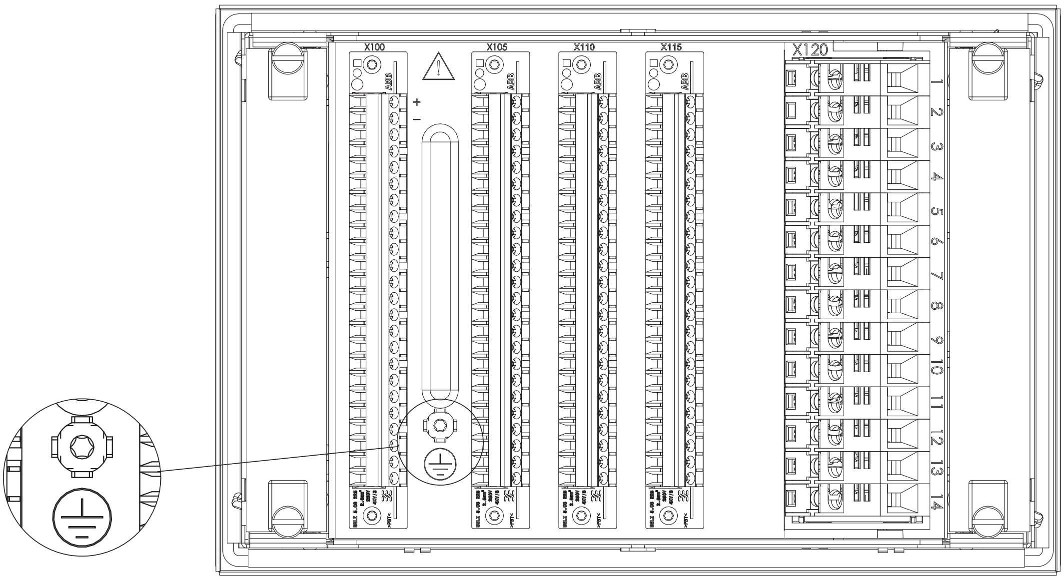


Figure 627: The protective earth screw is located between connectors X100 and X105

The earth lead must be at least 6.0 mm^2 and as short as possible.

13.3 Binary and analog connections

All binary and analog connections are described in the product specific application manuals.

13.4 Communication connections

The front communication connection is an RJ-45 type connector used mainly for configuration and setting.

- Galvanic RJ-45 Ethernet connection
- Optical LC Ethernet connection
- ST-type glass fiber serial connection
- EIA-485 serial connection
- EIA-232 serial connection

Never touch the end face of an optical fiber connector.

Always install dust caps on unplugged fiber connectors.

If contaminated, clean optical connectors only with fiber-optic cleaning products.

13.4.1 Ethernet RJ-45 front connection

The protection relay is provided with an RJ-45 connector on the LHMI. 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 protection relay 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 protection relay 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.

The speed of the front connector interface is limited to 10 Mbps.

13.4.2 Ethernet rear connections

The Ethernet station bus communication module is provided with either galvanic RJ-45 connection or optical multimode LC type connection, depending on the product variant and the selected communication interface option. A shielded twisted-pair cable CAT 5e is used with the RJ-45 connector and an optical multi-mode cable (≤2 km) with the LC type connector.

In addition, communication modules with multiple Ethernet connectors enable the forwarding of Ethernet traffic. These variants include an internal Ethernet switch that handles the Ethernet traffic between an protection relay and a station bus. In this case, the used network can be a ring or daisy-chain type of network topology. In loop type topology, a self-healing Ethernet loop is closed by a managed switch supporting rapid spanning tree protocol. In daisy-chain type of topology, the network is bus type and it is either without switches, where the station bus starts from the station client, or with a switch to connect some devices and the protection relays of this product series to the same network.Internal Ethernet switch MAC table size is 512 entries. All Ethernet ports share this one common MAC table.

Communication modules including Ethernet connectors X1, X2, and X3 can utilize the third port for connecting any other device (for example, an SNTP server, that is visible for the whole local subnet) to a station bus.

The protection relay's default IP address through rear Ethernet port is 192.168.2.10 with the TCP/IP protocol. The data transfer rate is 10 or 100 Mbps full duplex.

13.4.3 EIA-232 serial rear connection

The EIA-232 connection follows the TIA/EIA-232 standard and is intended to be used with a point-to-point connection. The connection supports hardware flow control (RTS, CTS, DTR, DSR), full-duplex and half-duplex communication.

13.4.4 EIA-485 serial rear connection

The EIA-485 communication module follows the TIA/EIA-485 standard and is intended to be used in a daisy-chain bus wiring scheme with 2-wire half-duplex or 4-wire full-duplex, multi-point communication.

The maximum number of devices (nodes) connected to the bus where the protection relay is used is 32, and the maximum length of the bus is 1200 meters.

13.4.5 Optical ST serial rear connection

Serial communication can be used optionally through an optical connection either in loop or star topology. The connection idle state is light on or light off.

Using ST loop mode requires an ST serial converter that supports detecting and removing of duplicate request after transmission trough full circle.

13.4.6 Communication interfaces and protocols

The communication protocols supported depend on the optional rear communication module.

Table 1063: Supported station communication interfaces and protocols

Interfaces/ Protocols	Ethernet		Serial	
	100BASE-TX RJ-45	100BASE-FX LC	EIA-232/ EIA-485	Fiber optic ST
IEC 61850-8-1	●	●	-	-
IEC 61850-9-2 LE	●	●	-	-
MODBUS RTU/ ASCII	-	-	●	●
MODBUS TCP/IP	●	●	-	-
DNP3 (serial)	-	-	●	●
DNP3 TCP/IP	●	●	-	-

Table continues on the next page

Interfaces/ Protocols	Ethernet		Serial	
	100BASE-TX RJ-45	100BASE-FX LC	EIA-232/ EIA-485	Fiber optic ST
IEC 60870-5-103	-	-	●	●
● = Supported				

13.4.7 Rear communication modules

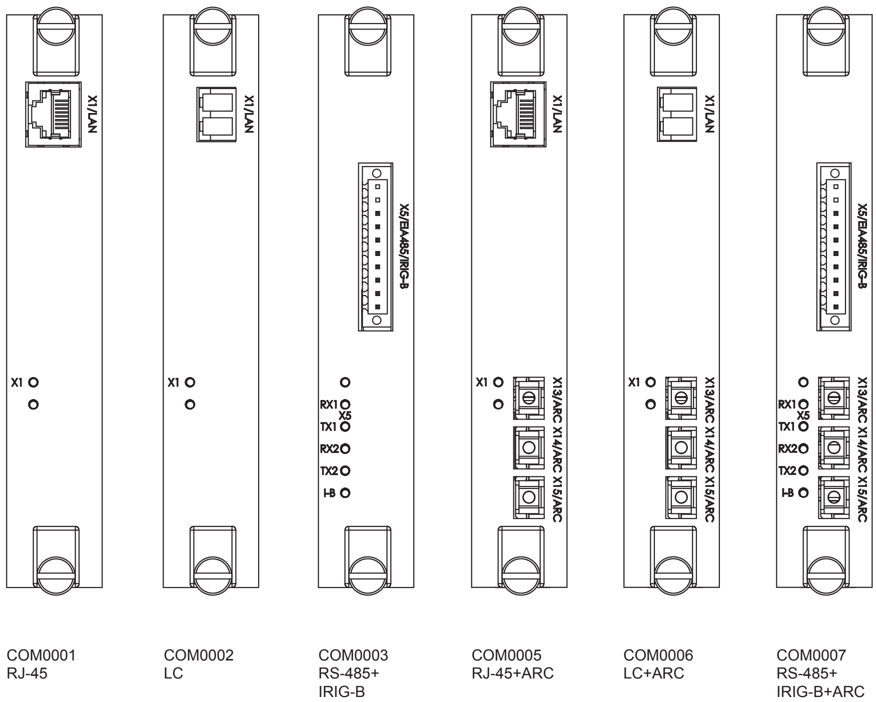
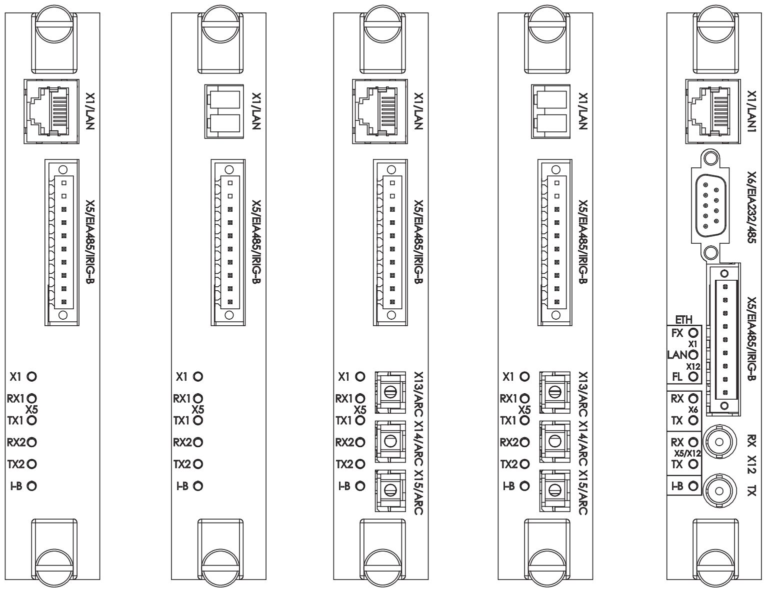


Figure 628: Communication module options



COM0011
RJ-45+RS-485
+IRIG-B

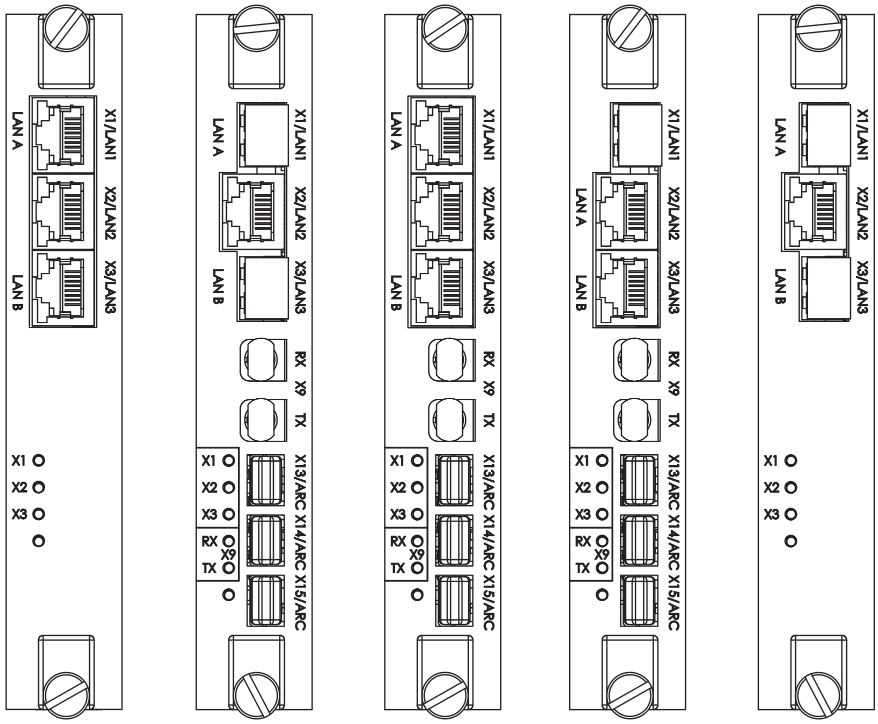
COM0012
LC+RS-485+
IRIG-B

COM0013
RJ-45+RS-485
+IRIG-B+ARC

COM0014
LC+RS-485+
IRIG-B+ARC

COM0023
RJ-45+RS-232/485+
RS-485+ST+
IRIG-B

Figure 629: Communication module options



COM0031
3xRJ-45

COM0032
2xLC+RJ-45+
ST+ARC

COM0033
3xRJ-45+
ST+ARC

COM0034
LC+2xRJ-45+
ST+ARC

COM0037
2xLC+RJ-45

Figure 630: Communication module options

Ethernet ports marked with LAN A and LAN B are used with redundant Ethernet protocols HSR and PRP. The third port without the LAN A or LAN B label is an interlink port which is used as a redundancy box connector with redundant Ethernet protocols.

Table 1064: Station bus communication interfaces included in communication modules

Module ID	RJ-45	LC	EIA-485	EIA-232	ST
COM0001	1	-	-	-	-
COM0002	-	1	-	-	-
COM0003	-	-	1	-	-
COM0005	1	-	-	-	-
COM0006	-	1	-	-	-
COM0007	-	-	1	-	-
COM0011	1	-	1	-	-
COM0012	-	1	1	-	-
COM0013	1	-	1	-	-
COM0014	-	1	1	-	-
COM0023	1	-	1	1	1
COM0031	3	-	-	-	-
COM0032	1	2	-	-	1
COM0033	3	-	-	-	1
COM0034	2	1	-	-	1
COM0037	1	2	-	-	-

Table 1065: LED descriptions for COM0001-COM0014

LED	Connector	Description
X1	X1	X1/LAN link status and activity (RJ-45 and LC)
RX1	X5	COM2 2-wire/4-wire receiving activity
TX1	X5	COM2 2-wire/4-wire transmitting activity
RX2	X5	COM1 2-wire receiving activity
TX2	X5	COM1 2-wire transmitting activity
I-B	X5	IRIG-B signal activity

[1] Depending on the COM module and jumper configuration

Table 1066: LED descriptions for COM0023

LED	Connector	Description [2]
FX	X12	Not used by COM0023
X1	X1	LAN Link status and activity (RJ-45 and LC)
FL	X12	Not used by COM0023
RX	X6	COM1 2-wire / 4-wire receiving activity
TX	X6	COM1 2-wire / 4-wire transmitting activity
RX	X5 / X12	COM2 2-wire / 4-wire or fiber-optic receiving activity
TX	X5 / X12	COM2 2-wire / 4-wire or fiber-optic transmitting activity
I-B	X5	IRIG-B signal activity

Table 1067: LED descriptions for COM0031-COM0034 and COM0037

LED	Connector	Description
X1	X1	X1/LAN1 link status and activity
X2	X2	X2/LAN2 link status and activity
X3	X3	X3/LAN3 link status and activity
RX	X9	COM1 fiber-optic receiving activity
TX	X9	COM1 fiber-optic transmitting activity

Table 1068: LED descriptions for COM0035 and COM0036

LED	Connector	Description
X1	X1	X1/LAN link status and activity
X2	X2	X2/LAN link status and activity
X16	X16	X16/LD link status and activity

[2] Depending on the jumper configuration

13.4.7.1 COM0001-COM0014 jumper locations and connections

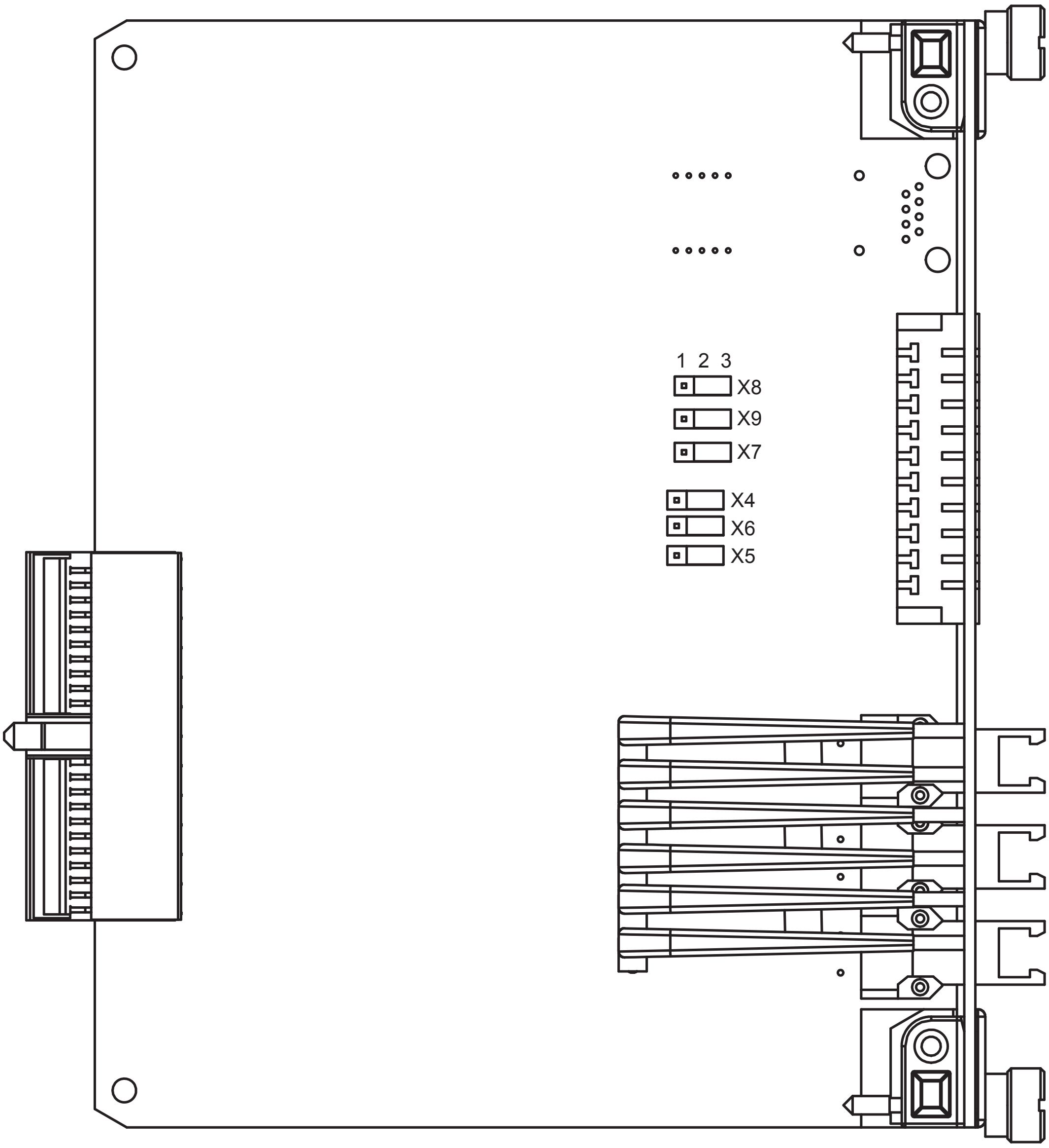


Figure 631: Jumper connectors on communication module

Table 1069: 2-wire EIA-485 jumper connectors

Group	Jumper connection	Description	Notes
X4	1-2	A+ bias enabled	COM2 2-wire connection
	2-3	A+ bias disabled	
X5	1-2	B- bias enabled	
	2-3	B- bias disabled	
X6	1-2	Bus termination enabled	
	2-3	Bus termination disabled	

Table continues on the next page

Group	Jumper connection	Description	Notes
X7	1-2	B- bias enabled	COM1 2-wire connection
	2-3	B- bias disabled	
X8	1-2	A+ bias enabled	
	2-3	A+ bias disabled	
X9	1-2	Bus termination enabled	
	2-3	Bus termination disabled	

The bus is to be biased at one end to ensure fail-safe operation, which can be done using the pull-up and pull-down resistors on the communication module. In 4-wire connection the pull-up and pull-down resistors are selected by setting jumpers X4, X5, X7 and X8 to enabled position. The bus termination is selected by setting jumpers X6 and X9 to enabled position.

The jumpers have been set to no termination and no biasing as default.

Table 1070: 4-wire EIA-485 jumper connectors for COM2

Group	Jumper connection	Description	Notes
X4	**1-2**	A+ bias enabled	COM2 4-wire TX channel
	2-3	A+ bias disabled	
X5	**1-2**	B- bias enabled	
	2-3	B- bias disabled [1]	
X6	**1-2**	Bus termination enabled	
	2-3	Bus termination disabled [1]	
X7	**1-2**	B- bias enabled	COM2 4-wire RX channel
	2-3	B- bias disabled [1]	
X8	**1-2**	A+ bias enabled	
	2-3	A+ bias disabled [1]	
X9	**1-2**	Bus termination enabled	
	2-3	Bus termination disabled [1]	

It is recommended to enable biasing only at one end of the bus.

It is recommended to enable termination at each end of the bus.

It is recommended to ground the signal directly to earth from one node using a GND pin and through capacitor from other nodes using a GNDC pin.

[1] Default setting

Signal grounding should be used with all devices in RS-485 bus having an isolated communication port. Grounding ensures that different RS-485 nodes have the same signal reference ground. Without grounding the differential RS-485 signal might be superimposed between different nodes with respect to the node's local ground. For signal grounding it is recommended to connect to AGND pin in RS-485 connector an additional ground wire which runs inside the shielded serial cable.

The optional communication modules include support for EIA-485 serial communication (X5 connector). Depending on the configuration, the communication modules can host either two 2-wire ports or one 4-wire port.

The two 2-wire ports are called COM1 and COM2. Alternatively, if there is only one 4-wire port configured, the port is called COM2. The fiber optic ST connection uses the COM1 port.

Table 1071: EIA-485 connections for COM0001-COM0014

Pin	2-wire mode		4-wire mode	
10	COM1	A/+	COM2	Rx/+
9		B/-		Rx/-
8	COM2	A/+		Tx/+
7		B/-		Tx/-
6	AGND (isolated ground)			
5	IRIG-B +			
4	IRIG-B -			
3	-			
2	GNDC (case via capacitor)			
1	GND (case)			

13.4.7.2 COM0023 jumper locations and connections

The optional communication module supports EIA-232/EIA-485 serial communication (X6 connector), EIA-485 serial communication (X5 connector) and optical ST serial communication (X12 connector).

Two independent communication ports are supported. The two 2-wire ports are called COM1 and COM2. Alternatively, if only one 4-wire port is configured, the port is called COM2. The fiber optic ST connection uses the COM1 port.

Table 1072: Configuration options of the two independent communication ports

COM1 connector X6	COM2 connector X5 or X12
EIA-232	Optical ST (X12)
EIA-485 2-wire	EIA-485 2-wire (X5)
EIA-485 4-wire	EIA-485 4-wire (X5)

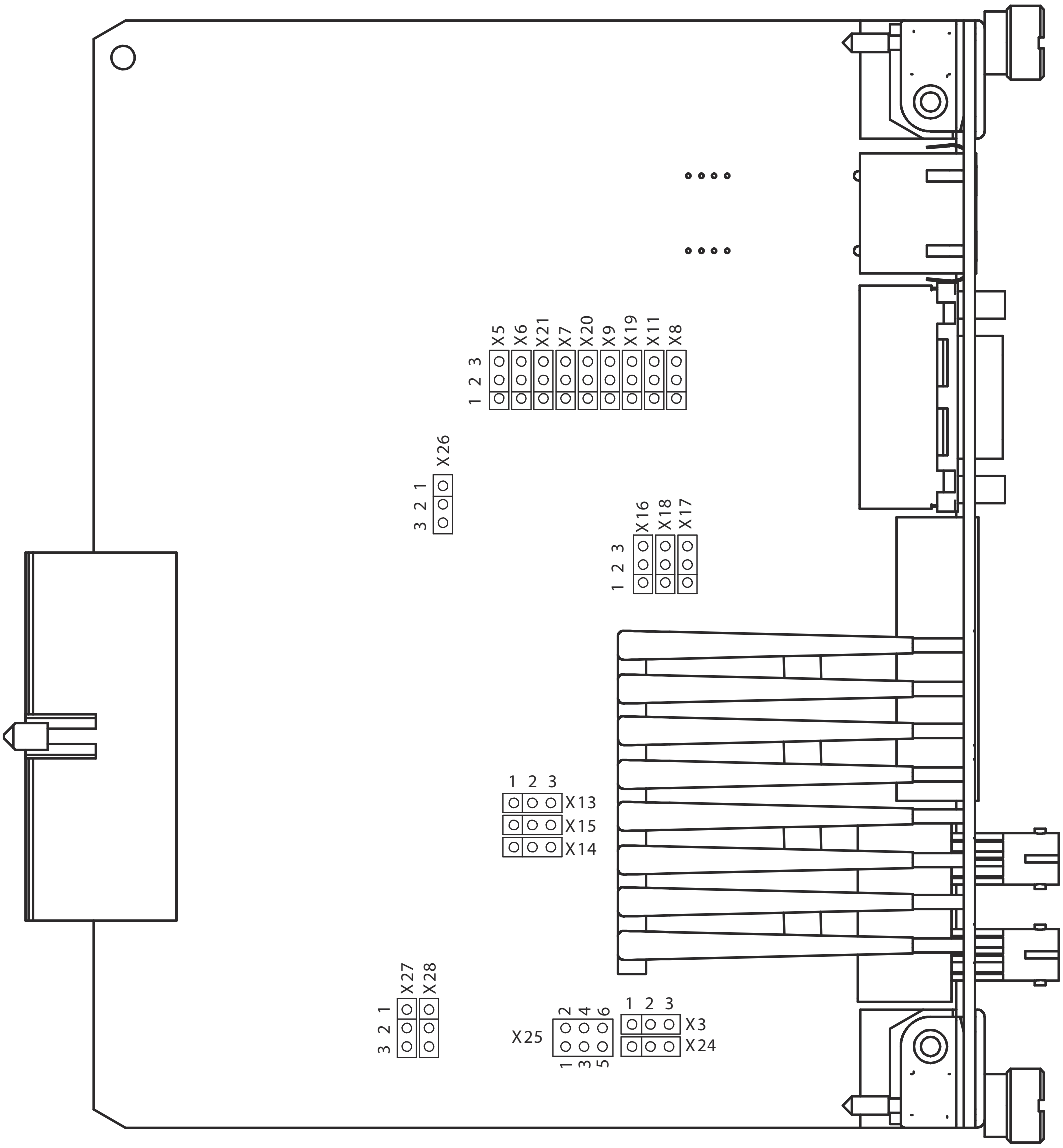


Figure 632: Jumper connections on communication module COM0023 revisions A-F

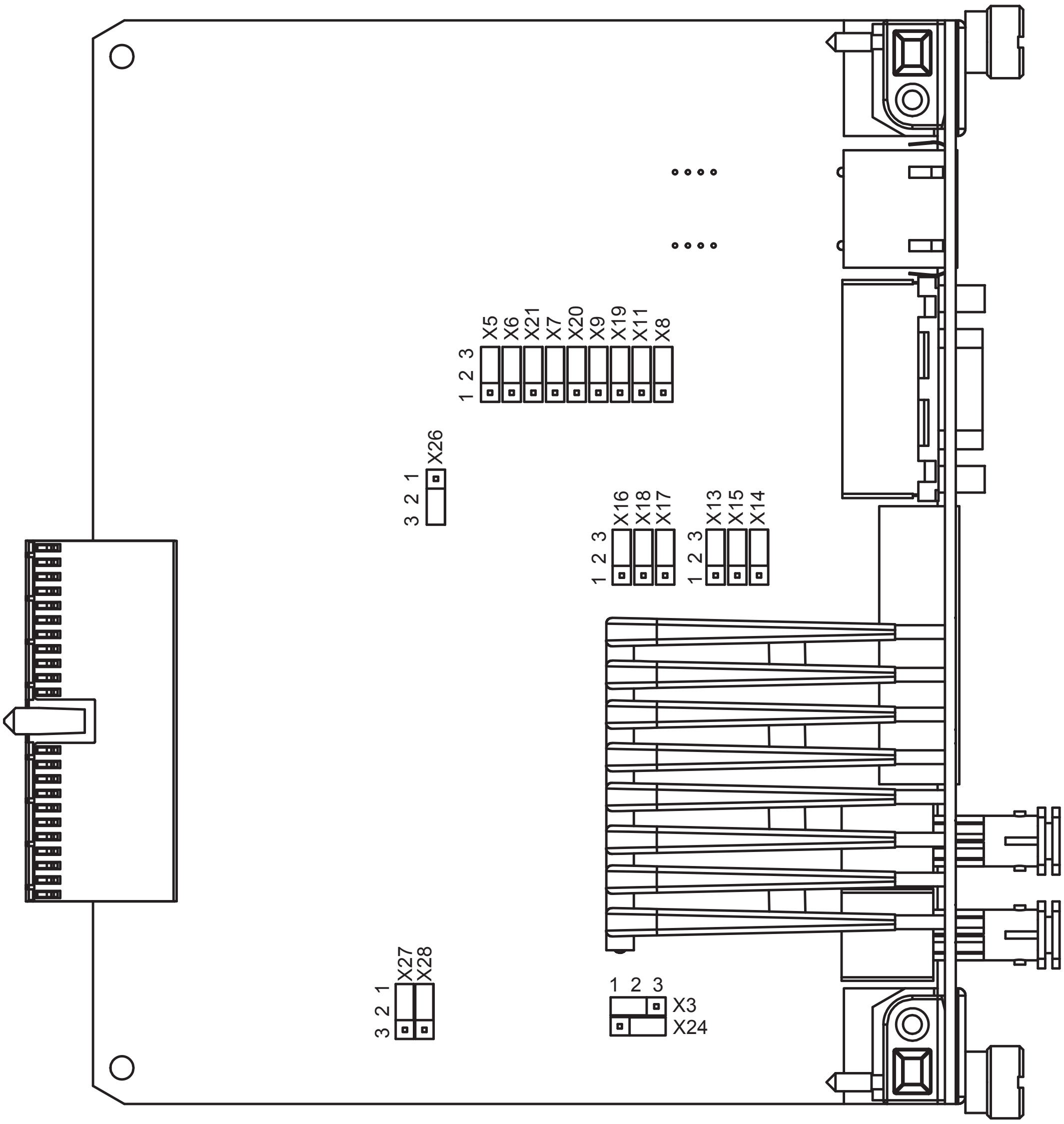


Figure 633: Jumper connections on communication module COM0023 revision G

COM1 port connection type can be either EIA-232 or EIA-485. Type is selected by setting jumpers X19, X20, X21 and X26.

The jumpers are set to EIA-232 by default.

Table 1073: EIA-232 and EIA-485 jumper connectors for COM1

Group	Jumper connection	Description
X19	1-2 2-3	EIA-485 EIA-232
X20	1-2 2-3	EIA-485 EIA-232
X21	1-2	EIA-485

Table continues on the next page

Group	Jumper connection	Description
	2-3	EIA-232
X26	1-2 2-3	EIA-485 EIA-232

To ensure fail-safe operation, the bus is to be biased at one end using the pull-up and pull-down resistors on the communication module. In the 4-wire connection, the pull-up and pull-down resistors are selected by setting jumpers X5, X6, X8 and X9 to enabled position. The bus termination is selected by setting jumpers X7 and X11 to enabled position.

The jumpers have been set to no termination and no biasing as default.

Table 1074: 2-wire EIA-485 jumper connectors for COM1

Group	Jumper connection	Description	Notes
X5	1-2 2-3	A+ bias enabled A+ bias disabled [1]	COM1 Rear connector X6 2-wire connection
X6	1-2 2-3	B- bias enabled B- bias disabled [1]	
X7	1-2 2-3	Bus termination enabled Bus termination disabled [1]	

Table 1075: 4–wire EIA-485 jumper connectors for COM1

Group	Jumper connection	Description	Notes
X5	1-2 2-3	A+ bias enabled A+ bias disabled [1]	COM1 Rear connector X6 4-wire TX channel
X6	1-2 2-3	B- bias enabled B- bias disabled [1]	
X7	1-2 2-3	Bus termination enabled Bus termination disabled [1]	
X9	1-2 2-3	A+ bias enabled A+ bias disabled [1]	4-wire RX channel
X8	1-2 2-3	B- bias enabled B- bias disabled [1]	
X11	1-2	Bus termination ena-	

[1] Default setting

Group	Jumper connection	Description	Notes
	2-3	bled Bus termination disa-bled [1]	

COM2 port connection can be either EIA-485 or optical ST. Connection type is selected by setting jumpers X27 and X28.

Table 1076: COM2 serial connection X5 EIA-485/ X12 Optical ST

Group	Jumper connection	Description
X27	1-2 2-3	EIA-485 Optical ST
X28	1-2 2-3	EIA-485 Optical ST

Table 1077: 2-wire EIA-485 jumper connectors for COM2

Group	Jumper connection	Description
X13	1-2 2-3	A+ bias enabled A+ bias disabled
X14	1-2 2-3	B- bias enabled B- bias disabled
X15	1-2 2-3	Bus termination enabled Bus termination disabled

Table 1078: 4-wire EIA-485 jumper connectors for COM2

Group	Jumper connection	Description	Notes
X13	1-2 2-3	A+ bias enabled A+ bias disabled	COM2 4-wire TX channel
X14	1-2 2-3	B- bias enabled B- bias disabled	
X15	1-2 2-3	Bus termination ena-bled Bus termination disa-bled	
X16	1-2 2-3	Bus termination ena-bled Bus termination disa-bled	4-wire RX channel
X17	1-2	A+ bias enabled	

Table continues on the next page

Group	Jumper connection	Description	Notes
	2-3	A+ bias disabled	
X18	1-2 2-3	B- bias enabled B- bias disabled	

Table 1079: X12 Optical ST connection

Group	Jumper connection	Description
X3	1-2 2-3	Star topology Loop topology
X24	1-2 2-3	Idle state = Light on Idle state = Light off

Table 1080: EIA-232 connections for COM0023 (X6)

Pin	EIA-232
1	DCD
2	RxD
3	TxD
4	DTR
5	AGND
6	-
7	RTS
8	CTS

Table 1081: EIA-485 connections for COM0023 (X6)

Pin	2-wire mode	4-wire mode
1	-	Rx/+
6	-	Rx/-
7	B/-	Tx/-
8	A/+	Tx/+

Table 1082: EIA-485 connections for COM0023 (X5)

Pin	2-wire mode	4-wire mode
9	-	Rx/+
8	-	Rx/-
7	A/+	Tx/+
6	B/-	Tx/-
5	AGND (isolated ground)	
4	IRIG-B +	
3	IRIG-B -	
2	-	
1	GND (case)	

13.4.7.3 COM0032-COM0034 jumper locations and connections

The optional communication modules include support for optical ST serial communication (X9 connector). The fiber optic ST connection uses the COM1 port.

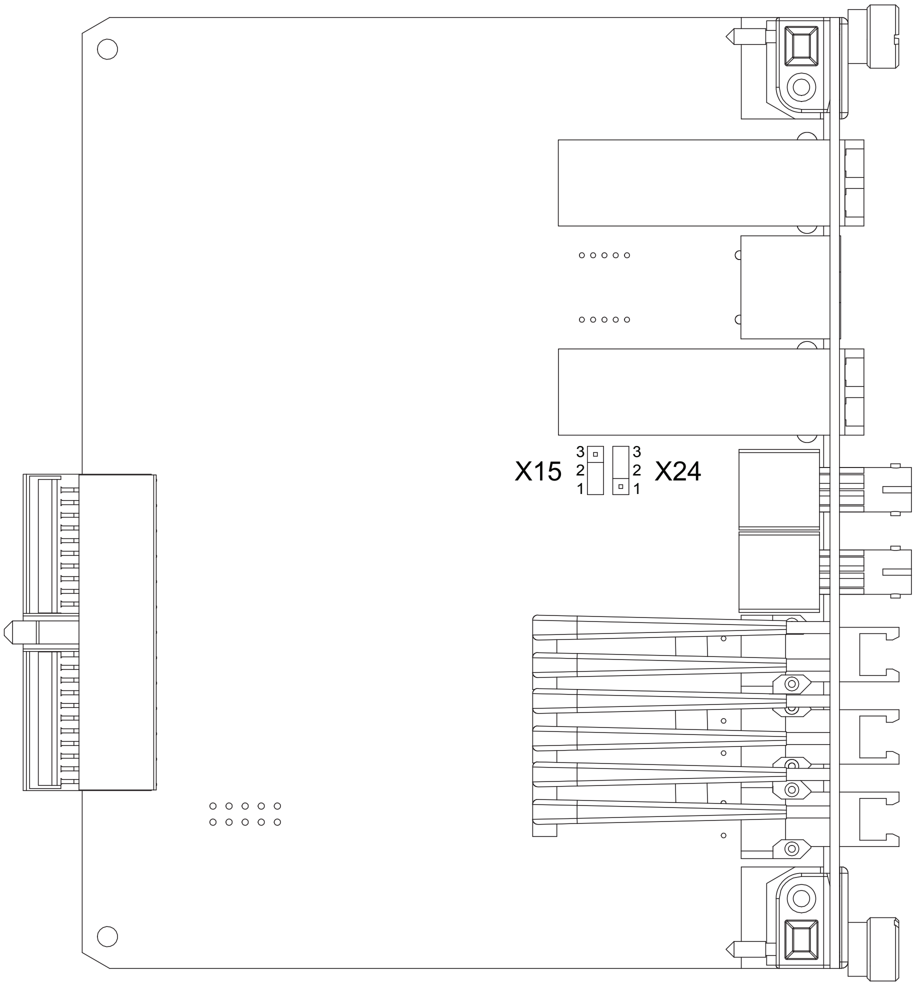


Figure 634: Jumper connections on communication module COM0032

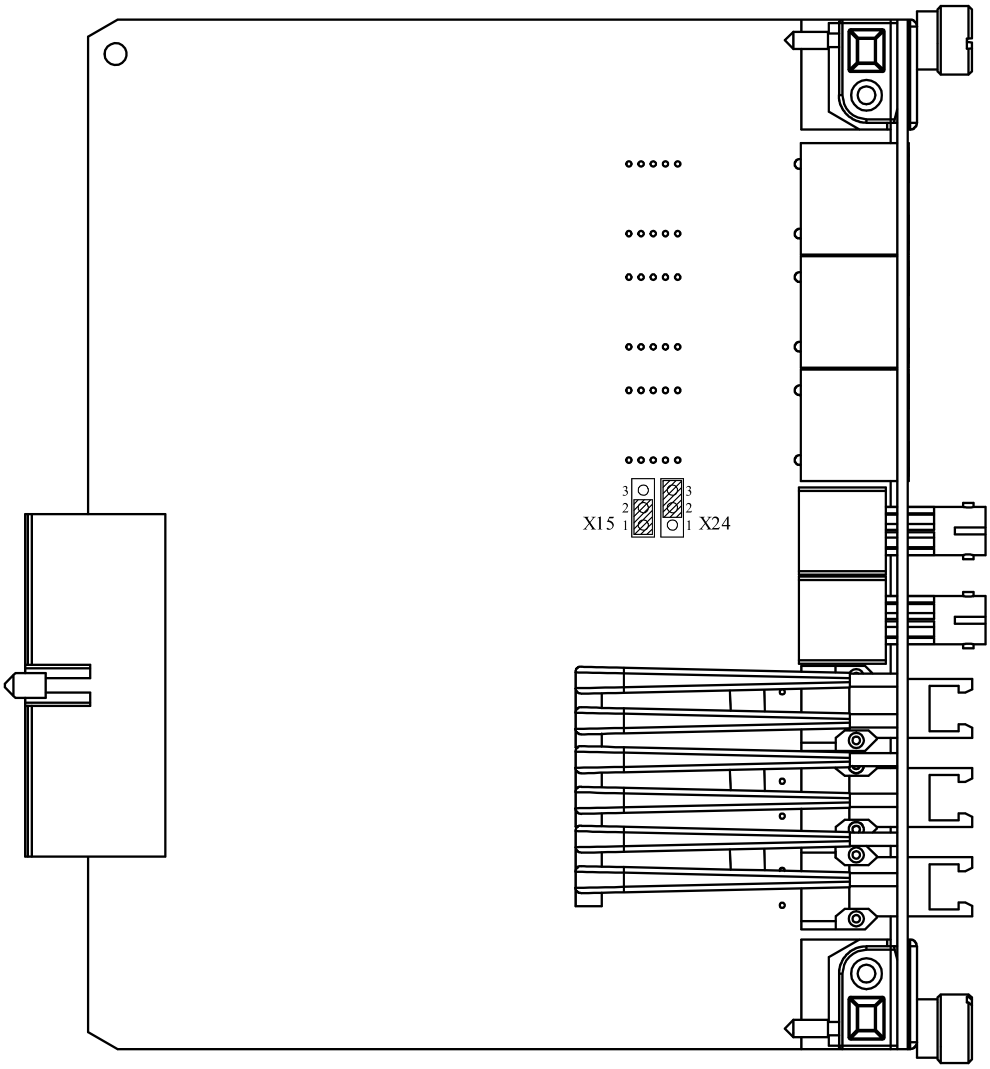


Figure 635: Jumper connections on communication module COM0033

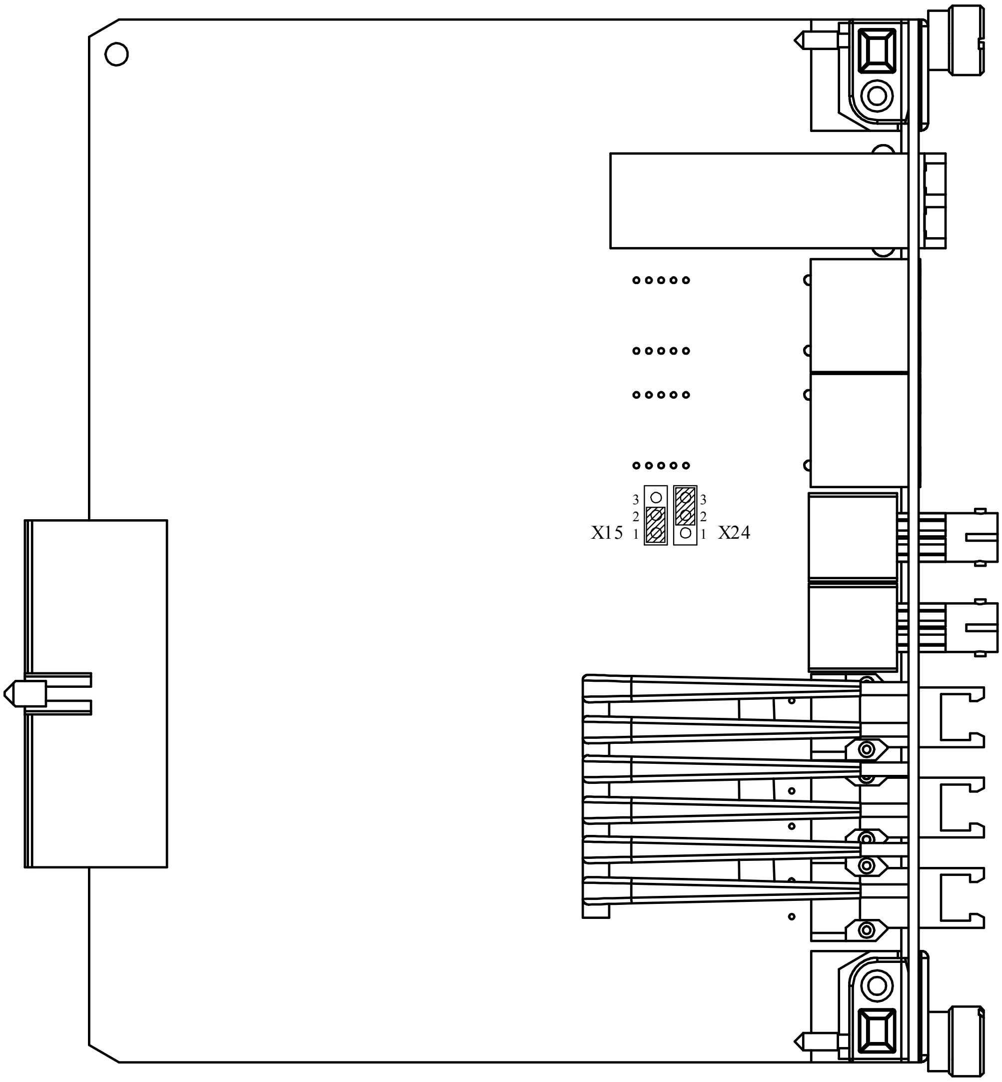


Figure 636: Jumper connections on communication module COM0034

Table 1083: X9 Optical ST jumper connectors

Group	Jumper connection	Description
X15	1-2 2-3	Star topology Loop topology
X24	1-2 2-3	Idle state = Light on Idle state = Light off

14 Technical data

14.1 Dimensions

Table 1084: Dimensions

Description	Value	
Width	Frame	262.2 mm
	Case	246 mm
Height	Frame	177 mm, 4U
	Case	160 mm
Depth		201 mm
Weight	Complete protection relay	max. 5.5 kg
	Plug-in unit only	max. 3.0 kg

14.2 Power supply

Table 1085: Power supply

Description	Type 1	Type 2
U_{aux} nominal	100, 110, 120, 220, 240 V AC, 50 and 60 Hz	24, 30, 48, 60 V DC
	48, 60, 110, 125, 220, 250 V DC	
Maximum interruption time in the auxiliary DC voltage without resetting the relay	50 ms at U_n rated	
U_{aux} variation	38...110% of U_n (38...264 V AC)	50...120% of U_n (12...72 V DC)
	80...120% of U_n (38.4...300 V DC)	
Start-up threshold		19.2 V DC (24 V DC × 80%)
Burden of auxiliary voltage supply under quiescent (P_q)/operating condition	DC <18.0 W (nominal [1])/<22.5 W (max. [2]) AC <19.0 W (nominal [1])/<23.0 W (max. [2])	DC <18.5 W (nominal [1])/<22.5 W (max. [2])
Ripple in the DC auxiliary voltage	Max 15% of the DC value (at frequency of 100 Hz)	
Fuse type	T4A/250 V	

[1] During the power consumption measurement, the relay is powered at rated auxiliary energizing voltage and the energizing quantities are energized without any binary output being active

[2] During the power consumption measurement, the relay is powered at rated auxiliary energizing voltage and the energizing quantities are energized to activate at least half of the binary outputs

14.3 Energizing inputs

Table 1086: Energizing inputs

Description		Value	
Rated frequency		50/60 Hz	
Current inputs	Rated current, I_n	0.2/1 A [1], [2]	1/5 A
	Thermal withstand capability: • Continuously • For 1 s	 4 A 100 A	 20 A 500 A
	Dynamic current withstand: • Half-wave value	 250 A	 1250 A
	Input impedance	<100 mΩ	<20 mΩ
Voltage inputs	Rated voltage	60...210 V AC	
	Voltage withstand: • Continuous • For 10 s	 240 V AC 360 V AC	
	Burden at rated voltage	<0.05 VA	

14.4 Energizing inputs (sensors)

Table 1087: Energizing Inputs (SIM0002)

Description		Value
Current sensor input	Rated current voltage	75 mV ... 9000 mV [1]
	Continuous voltage withstand	125 V
	Input impedance at 50/60Hz	2...3 MΩ [2]
Voltage sensor input	Rated secondary voltage	346 mV…1733 mV [3]
	Continuous voltage withstand	50 V
	Input impedance at 50/60Hz	3 MΩ

1 Ordering option for residual current input
2 Not available for RET620
3 Residual current and/or phase current
1 Equals the current range of 40 … 4000 A with 80A, 3mV/Hz Rogowski
2 Depending on the used nominal current (hardware gain)
3 Covers 6 kV … 30 kV sensors with division ratio of 10 000:1. Secondary voltages 600mV/√3 … 3 V / √3. Range up to 2 x Rated.

Table 1088: Energizing Inputs (SIM0005)

Description		Value
Current sensor input	Rated current voltage	75 mV ... 9000 mV [1]
	Continuous voltage withstand	125 V
	Input impedance at 50/60Hz	2 MΩ
Voltage sensor input	Rated secondary voltage	346 mV…2339 mV [4]
	Continuous voltage withstand	50 V
	Input impedance at 50/60Hz	2 MΩ

14.5 Binary inputs

Table 1089: Binary inputs

Description	Value
Operating range	±20% of the rated voltage
Rated voltage	24...250 V DC
Current drain	1.6...1.9 mA
Power consumption	31.0...570.0 mW
Threshold voltage	16...176 V DC
Reaction time	<3 ms

Adjust the binary input threshold voltage correctly. The threshold voltage should be set 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.

[4] Covers 6 kV … 40.5 kV sensors with division ratio of 10 000:1. Secondary voltages 600mV/√3 … 4.05V / √3. Range up to 2 x Rated.

14.6 RTD/mA inputs

Table 1090: RTD/mA inputs

Description		Value	
RTD inputs	Supported RTD sensors	100 Ω platinum 250 Ω platinum 100 Ω nickel 120 Ω nickel 250 Ω nickel 10 Ω copper	TCR 0.00385 (DIN 43760) TCR 0.00385 TCR 0.00618 (DIN 43760) TCR 0.00618 TCR 0.00618 TCR 0.00427
	Supported resistance range	0...2 kΩ	
	Maximum lead resistance (three-wire measurement)	25 Ω per lead	
	Isolation	2 kV (inputs to protective earth)	
	Response time	<4 s	
	RTD/resistance sensing current	Maximum 0.33 mA rms	
	Operation accuracy	Resistance	Temperature
		± 2.0% or ±1 Ω	±1°C 10 Ω copper: ±2°C
mA inputs	Supported current range	0…20 mA	
	Current input impedance	44 Ω ± 0.1%	
	Operation accuracy	±0.5% or ±0.01 mA	

14.7 Signal output with high make and carry

Table 1091: Signal output with high make and carry

Description	Value[1]
Rated voltage	250 V AC/DC
Continuous contact carry	5 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	1 A/0.25 A/0.15 A
Minimum contact load	100 mA at 24 V AC/DC

[1] X100: SO1

X105: SO1, SO2, when any of the protection relays is equipped with BIO0005.

X110: SO1, SO2 when REF620 or RET620 is equipped with BIO0005

X115: SO1, SO2 when REF620 or REM620 is equipped with BIO0005

14.8 Signal outputs and IRF output

Table 1092: Signal outputs and IRF output

Description	Value[1]
Rated voltage	250 V AC/DC
Continuous contact carry	5 A
Make and carry for 3.0 s	10 A
Make and carry for 0.5 s	15 A
Breaking capacity when the control-circuit time constant L/R <40 ms	1 A/0.25 A/0.15 A
Minimum contact load	10 mA at 5 V AC/DC

14.9 Double-pole power outputs with TCS function X100: PO3 and PO4

Table 1093: Double-pole power outputs with TCS function X100: PO3 and PO4

Description	Value[2]
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 48/110/220 V DC (two contacts connected in a series)	5 A/3 A/1 A
Minimum contact load	100 mA at 24 V AC/DC
Trip-circuit monitoring (TCS):	
• Control voltage range	20...250 V AC/DC
• Current drain through the monitoring circuit	~1.5 mA
• Minimum voltage over the TCS contact	20 V AC/DC (15...20 V)

1 X100: IRF,SO2

X105: SO3, SO4, when any of the protection relays is equipped with BIO0005

X110: SO3, SO4, when REF620 or RET620 is equipped with BIO0005

X115:SO3, SO4, when REF620 or REM620 is equipped with BIO0005

X130: SO1, SO2, when RET620 is equipped with RTD0002

2 PSM0003: PO3, PSM0004: PO3, PSM0003: PO4 and PSM0004: PO4.

14.10 Signal/trip output with high make and carry and with TCS function

Table 1094: Signal/trip output with high make and carry and with TCS function

Description	Value[1]
Rated voltage	250 V AC/DC
Continuous contact carry	5 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 48/110/220 V DC (two contacts connected in series)	1 A/0.25 A/0.15 A
Minimum contact load	100 mA at 24 V AC/DC

14.11 Single-pole power output relays X100: PO1 and PO2

Table 1095: Single-pole power output relays X100: PO1 and PO2

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 48/110/220 V DC	5 A/3 A/1 A
Minimum contact load	100 mA at 24 V AC/DC

[1] X130: SO3 of RET620 equipped with RTD0002

14.12 High-speed output HSO

Table 1096: High-speed output HSO

Description	Value [1]
Rated voltage	250 V AC/DC
Continuous contact carry	6 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 48/110/220 V DC	5 A/3 A/1 A
Operate time	<1 ms
Reset	<20 ms, resistive load

14.13 Ethernet interfaces

Table 1097: Ethernet interfaces

Ethernet interface	Protocol	Cable	Data transfer rate
Front	TCP/IP protocol	Standard Ethernet CAT 5 cable with RJ-45 connector	10 MBits/s
Rear	TCP/IP protocol	Shielded twisted pair CAT 5e cable with RJ-45 connector or fiber optic cable with LC connector	100 MBits/s

14.14 Serial rear interface

Table 1098: Serial rear interface

Type	Counter connector
Serial port (X5)	10-pin counter connector Weidmüller BL 3.5/10/180F AU OR BEDR or 9-pin counter connector Weidmüller BL 3.5/9/180F AU OR BEDR [1]
Serial port (X16)	9-pin D-sub connector DE-9
Serial port (X12)	Optical ST-connector

[1] X105: HSO1, HSO2 HSO3, when any of the protection relays is equipped with BIO0007
[1] Depending on the optional communication module

14.15 Fiber optic communication link

Table 1099: Fiber optic communication link

Connector	Fiber type	Wave length	Typical max. length [1]	Permitted path attenuation [2]
LC	MM 62.5/125 or 50/125 µm glass fiber core	1300 nm	2 km	<8 dB
ST	MM 62.5/125 or 50/125 µm glass fiber core	820...900 nm	1 km	<11 dB

14.16 IRIG-B

Table 1100: IRIG-B

Description	Value
IRIG time code format	B004, B005 [1]
Isolation	500V 1 min
Modulation	Unmodulated
Logic level	5 V TTL
Current consumption	<4 mA
Power consumption	<20 mW

14.17 Lens sensor and optical fiber for arc protection

Table 1101: Lens sensor and optical fiber for arc protection

Description	Value
Fiber optic cable including lens	1.5 m, 3.0 m or 5.0 m
Normal service temperature range of the lens	-40...+100°C

Table continues on the next page

[1] Maximum length depends on the cable attenuation and quality, the amount of splices and connectors in the path.
[2] Maximum allowed attenuation caused by connectors and cable together
[1] According to the 200-04 IRIG standard

Description	Value
Maximum service temperature range of the lens, max 1 h	+140°C
Minimum permissible bending radius of the connection fiber	100 mm

14.18 Degree of protection of flush-mounted protection relay

Table 1102: Degree of protection of flush-mounted protection relay

Description	Value
Front side	IP 54[1]
Rear side, connection terminals	IP 20[1]

14.19 Environmental conditions

Table 1103: Environmental conditions

Description	Value
Operating temperature range	-25...+55°C (continuous)
Short-time service temperature range	-40...+85°C (<16 h) [2], [3]
Relative humidity	<93%, non-condensing
Atmospheric pressure	86...106 kPa
Altitude	Up to 2000 m
Transport and storage temperature range	-40...+85°C

[1] According to IEC 60529
[2] Degradation in MTBF and HMI performance outside the temperature range of -25...+55 °C
[3] For relays with an LC communication interface the maximum operating temperature is +70 °C

15 Protection relay and functionality tests

15.1 Electromagnetic compatibility tests

Table 1104: Electromagnetic compatibility tests

Description	Type test value	Reference
1 MHz/100 kHz burst disturbance test • Common mode • Differential mode	 2.5 kV 2.5 kV	IEC 61000-4-18 IEC 60255-26 IEEE C37.90.1-2012
3 MHz, 10 MHz and 30 MHz burst disturbance test • Common mode	 2.5 kV	IEC 61000-4-18 IEC 60255-26
Electrostatic discharge test • Contact discharge • Air discharge	 8 kV 15 kV	IEC 61000-4-2 IEC 60255-26 IEEE C37.90.3-2001
Radio frequency interference test	10 V (rms) f = 150 kHz...80 MHz 10 V/m (rms) f = 80...2700 MHz 10 V/m f = 900 MHz 20 V/m (rms) f = 80...1000 MHz	IEC 61000-4-6 IEC 60255-26 IEC 61000-4-3 IEC 60255-26 ENV 50204 IEC 60255-26 IEEE C37.90.2-2004
Fast transient disturbance test • All ports	 4 kV	IEC 61000-4-4 IEC 60255-26 IEEE C37.90.1-2012

Table continues on the next page

Description	Type test value	Reference
Surge immunity test • Communication • Other ports	 2 kV, line-to-earth 4 kV, line-to-earth 2 kV, line-to-line	IEC 61000-4-5 IEC 60255-26
Power frequency (50 Hz) magnetic field immunity test • Continuous • 1...3 s	 300 A/m 1000 A/m	IEC 61000-4-8 IEC 60255-26
Pulse magnetic field immunity test	1000 A/m 6.4/16 µs	IEC 61000-4-9
Damped oscillatory magnetic field immunity test • 2 s • 1 MHz	 100 A/m 400 transients/s	IEC 61000-4-10
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
Power frequency immunity test • Common mode • Differential mode	Binary inputs only 300 V rms 150 V rms	IEC 61000-4-16 IEC 60255-26, class A
Conducted common mode disturbances	15 Hz...150 kHz Test level 3 (10/1/10 V rms)	IEC 61000-4-16
Emission tests • Conducted 0.15...0.50 MHz 0.5...30 MHz • Radiated	 <79 dB (µV) quasi peak <66 dB (µV) average <73 dB (µV) quasi peak <60 dB (µV) average	EN 55011, class A IEC 60255-26 CISPR 11 CISPR 12

Table continues on the next page

Description	Type test value	Reference
30...230 MHz 230...1000 MHz 1…3 GHz 3…6 GHz AC component in DC (ripple)	<40 dB (µV/m) quasi peak, measured at 10 m distance <47 dB (µV/m) quasi peak, measured at 10 m distance <76 dB (µV/m) peak <56 dB (µV/m) average, measured at 3 m distance <80 dB (µV/m) peak <60 dB (µV/m) average, measured at 3 m distance 15% of rated DC, 100/120Hz, Criterion A	IEC 61000-4-17 IEC 60255-26
Gradual shut down / start-up test	Shut down time 60s Power off time 5 min Start-up time 60s	IEC 60255-26

15.2 Insulation tests

Table 1105: Insulation tests

Description	Type test value	Reference
Dielectric tests	2 kV, 50 Hz, 1 min 500 V, 50 Hz, 1 min, communication 820 V, 50 Hz, 1 min, sensor inputs of SIM0005	IEC 60255-27 IEC 61869-6
Impulse voltage test	5 kV, 1.2/50 µs, 0.5 J 1 kV, 1.2/50 µs, 0.5 J, communication 1,5 kV, 1,2/50 µs, 0,5 J, sensor inputs of SIM0005	IEC 60255-27 IEC 61869-6
Insulation resistance measurements	>100 M Ω, 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

15.3 Mechanical tests

Table 1106: Mechanical tests

Description	Requirement	Reference
Vibration tests (sinusoidal)	Class 2	IEC 60068-2-6 (test Fc) IEC 60255-21-1
Shock and bump test	Class 2	IEC 60068-2-27 (test Ea shock) IEC 60068-2-29 (test Eb bump) IEC 60255-21-2
Seismic test	Class 2	IEC 60255-21-3

15.4 Environmental tests

Table 1107: Environmental tests

Description	Type test value	Reference
Dry heat test	• 96 h at +55°C • 16 h at +85°C [3]	IEC 60068-2-2
Dry cold test	• 96 h at -25°C • 16 h at -40°C	IEC 60068-2-1
Damp heat test	• 6 cycles (12 h + 12 h) at +25°C… +55°C, humidity >93%	IEC 60068-2-30
Change of temperature test	• 5 cycles (3 h + 3 h) at -25°C...+55°C	IEC60068-2-14
Storage test	• 96 h at -40°C • 96 h at +85°C	IEC 60068-2-1 IEC 60068-2-2

15.5 Product safety

Table 1108: Product safety

Description	Reference
LV directive	2014/35/EU
Standard	EN 60255-27

[3] For relays with an LC communication interface the maximum operating temperature is +70 °C

Description	Reference
	EN 60255-1

15.6 EMC compliance

Table 1109: EMC compliance

Description	Reference
EMC directive	2014/30/EU
Standard	EN 60255-26

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

UL-listed (c-UL-us):

- UL 508 & CSA C22.2 No. 14-18 - Industrial Control Equipment
- IEEE C37.90
- IEEE C37.90.1
- IEEE C37.90.2

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
620 series	Series of numerical protection and control relays for high-end protection and supervision applications of utility substations, and industrial switchgear and equipment
AC	Alternating current
ACT	1. Application Configuration tool in PCM600 2. Trip status in IEC 61850
AR	Autoreclosing
AVR	Automatic voltage regulator
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
CBB	Cycle building block
COMTRADE	Common format for transient data exchange for power systems. Defined by the IEEE Standard.
CPU	Central processing unit
CT	Current transformer
CTS	Clear to send
DAN	Doubly attached node
DC	1. Direct current 2. Disconnector 3. Double command
DCD	Data carrier detect
DFT	Discrete Fourier transform
DG	Distributed generation
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.
DPC	Double-point control
DSR	Data set ready
DT	Definite time
DTR	Data terminal ready

Table continues on the next page

EEPROM	Electrically erasable programmable read-only memory
EIA-232	Serial communication standard according to Electronics Industries Association
EIA-485	Serial communication standard according to Electronics Industries Association
EMC	Electromagnetic compatibility
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
FPGA	Field-programmable gate array
FTP	File transfer protocol
FTPS	FTP Secure
GFC	General fault criteria
GOOSE	Generic Object-Oriented Substation Event
GPS	Global Positioning System
HMI	Human-machine interface
HSO	High-speed output
HSR	High-availability seamless redundancy
HTTPS	Hypertext Transfer Protocol Secure
HV	High voltage
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
IEC 61850-9-2	A communication protocol based on the IEC 61850 standard series
IEC 61850-9-2 LE	Lite Edition of IEC 61850-9-2 offering process bus interface
IED	Intelligent electronic device
IEEE 1686	Standard for Substation Intelligent Electronic Devices' (IEDs') Cyber Security Capabilities
IP	Internet protocol
IP address	A set of four numbers between 0 and 255, separated by periods. Each server connected to the Internet is assigned a unique IP address that specifies the location for the TCP/IP 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

Table continues on the next page

LCD	Liquid crystal display
LDC	Line drop compensation
LE	Light Edition
LED	Light-emitting diode
LHMI	Local human-machine interface
LOG	Loss of grid
LOM	Loss of mains
MAC	Media access control
MCB	Miniature circuit breaker
MM	1. Multimode 2. Multimode optical fiber
MMS	1. Manufacturing message specification 2. Metering management system
Modbus	A serial communication protocol developed by the Modicon company in 1979. Originally used for communication in PLCs and RTU devices.
Modbus TCP/IP	Modbus RTU protocol which uses TCP/IP and Ethernet to carry data between devices
MV	Medium voltage
NC	Normally closed
P2P	peer-to-peer
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
PGU	Power generating unit
PLC	Programmable logic controller
PPS	Pulse per second
PRP	Parallel redundancy protocol
PTP	Precision Time Protocol
RAM	Random access memory
RCA	Also known as MTA or base angle. Characteristic angle.
RJ-45	Galvanic connector type

Table continues on the next page

RMS	Root-mean-square (value)
ROM	Read-only memory
RSTP	Rapid spanning tree protocol
RTC	Real-time clock
RTD	Resistance temperature detector
RTS	Ready to send
SAN	Single attached node
SBO	Select-before-operate
SCADA	Supervision, control and data acquisition
SCL	XML-based substation description configuration language defined by IEC 61850
Single-line diagram	Simplified notation for representing a three-phase power system. Instead of representing each of three phases with a separate line or terminal, only one conductor is represented.
SMT	Signal Matrix tool in PCM600
SMV	Sampled measured values
SNTP	Simple Network Time Protocol
SOF	Status of fault
SOTF	Switch onto fault
ST	Connector type for glass fiber cable
SW	Software
TCP/IP	Transmission Control Protocol/Internet Protocol
TCS	Trip-circuit supervision
TLV	Type length value
UTC	Coordinated universal time
VDR	Voltage-depended resistor
VT	Voltage transformer
WAN	Wide area network
WHMI	Web human-machine interface

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