
Relion® Protection and Control

# 615 series
# Technical Manual

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ABB

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# Conformity

This product complies with the directive of the Council of the European Communities on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive 2004/108/EC) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2006/95/EC). This conformity is the result of tests conducted by ABB in accordance with the product standards EN 50263 and EN 60255-26 for the EMC directive, and with the product standards EN 60255-6 and EN 60255-27 for the low voltage directive. The IED is designed in accordance with the international standards of the IEC 60255 series.

# Table of contents

# Section 1 Introduction

## 1.1 This manual

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 IEDs. The installation and commissioning personnel must have a basic knowledge in handling electronic equipment.

# 1.3 Product documentation

## 1.3.1 Product documentation set

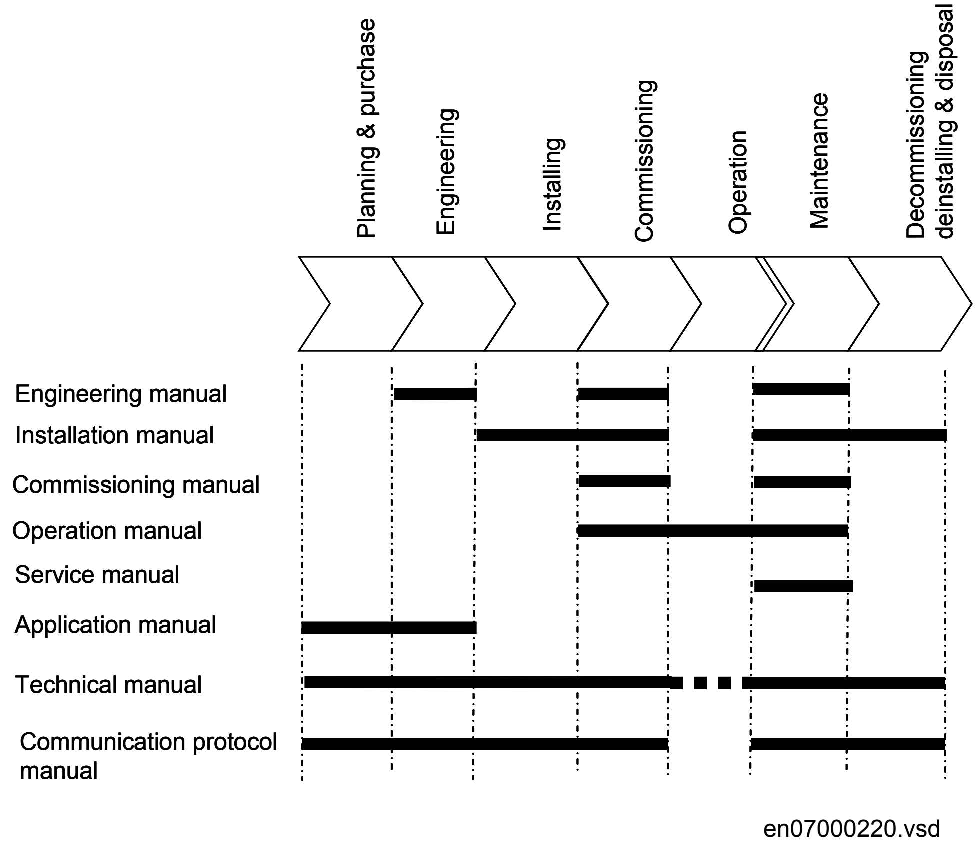



*Figure 1: The intended use of manuals in different lifecycles*

Engineering Manual contains instructions on how to engineer the IEDs. The manual provides instructions on how to use the different tools for IED engineering. It also includes instructions on how to handle the tool component available to read disturbance files from the IEDs on the basis of the IEC 61850 definitions. It further introduces the diagnostic tool components available for IEDs and the PCM600 tool.

Installation Manual contains instructions on how to install the IED. The manual provides procedures for mechanical and electrical installation. The chapters are organized in chronological order in which the IED should be installed.

Commissioning Manual contains instructions on how to commission the IED. The manual can also be used as a reference during periodic testing. The manual provides procedures for energizing and checking of external circuitry, setting and configuration as well as verifying settings and performing directional tests. The chapters are organized in chronological order in which the IED should be commissioned.

Operation Manual contains instructions on how to operate the IED once it has been commissioned. The manual provides instructions for monitoring, controlling and setting the IED. The manual also describes how to identify disturbances and how to view calculated and measured network data to determine the cause of a fault.

Service Manual contains instructions on how to service and maintain the IED. The manual also provides procedures for de-energizing, de-commissioning and disposal of the IED.

Application Manual contains application descriptions and setting guidelines sorted per function. The manual can be used to find out when and for what purpose a typical protection function can be used. The manual can also be used when calculating settings.

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.

Communication Protocol Manual describes a communication protocol supported by the IED. The manual concentrates on vendor-specific implementations.

Point List Manual describes the outlook and properties of the data points specific to the IED. The manual should be used in conjunction with the corresponding Communication Protocol Manual.

Some of the manuals are not available yet.

## 1.3.2 Document revision history

| Document revision/date | Product version | History |
|---|---|---|
| A/03.07.2009 | 2.0 | First release |
| B/02.12.2009 | 2.0 | Content updated |

Download the latest documents from the ABB web site http://www.abb.com/substationautomation.

### 1.3.3 Related documentation

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

## 1.4 Document symbols and conventions

### 1.4.1 Safety indication symbols

This publication includes icons that point out safety-related conditions or other important information.

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 to 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 should be understood that operation of damaged equipment could, under certain operational conditions, 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

- Abbreviations and acronyms in this manual are spelled out in Glossary. Glossary also contains definitions of important terms.
- Push button navigation in the LHMI menu structure is presented by using the push button icons, for example:

To navigate between the options, use and .

- HMI menu paths are presented in bold, for example:
  Select **Main menu/Information**.
- LHMI messages are shown in Courier font, for example:
  To save the changes in non-volatile memory, select `Yes` and press .
- Parameter names are shown in italics, for example:
  The function can be enabled and disabled with the *Operation* setting.
- Parameter values are indicated with quotation marks, for example:
  The corresponding parameter values are "On" and "Off".
- IED input/output messages and monitored data names are shown in Courier font, for example:
  When the function starts, the `START` output is set to TRUE.

## 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 standard configurations*

| Function | IEC 61850 | IEC 60617 | IEC-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>> → | 67-2 |
| Non-directional earth-fault protection, low stage | EFLPTOC1 | $I_0$> (1) | 51N-1 (1) |
| | EFLPTOC2 | $I_0$> (2) | 51N-1 (2) |
| Non-directional earth-fault protection, high stage | EFHPTOC1 | $I_0$>> (1) | 51N-2 (1) |
| | EFHPTOC2 | $I_0$>> (2) | 51N-2 (2) |
| Non-directional earth-fault protection, instantaneous stage | EFIPTOC1 | $I_0$>>> | 50N/51N |
| Directional earth-fault protection, low stage | DEFLPDEF1 | $I_0$> → (1) | 67N-1 (1) |
| | DEFLPDEF2 | $I_0$> → (2) | 67N-1 (2) |

Table continues on next page

| Function | IEC 61850 | IEC 60617 | IEC-ANSI |
|---|---|---|---|
| Directional earth-fault protection, high stage | DEFHPDEF1 | $I_0$>> → | 67N-2 |
| Transient / intermittent earth-fault protection | INTRPTEF1 | $I_0$> → IEF | 67NIEF |
| Non-directional (cross-country) earth fault protection, using calculated $I_0$ | EFHPTOC1 | $I_0$>> | 51N-2 |
| Negative-sequence overcurrent protection | NSPTOC1 | $I_2$> (1) | 46 (1) |
| | NSPTOC2 | $I_2$> (2) | 46 (2) |
| Phase discontinuity protection | PDNSPTOC1 | $I_2/I_1$> | 46PD |
| Residual overvoltage protection | ROVPTOV1 | $U_0$> (1) | 59G (1) |
| | ROVPTOV2 | $U_0$> (2) | 59G (2) |
| | ROVPTOV3 | $U_0$> (3) | 59G (3) |
| Three-phase undervoltage protection | PHPTUV1 | 3U< (1) | 27 (1) |
| | PHPTUV2 | 3U< (2) | 27 (2) |
| | PHPTUV3 | 3U< (3) | 27 (3) |
| Three-phase overvoltage protection | PHPTOV1 | 3U> (1) | 59 (1) |
| | PHPTOV2 | 3U> (2) | 59 (2) |
| | PHPTOV3 | 3U> (3) | 59 (3) |
| Positive-sequence undervoltage protection | PSPTUV1 | U1< | 47U+ |
| Negative-sequence overvoltage protection | NSPTOV1 | U2> | 47O- |
| Three-phase thermal protection for feeders, cables and distribution transformers | T1PTTR1 | 3Ith>F | 49F |
| Three-phase thermal overload protection for power transformers, two time constants | T2PTTR1 | 3Ith>T | 49T |
| Negative-sequence overcurrent protection for motors | MNSPTOC1 | I2>M (1) | 46M (1) |
| | MNSPTOC2 | I2>M (2) | 46M (2) |
| Loss of load supervision | LOFLPTUC1 | 3I< | 37 |
| Motor load jam protection | JAMPTOC1 | Ist> | 51LR |
| Motor start-up supervision | STTPMSU1 | Is2t n< | 49,66,48,51LR |
| Phase reversal protection | PREVPTOC | $I_2$>> | 46R |
| Thermal overload protection for motors | MPTTR1 | 3Ith>M | 49M |
| Binary signal transfer | BSTGGIO1 | BST | BST |
| Stabilized and instantaneous differential protection for 2W-transformers | TR2PTDF1 | 3dI>T | 87T |
| Line differential protection and related measurements, stabilized and instantaneous stages | LNPLDF1 | 3dI>L | 87L |
| Numerical stabilized low impedance restricted earth-fault protection | LREFPNDF1 | dI0Lo> | 87NL |
| High impedance based restricted earth-fault protection | HREFPDIF1 | $dI_0$Hi> | 87NH |
| Circuit breaker failure protection | CCBRBRF1 | 3I>/$I_0$>BF | 51BF/51NBF |
| Three-phase inrush detector | INRPHAR1 | 3I2f> | 68 |
| Table continues on next page | | | |

| Function | IEC 61850 | IEC 60617 | IEC-ANSI |
|---|---|---|---|
| Master trip | TRPPTRC1 | Master Trip (1) | 94/86 (1) |
| | TRPPTRC2 | Master Trip (2) | 94/86 (2) |
| Arc protection | ARCSARC1 | ARC (1) | 50L/50NL (1) |
| | ARCSARC2 | ARC (2) | 50L/50NL (2) |
| | ARCSARC3 | ARC (3) | 50L/50NL (3) |
| **Control** | | | |
| Circuit-breaker control | CBXCBR1 | I ↔ O CB | I ↔ O CB |
| 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) |
| Earthing switch indication | ESSXSWI1 | I ↔ O ES | I ↔ O ES |
| Emergergency startup | ESMGAPC1 | ESTART | ESTART |
| Auto-reclosing | DARREC1 | O → I | 79 |
| Tap changer position indication | TPOSSLTC1 | TPOSM | 84M |
| **Condition monitoring** | | | |
| Circuit-breaker condition monitoring | SSCBR1 | CBCM | CBCM |
| Trip circuit supervision | TCSSCBR1 | TCS (1) | TCM (1) |
| | TCSSCBR2 | TCS (2) | TCM (2) |
| Current circuit supervision | CCRDIF1 | MCS 3I | MCS 3I |
| Fuse failure supervision | SEQRFUF1 | FUSEF | 60 |
| Protection communication supervision | PCSRTPC1 | PCS | PCS |
| Motor runtime counter | MDSOPT1 | OPTS | OPTM |
| **Measurement** | | | |
| Disturbance recorder | RDRE1 | - | - |
| Three-phase current measurement | CMMXU1 | 3I | 3I |
| | CMMXU2 | 3I(B) | 3I(B) |
| Sequence current measurement | CSMSQI1 | $I_1$, $I_2$, $I_0$ | $I_1$, $I_2$, $I_0$ |
| Residual current measurement | RESCMMXU1 | $I_0$ | $I_n$ |
| | RESCMMXU2 | $I_0$(B) | $I_n$(B) |
| Three-phase voltage measurement | VMMXU1 | 3U | 3U |
| Residual voltage measurement | RESVMMXU1 | $U_0$ | $V_n$ |
| Sequence voltage measurement | VSMSQI1 | $U_1$, $U_2$, $U_0$ | $U_1$, $U_2$, $U_0$ |
| Three-phase power and energy measurement | PEMMXU1 | P, E | P, E |

# Section 2 615 series overview

## 2.1 Overview

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

The IEDs 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, autoreclosure and additional I/Os.

The 615 series IEDs support a range of communication protocols including IEC 61850 with GOOSE messaging, Modbus®, DNP3 and IEC 60870-5-103.

## 2.1.1 Product series version history

| Product series version | Product series history |
|---|---|
| 1.0 | First product from 615 series REF615 released with configurations A-D |
| 1.1 | New product: RED615<br><br>Platform enhancements:<br><br>• IRIG-B support<br>• Support for parallel protocols: IEC 61850 and Modbus<br>• Additional binary input/output module X130 as an option<br>• Enhanced CB interlocking functionality<br>• Enhanced TCS functionality in HW<br>• Non-volatile memory support |
| 2.0 | New products:<br><br>• RET615 with configurations A-D<br>• REM615 with configuration C<br><br>New configurations<br><br>• REF615: E and F<br>• RED615: B and C<br><br>Platform enhancements<br><br>• Support for DNP3 serial or TCP/IP<br>• Support for IEC 60870-5-103<br>• Voltage measurement and protection<br>• Power and energy measurement<br>• Disturbance recorder upload via WHMI<br>• Fuse failure supervision |

## 2.1.2 PCM600 and IED connectivity package version

- Protection and Control IED Manager PCM600 Ver. 2.0 SP2 or later
- RED615 Connectivity Package Ver. 2.5 or later
- REF615 Connectivity Package Ver. 2.5 or later
- REM615 Connectivity Package Ver. 2.5 or later
- RET615 Connectivity Package Ver. 2.5 or later

Download connectivity packages from the ABB web site http://www.abb.com/substationautomation

## 2.2 Local HMI

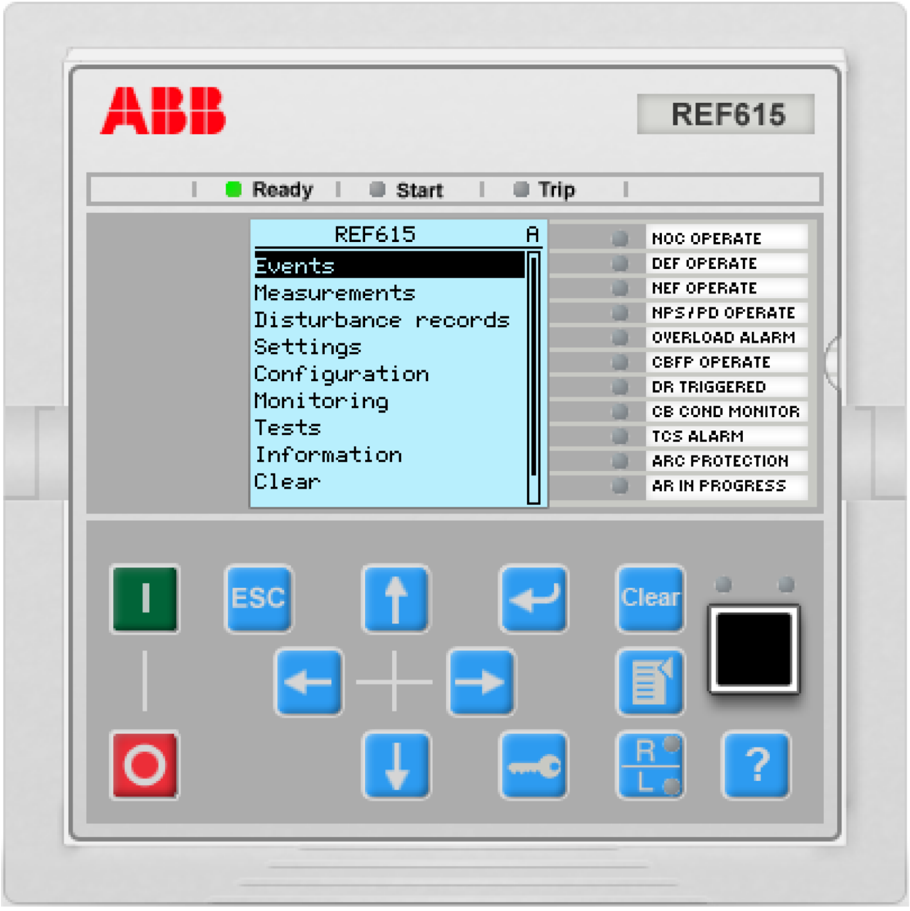



*Figure 2: LHMI*

The LHMI of the IED contains the following elements:

- Display
- Buttons
- LED indicators
- Communication port

The LHMI is used for setting, monitoring and controlling.

### 2.2.1 LCD

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

*Table 2: Characters and rows on the view*

| Character size | Rows in view | Characters on row |
|---|---|---|
| Small, mono-spaced (6x12 pixels) | 5 rows<br>10 rows with large screen | 20 |
| Large, variable width (13x14 pixels) | 4 rows<br>8 rows with large screen | min 8 |

The display view is divided into four basic areas.

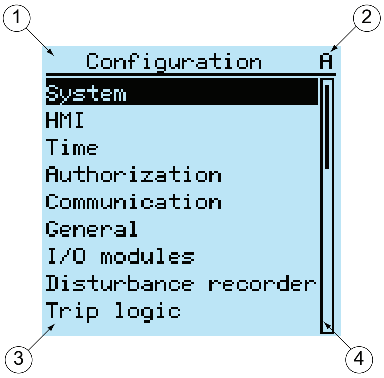



*Figure 3: Display layout*

1 Header

2 Icon

3 Content

4 Scroll bar (displayed when needed)

## 2.2.2 LEDs

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

There are also 11 matrix programmable alarm 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 push-buttons you can give open or close commands to one primary object, for example, a circuit breaker, disconnector or switch. The push-buttons are also used to acknowledge alarms, reset indications, provide help and switch between local and remote control mode.

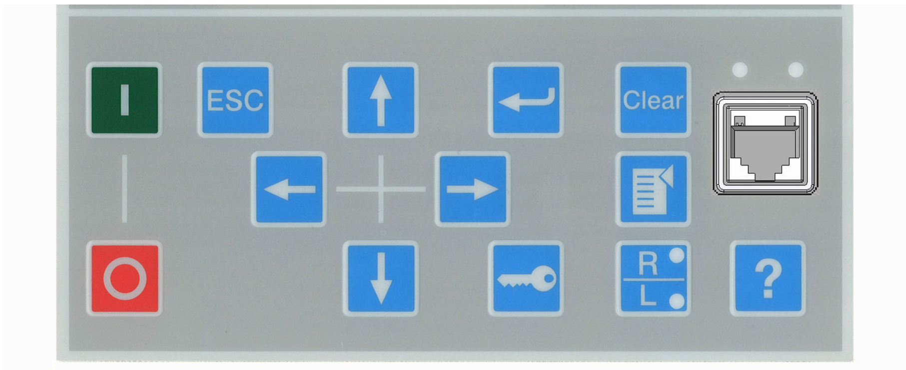



*Figure 4: LHMI keypad with object control, navigation and command push-buttons and RJ-45 communication port*

## 2.3 Web HMI

The WHMI enables the user to access the IED via a web browser. The supported web browser version is Internet Explorer 7.0 or later.

WHMI is disabled by default.

WHMI offers several functions.

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

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

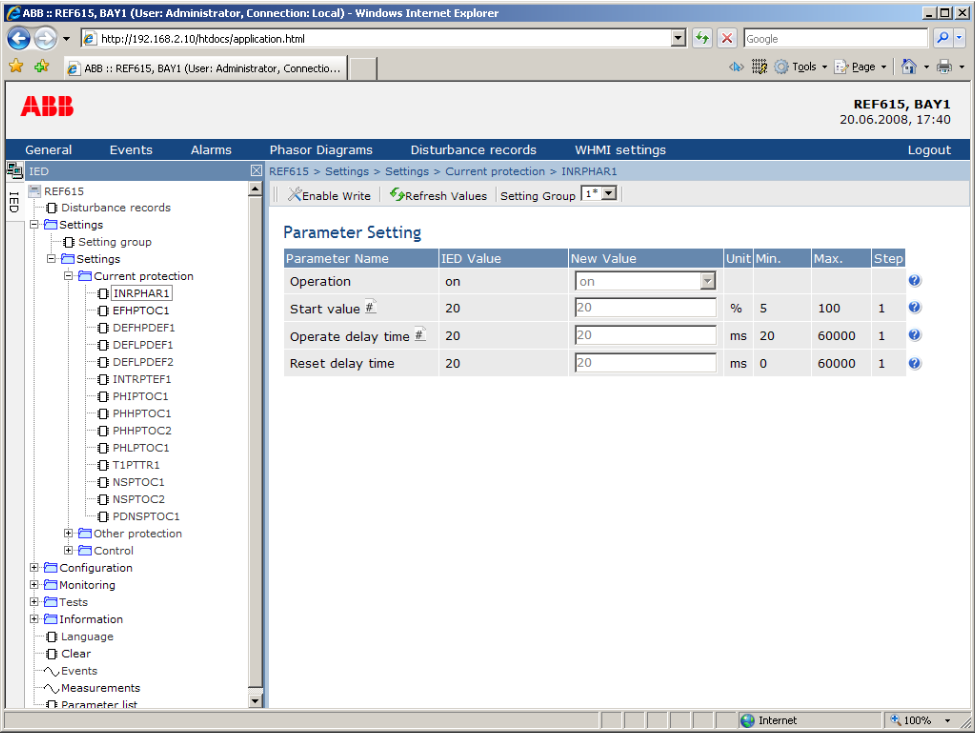



*Figure 5: Example view of the WHMI*

The WHMI can be accessed locally and remotely.

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

## 2.4 Authorization

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

The default passwords can be changed with Administrator user rights.

User authorization is disabled by default 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)<br>• Changing setting groups<br>• Controlling<br>• Clearing alarm and indication LEDs and textual indications |
| ENGINEER | • Changing settings<br>• Clearing event list<br>• Clearing disturbance records<br>• Changing system settings such as IP address, serial baud rate or disturbance recorder settings<br>• Setting the IED to test mode<br>• Selecting language |
| ADMINISTRATOR | • All listed above<br>• Changing password<br>• Factory default activation |

For user authorization for PCM600, see PCM600 documentation.

## 2.5 Communication

The IED supports a range of communication protocols including IEC 61850, IEC 60870-5-103, Modbus® and DNP3. Operational information and controls are available through these protocols.

The IEC 61850 communication implementation supports all monitoring and control functions. Additionally, parameter setting and disturbance file records can be accessed using the IEC 61850 protocol. Disturbance files are available to any Ethernet-based application in the standard COMTRADE format. Further, the IED can send and receive binary signals from other IEDs (so called horizontal communication) using the IEC61850-8-1 GOOSE profile, where the highest performance class with a total transmission time of 3 ms is supported. The IED meets the GOOSE performance requirements for tripping applications in distribution substations, as defined by the IEC 61850 standard. The IED can simultaneously report events to five different clients on the station bus.

The IED 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 IED can be connected to Ethernet-based communication systems via the RJ-45 connector (100BASE-TX).

# Section 3 Basic functions

## 3.1 General parameters

*Table 4: Analog input settings, phase currents*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Secondary current | 1=0.2A<br>2=1A<br>3=5A | | | 2=1A | Rated secondary current |
| Primary current | 1.0...6000.0 | A | 0.1 | 100.0 | Rated primary current |
| Amplitude corr. A | 0.900...1.100 | | 0.001 | 1.000 | Phase A amplitude correction factor |
| Amplitude corr. B | 0.900...1.100 | | 0.001 | 1.000 | Phase B amplitude correction factor |
| Amplitude corr. C | 0.900...1.100 | | 0.001 | 1.000 | Phase C amplitude correction factor |

*Table 5: Analog input settings, residual current*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Secondary current | 1=0.2A<br>2=1A<br>3=5A | | | 2=1A | Secondary current |
| Primary current | 1.0...6000.0 | A | 0.1 | 100.0 | Primary current |
| Amplitude corr. | 0.900...1.100 | | 0.001 | 1.000 | Amplitude correction |

*Table 6: Analog input settings, phase voltages*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Primary voltage | 0.001...440.000 | kV | 0.001 | 20.000 | Primary rated voltage |
| Secondary voltage | 1=100V<br>2=110V<br>3=115V<br>4=120V | | | 1=100V | Secondary rated voltage |
| VT connection | 1=Wye<br>2=Delta | | | 2=Delta | Wye or delta VT connection |
| Amplitude corr. A | 0.900...1.100 | | 0.001 | 1.000 | Phase A Voltage phasor magnitude correction of an external voltage transformer |
| Amplitude corr. B | 0.900...1.100 | | 0.001 | 1.000 | Phase B Voltage phasor magnitude correction of an external voltage transformer |
| Amplitude corr. C | 0.900...1.100 | | 0.001 | 1.000 | Phase C Voltage phasor magnitude correction of an external voltage transformer |

*Table 7: Analog input settings, residual voltage*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Secondary voltage | 1=100V<br>2=110V<br>3=115V<br>4=120V | | | 1=100V | Secondary voltage |
| Primary voltage | 0.001...440.000 | kV | 0.001 | 11.547 | Primary voltage |
| Amplitude corr. | 0.900...1.100 | | 0.001 | 1.000 | Amplitude correction |

*Table 8: Alarm LED input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| Alarm LED 1 | BOOLEAN | 0=False | Status of Alarm LED 1 |
| Alarm LED 2 | BOOLEAN | 0=False | Status of Alarm LED 2 |
| Alarm LED 3 | BOOLEAN | 0=False | Status of Alarm LED 3 |
| Alarm LED 4 | BOOLEAN | 0=False | Status of Alarm LED 4 |
| Alarm LED 5 | BOOLEAN | 0=False | Status of Alarm LED 5 |
| Alarm LED 6 | BOOLEAN | 0=False | Status of Alarm LED 6 |
| Alarm LED 7 | BOOLEAN | 0=False | Status of Alarm LED 7 |
| Alarm LED 8 | BOOLEAN | 0=False | Status of Alarm LED 8 |
| Alarm LED 9 | BOOLEAN | 0=False | Status of Alarm LED 9 |
| Alarm LED 10 | BOOLEAN | 0=False | Status of Alarm LED 10 |
| Alarm LED 11 | BOOLEAN | 0=False | Status of Alarm LED 11 |

*Table 9: Alarm LED settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Alarm LED mode | 0=Follow-S [1)]<br>1=Follow-F [2)]<br>2=Latched-S [3)]<br>3=LatchedAck-F-S [4)] | | | 0=Follow-S | Alarm mode for LED 1 |
| Description | | | | Alarm LEDs LED 1 | Description of alarm |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 2 |
| Description | | | | Alarm LEDs LED 2 | Description of alarm |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 3 |
| Description | | | | Alarm LEDs LED 3 | Description of alarm |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 4 |
| Description | | | | Alarm LEDs LED 4 | Description of alarm |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
| --- | --- | --- | --- | --- | --- |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 5 |
| Description | | | | Alarm LEDs LED 5 | Description of alarm |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 6 |
| Description | | | | Alarm LEDs LED 6 | Description of alarm |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 7 |
| Description | | | | Alarm LEDs LED 7 | Description of alarm |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 8 |
| Description | | | | Alarm LEDs LED 8 | Description of alarm |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 9 |
| Description | | | | Alarm LEDs LED 9 | Description of alarm |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 10 |
| Description | | | | Alarm LEDs LED 10 | Description of alarm |
| Alarm LED mode | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck-F-S | | | 0=Follow-S | Alarm mode for LED 11 |
| Description | | | | Alarm LEDs LED 11 | Description of alarm |

1) Non-latched mode
2) Non-latched blinking mode
3) Latched mode
4) Latched blinking mode

*Table 10: Authorization settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
| --- | --- | --- | --- | --- | --- |
| Local override | 0=False [1]<br>1=True [2] | | | 1=True | Disable authority |
| Remote override | 0=False [3]<br>1=True [4] | | | 1=True | Disable authority |
| Local viewer | | | | 0 | Set password |
| Local operator | | | | 0 | Set password |
| Local engineer | | | | 0 | Set password |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Local admin | | | | 0 | Set password |
| Remote viewer | | | | 0 | Set password |
| Remote operator | | | | 0 | Set password |
| Remote engineer | | | | 0 | Set password |
| Remote admin | | | | 0 | Set password |

1) Authorization override is disabled, LHMI password must be entered.
2) Authorization override is enabled, LHMI password is not asked.
3) Authorization override is disabled, communication tools ask password to enter the IED.
4) Authorization override is enabled, communication tools do not need password to enter the IED, except for WHMI which always requires it.

*Table 11: Binary input settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Threshold voltage | 18...176 | Vdc | 2 | 18 | 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 |

*Table 12: 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 |

*Table 13: 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) |

*Table 14: General system settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Rated frequency | 1=50Hz<br>2=60Hz | | | 1=50Hz | Rated frequency of the network |
| Phase rotation | 1=ABC<br>2=ACB | | | 1=ABC | Phase rotation order |
| Blocking mode | 1=Freeze timer<br>2=Block all<br>3=Block OPERATE output | | | 1=Freeze timer | Behaviour for function BLOCK inputs |
| Bay name | | | | REx615[1)] | Bay name in system |
| SG follow input | 0=False<br>1=True | | | 0=False | Enable setting group change to follow the input state |

1) Depending on the product variant

*Table 15: HMI settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| FB naming convention | 1=IEC61850<br>2=IEC60617<br>3=IEC-ANSI | | | 1=IEC61850 | FB naming convention used in IED |
| Default view | 1=Measurements<br>2=Main menu | | | 1=Measurements | LHMI default view |
| Backlight timeout | 1...60 | min | 1 | 3 | LHMI backlight timeout |
| Web HMI mode | 1=Active read only<br>2=Active<br>3=Disabled | | | 3=Disabled | Web HMI functionality |
| Web HMI timeout | 1...60 | min | 1 | 3 | Web HMI login timeout |

*Table 16: IEC 60870-5-103 settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Serial port 1 | 0=Not in use<br>1=COM 1<br>2=COM 2 | | | 0=Not in use | COM port for instance 1 |
| Address 1 | 1...255 | | | 1 | Unit address for instance 1 |
| Start delay 1 | 0...20 | char | | 4 | Start frame delay in chars for instance 1 |
| End delay 1 | 0...20 | char | | 4 | End frame delay in chars for instance 1 |
| DevFunType 1 | 0...255 | | | 9 | Device Function Type for instance 1 |
| UsrFType 1 | 0...255 | | | 10 | Function type for User Class 2 Frame for instance 1 |
| UsrInfNo 1 | 0...255 | | | 230 | Information Number for User Class2 Frame for instance 1 |
| Class1Priority 1 | 0=Ev High<br>1=Ev/DR Equal<br>2=DR High | | | 0=Ev High | Class 1 data sending priority relationship between Events and Disturbance Recorder data. |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Frame1InUse 1 | -1=Not in use<br>0=User frame<br>1=Standard frame 1<br>2=Standard frame 2<br>3=Standard frame 3<br>4=Standard frame 4<br>5=Standard frame 5<br>6=Private frame 6<br>7=Private frame 7 | | | 6=Private frame 6 | Active Class2 Frame 1 for instance 1 |
| Frame2InUse 1 | -1=Not in use<br>0=User frame<br>1=Standard frame 1<br>2=Standard frame 2<br>3=Standard frame 3<br>4=Standard frame 4<br>5=Standard frame 5<br>6=Private frame 6<br>7=Private frame 7 | | | -1=Not in use | Active Class2 Frame 2 for instance 1 |
| Frame3InUse 1 | -1=Not in use<br>0=User frame<br>1=Standard frame 1<br>2=Standard frame 2<br>3=Standard frame 3<br>4=Standard frame 4<br>5=Standard frame 5<br>6=Private frame 6<br>7=Private frame 7 | | | -1=Not in use | Active Class2 Frame 3 for instance 1 |
| Frame4InUse 1 | -1=Not in use<br>0=User frame<br>1=Standard frame 1<br>2=Standard frame 2<br>3=Standard frame 3<br>4=Standard frame 4<br>5=Standard frame 5<br>6=Private frame 6<br>7=Private frame 7 | | | -1=Not in use | Active Class2 Frame 4 for instance 1 |
| Class1OvInd 1 | 0=No indication<br>1=Both edges<br>2=Rising edge | | | 2=Rising edge | Overflow Indication for instance 1 |
| Class1OvFType 1 | 0...255 | | | 10 | Function Type for Class 1 overflow indication for instance 1 |
| Class1OvInfNo 1 | 0...255 | | | 255 | Information Number for Class 1 overflow indication for instance 1 |
| Class1OvBackOff 1 | 0...500 | | | 500 | Backoff Range for Class1 buffer for instance 1 |
| GI Optimize 1 | 0=Standard behaviour<br>1=Skip spontaneous<br>2=Only overflown<br>3=Combined | | | 0=Standard behaviour | Optimize GI traffic for instance 1 |
| DR Notification 1 | 0=Disabled<br>1=Enabled | | | 0=Disabled | Disturbance Recorder spontaneous indications enabled/disabled |
| Serial port 2 | 0=Not in use<br>1=COM 1<br>2=COM 2 | | | 0=Not in use | COM port for instance 2 |
| Address 2 | 1...255 | | | 1 | Unit address for instance 2 |
| Start delay 2 | 0...20 | char | | 4 | Start frame delay in chars for instance 2 |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| End delay 2 | 0...20 | char | | 4 | End frame delay in chars for instance 2 |
| DevFunType 2 | 0...255 | | | 9 | Device Function Type for instance 2 |
| UsrFType 2 | 0...255 | | | 10 | Function type for User Class 2 Frame for instance 2 |
| UsrInfNo 2 | 0...255 | | | 230 | Information Number for User Class2 Frame for instance 2 |
| Class1Priority 2 | 0=Ev High<br>1=Ev/DR Equal<br>2=DR High | | | 0=Ev High | Class 1 data sending priority relationship between Events and Disturbance Recorder data. |
| Frame1InUse 2 | -1=Not in use<br>0=User frame<br>1=Standard frame 1<br>2=Standard frame 2<br>3=Standard frame 3<br>4=Standard frame 4<br>5=Standard frame 5<br>6=Private frame 6<br>7=Private frame 7 | | | 6=Private frame 6 | Active Class2 Frame 1 for instance 2 |
| Frame2InUse 2 | -1=Not in use<br>0=User frame<br>1=Standard frame 1<br>2=Standard frame 2<br>3=Standard frame 3<br>4=Standard frame 4<br>5=Standard frame 5<br>6=Private frame 6<br>7=Private frame 7 | | | -1=Not in use | Active Class2 Frame 2 for instance 2 |
| Frame3InUse 2 | -1=Not in use<br>0=User frame<br>1=Standard frame 1<br>2=Standard frame 2<br>3=Standard frame 3<br>4=Standard frame 4<br>5=Standard frame 5<br>6=Private frame 6<br>7=Private frame 7 | | | -1=Not in use | Active Class2 Frame 3 for instance 2 |
| Frame4InUse 2 | -1=Not in use<br>0=User frame<br>1=Standard frame 1<br>2=Standard frame 2<br>3=Standard frame 3<br>4=Standard frame 4<br>5=Standard frame 5<br>6=Private frame 6<br>7=Private frame 7 | | | -1=Not in use | Active Class2 Frame 4 for instance 2 |
| Class1OvInd 2 | 0=No indication<br>1=Both edges<br>2=Rising edge | | | 2=Rising edge | Overflow Indication for instance 2 |
| Class1OvFType 2 | 0...255 | | | 10 | Function Type for Class 1 overflow indication for instance 2 |
| Class1OvInfNo 2 | 0...255 | | | 255 | Information Number for Class 1 overflow indication for instance 2 |
| Class1OvBackOff 2 | 0...500 | | | 500 | Backoff Range for Class1 buffer for instance 2 |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| GI Optimize 2 | 0=Standard behaviour<br>1=Skip spontaneous<br>2=Only overflown<br>3=Combined | | | 0=Standard behaviour | Optimize GI traffic for instance 2 |
| DR Notification 2 | 0=Disabled<br>1=Enabled | | | 0=Disabled | Disturbance Recorder spontaneous indications enabled/disabled |
| Internal Overflow | 0=False<br>1=True | | | 0=False | Internal Overflow: TRUE-System level overflow occured (indication only) |

*Table 17: IEC 61850-8-1 MMS settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Unit mode | 1=Primary<br>0=Nominal<br>2=Primary-Nominal | | | 0=Nominal | IEC 61850-8-1 unit mode |

*Table 18: MODBUS settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Serial port 1 | 0=Not in use<br>1=COM 1<br>2=COM 2 | | | 0=Not in use | COM port for Serial interface 1 |
| Parity 1 | 0=none<br>1=odd<br>2=even | | | 2=even | Parity for Serial interface 1 |
| Address 1 | 1...255 | | | 1 | Modbus unit address on Serial interface 1 |
| Link mode 1 | 1=RTU<br>2=ASCII | | | 1=RTU | Modbus link mode on Serial interface 1 |
| Start delay 1 | 0...20 | char | | 4 | Start frame delay in chars on Serial interface 1 |
| End delay 1 | 0...20 | char | | 3 | End frame delay in chars on Serial interface 1 |
| Serial port 2 | 0=Not in use<br>1=COM 1<br>2=COM 2 | | | 0=Not in use | COM port for Serial interface 2 |
| Parity 2 | 0=none<br>1=odd<br>2=even | | | 2=even | Parity for Serial interface 2 |
| Address 2 | 1...255 | | | 2 | Modbus unit address on Serial interface 2 |
| Link mode 2 | 1=RTU<br>2=ASCII | | | 1=RTU | Modbus link mode on Serial interface 2 |
| Start delay 2 | 0...20 | | | 4 | Start frame delay in chars on Serial interface 2 |
| End delay 2 | 0...20 | | | 3 | End frame delay in chars on Serial interface 2 |
| MaxTCPClients | 0...5 | | | 5 | Maximum number of Modbus TCP/IP clients |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| TCPWriteAuthority | 0=No clients<br>1=Reg. clients<br>2=All clients | | | 2=All clients | Write authority setting for Modbus TCP/IP clients |
| EventID | 0=Address<br>1=UID | | | 0=Address | Event ID selection |
| TimeFormat | 0=UTC<br>1=Local | | | 1=Local | Time format for Modbus time stamps |
| ClientIP1 | | | | 000.000.000.000 | Modbus Registered Client 1 |
| ClientIP2 | | | | 000.000.000.000 | Modbus Registered Client 2 |
| ClientIP3 | | | | 000.000.000.000 | Modbus Registered Client 3 |
| ClientIP4 | | | | 000.000.000.000 | Modbus Registered Client 4 |
| ClientIP5 | | | | 000.000.000.000 | Modbus Registered Client 5 |
| CtlStructPWd1 | | | | **** | Password for Modbus control struct 1 |
| CtlStructPWd2 | | | | **** | Password for Modbus control struct 2 |
| CtlStructPWd3 | | | | **** | Password for Modbus control struct 3 |
| CtlStructPWd4 | | | | **** | Password for Modbus control struct 4 |
| CtlStructPWd5 | | | | **** | Password for Modbus control struct 5 |
| CtlStructPWd6 | | | | **** | Password for Modbus control struct 6 |
| CtlStructPWd7 | | | | **** | Password for Modbus control struct 7 |
| CtlStructPWd8 | | | | **** | Password for Modbus control struct 8 |
| Internal Overflow | 0=False<br>1=True | | | 0=False | Modbus Internal Overflow: TRUE-System level overflow occured (indication only) |

*Table 19: DNP3 settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| DNP physical layer | 1=Serial<br>2=TCP/IP | | | 2=TCP/IP | DNP physical layer |
| Unit address | 1...65519 | | 1 | 1 | DNP unit address |
| Master address | 1...65519 | | 1 | 3 | DNP master and UR address |
| Serial port | 0=Not in use<br>1=COM 1<br>2=COM 2 | | | 0=Not in use | COM port for serial interface, when physical layer is serial. |
| Need time interval | 0...65535 | min | 1 | 30 | Period to set IIN need time bit |
| Time format | 0=UTC<br>1=Local | | | 1=Local | UTC or local. Coordinate with master. |
| CROB select timeout | 1...65535 | sec | 1 | 10 | Control Relay Output Block select timeout |
| Data link confirm | 0=Never<br>1=Only Multiframe<br>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 |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Data link inter char delay | 0...20 | char | 1 | 4 | Inter character delay for incoming messages |
| App layer confirm | 1=Disable<br>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 |
| Legacy master SBO | 1=Disable<br>2=Enable | | | 1=Disable | Legacy DNP Master SBO sequence number relax enable |
| Default Var Obj 01 | 1...2 | | 1 | 1 | 1=BI; 2=BI with status. |
| Default Var Obj 02 | 1...2 | | 1 | 2 | 1=BI event; 2=BI event with time. |
| Default Var Obj 30 | 1...4 | | 1 | 2 | 1=32 bit AI; 2=16 bit AI; 3=32 bit AI without flag; 4=16 bit AI without flag. |
| Default Var Obj 32 | 1...4 | | 1 | 4 | 1=32 bit AI event; 2=16 bit AI event; 3=32 bit AI event with time; 4=16 bit AI event with time. |

*Table 20: Serial communication settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Fiber mode | 0=No fiber<br>1=Fiber light ON loop<br>2=Fiber light OFF loop<br>3=Fiber light ON star<br>4=Fiber light OFF star | | | 0=No fiber | Fiber mode for COM1 |
| Serial mode | 1=RS485 2Wire<br>2=RS485 4Wire<br>3=RS232 no handshake<br>4=RS232 with handshake | | | 1=RS485 2Wire | Serial mode for COM1 |
| CTS delay | 0...60000 | | | 0 | CTS delay for COM1 |
| RTS delay | 0...60000 | | | 0 | RTS delay for COM1 |
| Baudrate | 1=300<br>2=600<br>3=1200<br>4=2400<br>5=4800<br>6=9600<br>7=19200<br>8=38400<br>9=57600<br>10=115200 | | | 6=9600 | Baudrate for COM1 |

*Table 21: Serial communication settings*

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

*Table 22: Time settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Date | | | | 0 | Date |
| Time | | | | 0 | Time |
| Time format | 1=24H:MM:SS:MS<br>2=12H:MM:SS:MS | | | 1=24H:MM:SS:MS | Time format |
| Date format | 1=DD.MM.YYYY<br>2=DD/MM/YYYY<br>3=DD-MM-YYYY<br>4=MM.DD.YYYY<br>5=MM/DD/YYYY<br>6=YYYY-MM-DD<br>7=YYYY-DD-MM<br>8=YYYY/DD/MM | | | 1=DD.MM.YYYY | Date format |
| Local time offset | -720...720 | min | | 0 | Local time offset in minutes |
| Synch source | 0=None<br>1=SNTP<br>2=Modbus<br>5=IRIG-B<br>9=DNP<br>16=IEC60870-5-103 | | | 1=SNTP | Time synchronization source |
| IP SNTP primary | | | | 10.58.125.165 | IP address for SNTP primary server |
| IP SNTP secondary | | | | 192.168.2.165 | IP address for SNTP secondary server |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| DST on time | | | | 02:00 | Daylight savings time on, time (hh:mm) |
| DST on date | | | | 01.05. | Daylight savings time on, date (dd:mm) |
| DST on day | 0=Not in use<br>1=Mon<br>2=Tue<br>3=Wed<br>4=Thu<br>5=Fri<br>6=Sat<br>7=Sun | | | 0=Not in use | Daylight savings time on, day of week |
| DST offset | -720...720 | min | | 60 | Daylight savings time offset, in minutes |
| DST off time | | | | 02:00 | Daylight savings time off, time (hh:mm) |
| DST off date | | | | 25.09. | Daylight savings time off, date (dd:mm) |
| DST off day | 0=Not in use<br>1=Mon<br>2=Tue<br>3=Wed<br>4=Thu<br>5=Fri<br>6=Sat<br>7=Sun | | | 0=Not in use | Daylight savings time off, day of week |

*Table 23: Generic timers, TPGAPC1...4*

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

*Table 24: X100 PSM binary output signals*

| Name | Type | Default | Description |
|---|---|---|---|
| X100-PO1 | BOOLEAN | 0=False | Connectors 6-7 |
| X100-PO2 | BOOLEAN | 0=False | Connectors 8-9 |
| X100-SO1 | BOOLEAN | 0=False | Connectors 10c-11nc-12no |
| X100-SO2 | BOOLEAN | 0=False | Connectors 13c-14no |
| X100-PO3 | BOOLEAN | 0=False | Connectors 15-17/18-19 |
| X100-PO4 | BOOLEAN | 0=False | Connectors 20-22/23-24 |

*Table 25: X110 BIO binary output signals*

| Name | Type | Default | Description |
|---|---|---|---|
| X110-SO1 | BOOLEAN | 0=False | Connectors 14c-15no-16nc |
| X110-SO2 | BOOLEAN | 0=False | Connectors 17c-18no-19nc |
| X110-SO3 | BOOLEAN | 0=False | Connectors 20c-21no-22nc |
| X110-SO4 | BOOLEAN | 0=False | Connectors 23-24 |

*Table 26: X110 BIO binary input signals*

| Name | Type | Description |
|---|---|---|
| X110-Input 1 | BOOLEAN | Connectors 1-2 |
| X110-Input 2 | BOOLEAN | Connectors 3-4 |
| X110-Input 3 | BOOLEAN | Connectors 5-6c |
| X110-Input 4 | BOOLEAN | Connectors 7-6c |
| X110-Input 5 | BOOLEAN | Connectors 8-9c |
| X110-Input 6 | BOOLEAN | Connectors 10-9c |
| X110-Input 7 | BOOLEAN | Connectors 11-12c |
| X110-Input 8 | BOOLEAN | Connectors 13-12c |

*Table 27: X110 BIO binary input settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Input 1 filter time | 5...1000 | ms | | 5 | Connectors 1-2 |
| Input 2 filter time | 5...1000 | ms | | 5 | Connectors 3-4 |
| Input 3 filter time | 5...1000 | ms | | 5 | Connectors 5-6c |
| Input 4 filter time | 5...1000 | ms | | 5 | Connectors 7-6c |
| Input 5 filter time | 5...1000 | ms | | 5 | Connectors 8-9c |
| Input 6 filter time | 5...1000 | ms | | 5 | Connectors 10-9c |
| Input 7 filter time | 5...1000 | ms | | 5 | Connectors 11-12c |
| Input 8 filter time | 5...1000 | ms | | 5 | Connectors 13-12c |
| Input 1 inversion | 0=False<br>1=True | | | 0=False | Connectors 1-2 |
| Input 2 inversion | 0=False<br>1=True | | | 0=False | Connectors 3-4 |
| Input 3 inversion | 0=False<br>1=True | | | 0=False | Connectors 5-6c |
| Input 4 inversion | 0=False<br>1=True | | | 0=False | Connectors 7-6c |
| Input 5 inversion | 0=False<br>1=True | | | 0=False | Connectors 8-9c |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Input 6 inversion | 0=False<br>1=True | | | 0=False | Connectors 10-9c |
| Input 7 inversion | 0=False<br>1=True | | | 0=False | Connectors 11-12c |
| Input 8 inversion | 0=False<br>1=True | | | 0=False | Connectors 13-12c |

*Table 28: X120 AIM binary input signals*

| Name | Type | Description |
|---|---|---|
| X120-Input 1 | BOOLEAN | Connectors 1-2c |
| X120-Input 2 | BOOLEAN | Connectors 3-2c |
| X120-Input 3 | BOOLEAN | Connectors 4-2c |
| X120-Input 4 | BOOLEAN | Connectors 5-6 |

*Table 29: X120 AIM binary input settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Input 1 filter time | 5...1000 | ms | | 5 | Connectors 1-2c |
| Input 2 filter time | 5...1000 | ms | | 5 | Connectors 3-2c |
| Input 3 filter time | 5...1000 | ms | | 5 | Connectors 4-2c |
| Input 4 filter time | 5...1000 | ms | | 5 | Connectors 5-6 |
| Input 1 inversion | 0=False<br>1=True | | | 0=False | Connectors 1-2c |
| Input 2 inversion | 0=False<br>1=True | | | 0=False | Connectors 3-2c |
| Input 3 inversion | 0=False<br>1=True | | | 0=False | Connectors 4-2c |
| Input 4 inversion | 0=False<br>1=True | | | 0=False | Connectors 5-6 |

*Table 30: X130 BIO binary output signals*

| Name | Type | Default | Description |
|---|---|---|---|
| X130-SO1 | BOOLEAN | 0=False | Connectors 10c-11no-12nc |
| X130-SO2 | BOOLEAN | 0=False | Connectors 13c-14no-15nc |
| X130-SO3 | BOOLEAN | 0=False | Connectors 16c-17no-18nc |

*Table 31: X130 BIO binary input signals*

| Name | Type | Description |
|---|---|---|
| X130-Input 1 | BOOLEAN | Connectors 1-2c |
| X130-Input 2 | BOOLEAN | Connectors 3-2c |
| X130-Input 3 | BOOLEAN | Connectors 4-5c |
| X130-Input 4 | BOOLEAN | Connectors 6-5c |
| X130-Input 5 | BOOLEAN | Connectors 7-8c |
| X130-Input 6 | BOOLEAN | Connectors 9-8c |

*Table 32: X130 BIO binary input settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Input 1 filter time | 5...1000 | ms | | 5 | Connectors 1-2c |
| Input 2 filter time | 5...1000 | ms | | 5 | Connectors 3-2c |
| Input 3 filter time | 5...1000 | ms | | 5 | Connectors 4-5c |
| Input 4 filter time | 5...1000 | ms | | 5 | Connectors 6-5c |
| Input 5 filter time | 5...1000 | ms | | 5 | Connectors 7-8c |
| Input 6 filter time | 5...1000 | ms | | 5 | Connectors 9-8c |
| Input 1 inversion | 0=False<br>1=True | | | 0=False | Connectors 1-2c |
| Input 2 inversion | 0=False<br>1=True | | | 0=False | Connectors 3-2c |
| Input 3 inversion | 0=False<br>1=True | | | 0=False | Connectors 4-5c |
| Input 4 inversion | 0=False<br>1=True | | | 0=False | Connectors 6-5c |
| Input 5 inversion | 0=False<br>1=True | | | 0=False | Connectors 7-8c |
| Input 6 inversion | 0=False<br>1=True | | | 0=False | Connectors 9-8c |

*Table 33: X130 AIM binary input signals*

| Name | Type | Description |
|---|---|---|
| X130-Input 1 | BOOLEAN | Connectors 1-2 |
| X130-Input 2 | BOOLEAN | Connectors 3-4 |
| X130-Input 3 | BOOLEAN | Connectors 5-6 |
| X130-Input 4 | BOOLEAN | Connectors 7-8 |

*Table 34: X130 AIM binary input settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Input 1 filter time | 5...1000 | ms | | 5 | Connectors 1-2 |
| Input 2 filter time | 5...1000 | ms | | 5 | Connectors 3-4 |
| Input 3 filter time | 5...1000 | ms | | 5 | Connectors 5-6 |
| Input 4 filter time | 5...1000 | ms | | 5 | Connectors 7-8 |
| Input 1 inversion | 0=False<br>1=True | | | 0=False | Connectors 1-2 |
| Input 2 inversion | 0=False<br>1=True | | | 0=False | Connectors 3-4 |
| Input 3 inversion | 0=False<br>1=True | | | 0=False | Connectors 5-6 |
| Input 4 inversion | 0=False<br>1=True | | | 0=False | Connectors 7-8 |

## 3.2 Self-supervision

The IED's extensive self-supervision system continuously supervises the software and the electronics. It handles run-time fault situations and informs the user about the existing faults via the LHMI and the communication.

There are two types of fault indications.

- Internal faults
- Warnings

### 3.2.1 Internal faults

When an IED internal fault is detected, IED protection operation is disabled, the green Ready LED begins to flash and the self-supervision output contact is activated.

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 fault. The IED tries to eliminate the fault by restarting. After the fault is found to be permanent, the IED stays in internal fault mode. All other output contacts are released and locked for the internal fault. The IED continues to perform internal tests during the fault situation.

If an internal fault disappears, the green Ready LED stops flashing and the IED returns to the normal service state. The fault indication message remains on the LCD until manually cleared.

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

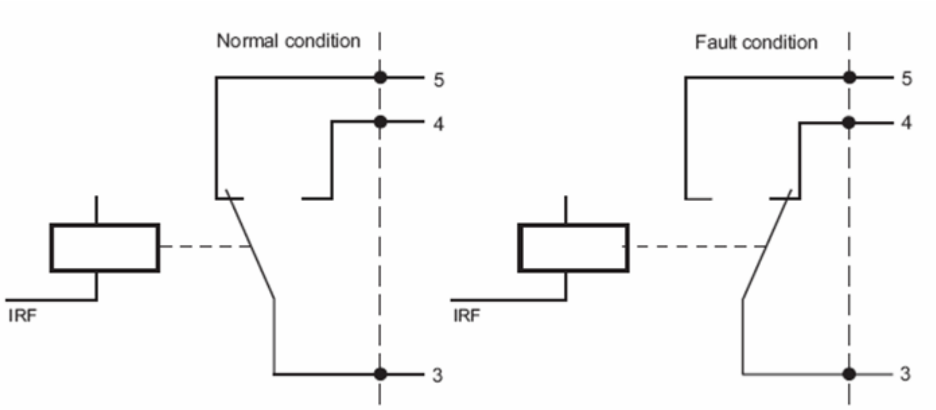



*Figure 6: Output contact*

The internal fault code indicates the type of internal IED fault. When a fault occurs, document the code and state it when ordering the service.

*Table 35: Internal fault indications and codes*

| Fault indication | Fault code | Additional information |
|---|---|---|
| Internal Fault<br>System error | 2 | An internal system error has occurred. |
| Internal Fault<br>File system error | 7 | A file system error has occurred. |
| Internal Fault<br>Test | 8 | Internal fault test activated manually by the user. |
| Internal Fault<br>SW watchdog error | 10 | Watchdog reset has occurred too many times within an hour. |
| Internal Fault<br>SO-relay(s),X100 | 43 | Faulty Signal Output relay(s) in card located in slot X100. |
| Internal Fault<br>SO-relay(s),X110 | 44 | Faulty Signal Output relay(s) in card located in slot X110. |
| Internal Fault<br>SO-relay(s),X130 | 46 | Faulty Signal Output relay(s) in card located in slot X130. |
| Internal Fault<br>PO-relay(s),X100 | 53 | Faulty Power Output relay(s) in card located in slot X100. |
| Internal Fault<br>PO-relay(s),X110 | 54 | Faulty Power Output relay(s) in card located in slot X110. |
| Internal Fault<br>PO-relay(s),X130 | 56 | Faulty Power Output relay(s) in card located in slot X130. |

Table continues on next page

| Fault indication | Fault code | Additional information |
|---|---|---|
| Internal Fault<br>Light sensor error | 57 | Faulty ARC light sensor input(s). |
| Internal Fault<br>Conf. error,X000 | 62 | Card in slot X000 is wrong type. |
| Internal Fault<br>Conf. error,X100 | 63 | Card in slot X100 is wrong type or does not belong to the original composition. |
| Internal Fault<br>Conf. error,X110 | 64 | Card in slot X110 is wrong type, is missing or does not belong to the original composition. |
| Internal Fault<br>Conf. error,X120 | 65 | Card in slot X120 is wrong type, is missing or does not belong to the original composition. |
| Internal Fault<br>Conf. error,X130 | 66 | Card in slot X130 is wrong type, is missing or does not belong to the original composition. |
| Internal Fault<br>Card error,X000 | 72 | Card in slot X000 is faulty. |
| Internal Fault<br>Card error,X100 | 73 | Card in slot X100 is faulty. |
| Internal Fault<br>Card error,X110 | 74 | Card in slot X110 is faulty. |
| Internal Fault<br>Card error,X120 | 75 | Card in slot X120 is faulty. |
| Internal Fault<br>Card error,X130 | 76 | Card in slot X130 is faulty. |
| Internal Fault<br>LHMI module | 79 | LHMI module is faulty. The fault indication may not be seen on the LHMI during the fault. |
| Internal Fault<br>RAM error | 80 | Error in the RAM memory on the CPU card. |
| Internal Fault<br>ROM error | 81 | Error in the ROM memory on the CPU card. |
| Internal Fault<br>EEPROM error | 82 | Error in the EEPROM memory on the CPU card. |
| Internal Fault<br>FPGA error | 83 | Error in the FPGA on the CPU card. |
| Internal Fault<br>RTC error | 84 | Error in the RTC on the CPU card. |

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

## 3.2.2 Warnings

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

A fault indication message, which includes text `Warning` with additional text, a code, date and time, is shown on the LHMI to indicate the fault type. If more than one type of fault occur at the same time, indication of the latest fault is displayed on the LCD. The fault indication message can be manually cleared.

When a fault appears, the fault indication message is to be recorded and stated when ordering service.

*Table 36: Warning indications and codes*

| Warning indication | Warning code | Additional information |
|---|---|---|
| Warning<br>Watchdog reset | 10 | A watchdog reset has occurred. |
| Warning<br>Power down det. | 11 | The auxiliary supply voltage has dropped too low. |
| Warning<br>IEC61850 error | 20 | Error when building the IEC 61850 data model. |
| Warning<br>Modbus error | 21 | Error in the Modbus communication. |
| Warning<br>DNP3 error | 22 | Error in the DNP3 communication. |
| Warning<br>Dataset error | 24 | Error in the Data set(s). |
| Warning<br>Report cont. error | 25 | Error in the Report control block(s). |
| Warning<br>GOOSE contr. error | 26 | Error in the GOOSE control block(s). |
| Warning<br>SCL config error | 27 | Error in the SCL configuration file or the file is missing. |
| Warning<br>Logic error | 28 | Too many connections in the configuration. |
| Warning<br>SMT logic error | 29 | Error in the SMT connections. |
| Warning<br>GOOSE input error | 30 | Error in the GOOSE connections. |
| Warning<br>GOOSE Rx. error | 32 | Error in the GOOSE message receiving. |
| Warning<br>AFL error | 33 | Analog channel configuration error. |
| Warning<br>Unack card comp. | 40 | A new composition has not been acknowledged/accepted. |
| Warning<br>Protection comm. | 50 | Error in protection communication. |
| Warning<br>ARC1 cont. light | 85 | A continuous light has been detected on the ARC light input 1. |
| Warning<br>ARC2 cont. light | 86 | A continuous light has been detected on the ARC light input 2. |
| Warning<br>ARC3 cont. light | 87 | A continuous light has been detected on the ARC light input 3. |

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

# 3.3 LED indication control

The IED 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 IED 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 IED configuration (available as output signals `OUT_ST_NEUT` and `OUT_OPR_NEUT`).

# 3.4 Time synchronization

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

Setting *Synch Source* determines the method how the real-time clock is synchronized. If 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 but SNTP provides time master redundancy.

The IED supports SNTP, IRIG-B, DNP3, Modbus and IEC 60870-5-103 to update the real-time clock. IRIG-B with GPS provides the best accuracy.

With Modbus or DNP3, SNTP or IRIG-B time synchronization should be used for better synchronization accuracy.

When the SNTP server IP setting is changed, the IED must be rebooted to activate the new IP address. The SNTP server IP settings are normally defined in the engineering phase via the SCL file.

The IED 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 IED 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.

IRIG-B time synchronization requires the IRIG-B format 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.

ABB has tested the IRIG-B with the following clock masters:

- Tekron TTM01 GPS clock with IRIG-B output
- Meinberg TCG511 controlled by GPS167
- Datum ET6000L
- Arbiter Systems 1088B

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

The time synchronization messages can be received from the other line end IED within the protection telegrams. The IED begins to synchronize its real-time clock with the remote end IEDs time if the Line differential time synchronization source is selected. This does not affect the protection synchronization used in the line differential protection or the selection of the remote end IEDs time synchronization method. [1]

## 3.5 Parameter setting groups

There are four IED variant specific setting groups. For each setting group, the parameter setting can be made independently.

The active setting group can be changed by parameter (setting groups 1...4) or via binary input (setting groups 1...2), if a binary input is enabled for it.

To enable active setting group changing via binary input, connect any of the (free) binary inputs to SMT:Protection:0 ActSG and set the setting *SG follow input* to “TRUE” in the general system settings.

[1] The line differential protection is available only in RED615.

*Table 37: Active setting group binary input state*

| BI state | Active setting group |
|---|---|
| OFF | 1 |
| ON | 2 |

The setting group parameter is overridden when a binary input is used for changing the active setting group.

*Table 38: Settings*

| Parameter | Setting | Value | Default | Description | Access rights |
|---|---|---|---|---|---|
| Setting group | Active group | 1...4 | 1 | Selected active group | RWRW |

Not all parameters belong to a setting group. For example protection function enable/disable settings are not part of a setting group.

## 3.6 Recorded data

The IED has the capacity to store the records of four latest fault events. The records enable the user to analyze the four most recent power system events. Each fault record (FLTMSTA) is marked with an up-counting fault number. Slot fault record 1 always contains the newest record, and fault record 4 the oldest. The time stamp is taken from the beginning of the fault.

The fault recording period begins on the start event of any protection function and ends if any protection function operates or the start is restored without the operate event.  The type of fault that triggers the fault recording is selected with the setting parameter *Trig mode*. When “From all faults” is selected, all types of detected faults trigger a new fault recording. When “From operate” is selected, only faults that cause an operate event trigger a new fault recording. Finally, when “From only start” is selected, only faults without an operate event are recorded.

The fault-related current, voltage and angle values are taken from the moment of the operate event, or from the beginning of the fault in case there is only a start event during the fault. The maximum current value collects maximum fault currents during the fault. Measuring mode for phase current and residual current values can be selected with the *A Measurement mode* setting parameter.

The data recorded depend on the product and the standard configuration.

*Table 39: Fault recorder settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Trig mode | 0=From all faults<br>1=From operate<br>2=From only start | | | 0=From all faults | Triggering mode |
| A measurement mode | 1=RMS<br>2=DFT<br>3=Peak-to-Peak | | | 2=DFT | Selects used measurement mode phase currents and residual current |

*Table 40: Fault recorder data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| Number | INT32 | 0...999999 | | Fault record number |
| Time | Timestamp | | | Time of recording |
| Max diff current IL1 | FLOAT32 | 0.000...80.000 | | Maximum phase A differential current |
| Max diff current IL2 | FLOAT32 | 0.000...80.000 | | Maximum phase B differential current |
| Max diff current IL3 | FLOAT32 | 0.000...80.000 | | Maximum phase C differential current |
| Diff current IL1 | FLOAT32 | 0.000...80.000 | | Differential current phase A |
| Diff current IL2 | FLOAT32 | 0.000...80.000 | | Differential current phase B |
| Diff current IL3 | FLOAT32 | 0.000...80.000 | | Differential current phase C |
| Max bias current IL1 | FLOAT32 | 0.000...50.000 | | Maximum phase A bias current |
| Max bias current IL2 | FLOAT32 | 0.000...50.000 | | Maximum phase B bias current |
| Max bias current IL3 | FLOAT32 | 0.000...50.000 | | Maximum phase C bias current |
| Bias current IL1 | FLOAT32 | 0.000...50.000 | | Bias current phase A |
| Bias current IL2 | FLOAT32 | 0.000...50.000 | | Bias current phase B |
| Bias current IL3 | FLOAT32 | 0.000...50.000 | | Bias current phase C |
| Diff current I0 | FLOAT32 | 0.000...80.000 | | Differential current residual |
| Bias current I0 | FLOAT32 | 0.000...50.000 | | 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 |
| 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 |
| Max current I0 | FLOAT32 | 0.000...50.000 | xIn | Maximum residual current |
| Current I0 | FLOAT32 | 0.000...50.000 | xIn | Residual current |
| Current Ng-Seq | FLOAT32 | 0.000...50.000 | xIn | Negative sequence current |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| Current I0-Calc | FLOAT32 | 0.000...50.000 | xIn | Calculated residual 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) |
| Current IL1B | FLOAT32 | 0.000...50.000 | xIn | Maximum phase A current (b) |
| Current IL2B | FLOAT32 | 0.000...50.000 | xIn | Maximum phase B current (b) |
| Current IL3B | FLOAT32 | 0.000...50.000 | xIn | Maximum phase C current (b) |
| Current I0-CalcB | FLOAT32 | 0.000...50.000 | xIn | Calculated residual current (b) |
| Current Ng-SeqB | FLOAT32 | 0.000...50.000 | xIn | Negative sequence current (b) |
| 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 U0 | FLOAT32 | 0.000...4.000 | xUn | Residual 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 |
| Angle U0 - I0 | 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 |
| PTTR thermal level | FLOAT32 | 0.00...99.99 | | PTTR calculated temperature of the protected object relative to the operate level |
| LNPLDF1 duration | FLOAT32 | 0.00...100.00 | % | LNPLDF1 Start duration |
| LREFPNDF1 duration | FLOAT32 | 0.00...100.00 | % | LREFPNDF1 Start duration |
| HREFPDIF1 duration | FLOAT32 | 0.00...100.00 | % | HREFPDIF1 Start duration |
| PHLPTOC1 duration | FLOAT32 | 0.00...100.00 | % | PHLPTOC1 Start duration |
| PHLPTOC2 duration | FLOAT32 | 0.00...100.00 | % | PHLPTOC2 Start duration |
| PHHPTOC1 duration | FLOAT32 | 0.00...100.00 | % | PHHPTOC1 Start duration |
| PHHPTOC2 duration | FLOAT32 | 0.00...100.00 | % | PHHPTOC2 Start duration |
| PHIPTOC1 duration | FLOAT32 | 0.00...100.00 | % | PHIPTOC1 Start duration |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| PHIPTOC2 duration | FLOAT32 | 0.00...100.00 | % | PHIPTOC2 Start duration |
| DPHLPDOC1 duration | FLOAT32 | 0.00...100.00 | % | DPHLPDOC1 Start duration |
| DPHLPDOC2 duration | FLOAT32 | 0.00...100.00 | % | DPHLPDOC2 Start duration |
| DPHHPDOC1 duration | FLOAT32 | 0.00...100.00 | % | DPHHPDOC1 Start duration |
| EFLPTOC1 duration | FLOAT32 | 0.00...100.00 | % | EFLPTOC1 Start duration |
| EFLPTOC2 duration | FLOAT32 | 0.00...100.00 | % | EFLPTOC2 Start duration |
| EFHPTOC1 duration | FLOAT32 | 0.00...100.00 | % | EFHPTOC1 Start duration |
| EFHPTOC2 duration | FLOAT32 | 0.00...100.00 | % | EFHPTOC2 Start duration |
| EFIPTOC1 duration | FLOAT32 | 0.00...100.00 | % | EFIPTOC1 Start duration |
| NSPTOC1 duration | FLOAT32 | 0.00...100.00 | % | NSPTOC1 Start duration |
| NSPTOC2 duration | FLOAT32 | 0.00...100.00 | % | NSPTOC2 Start duration |
| PDNSPTOC1 duration | FLOAT32 | 0.00...100.00 | % | PDNSPTOC1 Start duration |
| PDNSPTOC1 rat. I2/I1 | FLOAT32 | 0.00...999.99 | % | PDNSPTOC1 ratio I2/I1 |
| DEFLPDEF1 duration | FLOAT32 | 0.00...100.00 | % | DEFLPDEF1 Start duration |
| DEFLPDEF2 duration | FLOAT32 | 0.00...100.00 | % | DEFLPDEF2 Start duration |
| DEFHPDEF1 duration | FLOAT32 | 0.00...100.00 | % | DEFHPDEF1 Start duration |
| INTRPTEF1 duration | FLOAT32 | 0.00...100.00 | % | INTRPTEF1 Start duration |
| ROVPTOV1 duration | FLOAT32 | 0.00...100.00 | % | ROVPTOV1 Start duration |
| ROVPTOV2 duration | FLOAT32 | 0.00...100.00 | % | ROVPTOV2 Start duration |
| ROVPTOV3 duration | FLOAT32 | 0.00...100.00 | % | ROVPTOV3 Start duration |
| PHPTOV1 duration | FLOAT32 | 0.00...100.00 | % | PHPTOV1 Start duration |
| PHPTOV2 duration | FLOAT32 | 0.00...100.00 | % | PHPTOV2 Start duration |
| PHPTOV3 duration | FLOAT32 | 0.00...100.00 | % | PHPTOV3 Start duration |
| PHPTUV1 duration | FLOAT32 | 0.00...100.00 | % | PHPTUV1 Start duration |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| PHPTUV2 duration | FLOAT32 | 0.00...100.00 | % | PHPTUV2 Start duration |
| PHPTUV3 duration | FLOAT32 | 0.00...100.00 | % | PHPTUV3 Start duration |
| PSPTUV1 duration | FLOAT32 | 0.00...100.00 | % | PSPTUV1 Start duration |
| NSPTOV1 duration | FLOAT32 | 0.00...100.00 | % | NSPTOV1 Start duration |

## 3.7 Non-volatile memory

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

- Up to 50 events are stored. The stored events are visible in LHMI and WHMI only.
- Recorded data
  - Fault records
  - Maximum demands
- Circuit breaker condition monitoring
- Latched alarm and trip LEDs' status
- Trip circuit lockout
- Counter values

## 3.8 Binary input

### 3.8.1 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 IED.

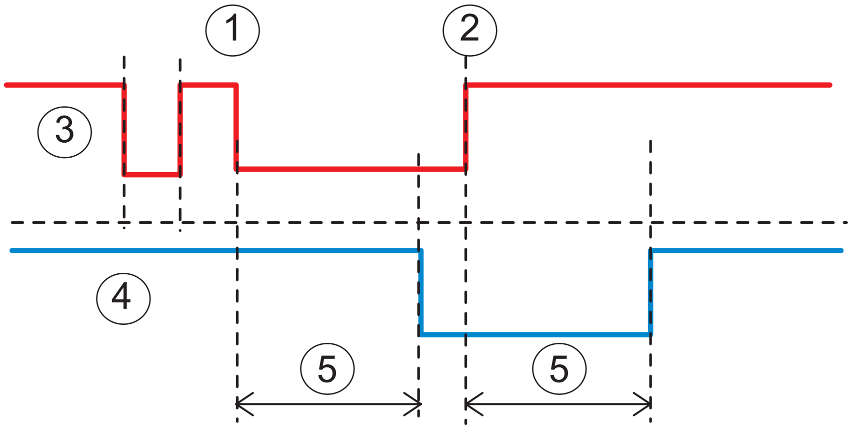



*Figure 7: Binary input filtering*

1 $t_0$

2 $t_1$

3 Input signal

4 Filtered input signal

5 Filter time

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 41: Input filter parameter values*

| Parameter | Values | Default |
|---|---|---|
| Input # filter | 1...15000 ms | 5 ms |

## 3.8.2 Binary input inversion

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

*Table 42: Binary input states*

| Control voltage | Input # invert | State of binary input |
|---|---|---|
| No | 0 | False (0) |
| Yes | 0 | True (1) |
| No | 1 | True (0) |
| 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.

### 3.8.3 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 43: Oscillation parameter values*

| Parameter | Values | Default |
|---|---|---|
| Input osc. level | 2...50 events/s | 50 events/s |
| Input osc. hyst. | 2...50 events/s | 10 events/s |

## 3.9 Factory settings restoration

In case of configuration data loss or any other file system error that prevents the IED 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.

# Section 4 Protection functions

## 4.1 Three-phase current protection

### 4.1.1 Three-phase non-directional overcurrent protection PHxPTOC

#### 4.1.1.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Three-phase non-directional overcurrent protection - Low stage | PHLPTOC | 3I> | 51P-1 |
| Three-phase non-directional overcurrent protection - High stage | PHHPTOC | 3I>> | 51P-2 |
| Three-phase non-directional overcurrent protection - Instantaneous stage | PHIPTOC | 3I>>> | 50P/51P |

#### 4.1.1.2 Function block

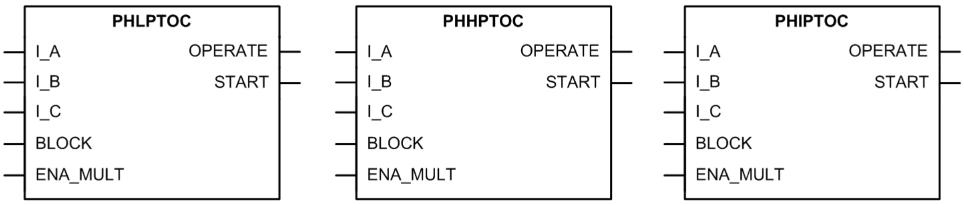



*Figure 8: Function block symbol*

#### 4.1.1.3 Functionality

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

The function starts when the current exceeds the set limit. The operate time characteristics for low stage PHLPTOC and high stage PHHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).The instantaneous stage PHIPTOC always operates with the DT characteristic.

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

### 4.1.1.4 Operation principle

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

The operation of three-phase non-directional overcurrent protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

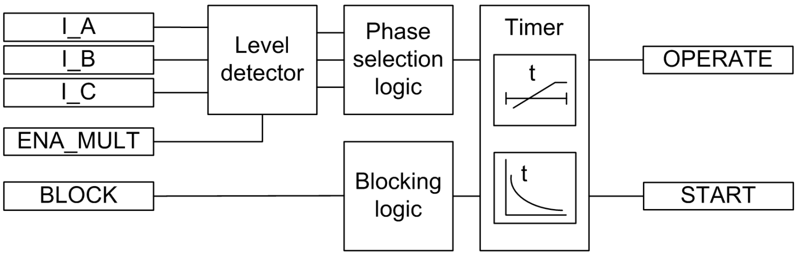



*Figure 9: Functional module diagram. I_A, I_B and I_C represent phase currents.*

#### Level detector

The measured phase currents are compared phase-wise with 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. See more details on the inrush detection function in the relevant chapter.

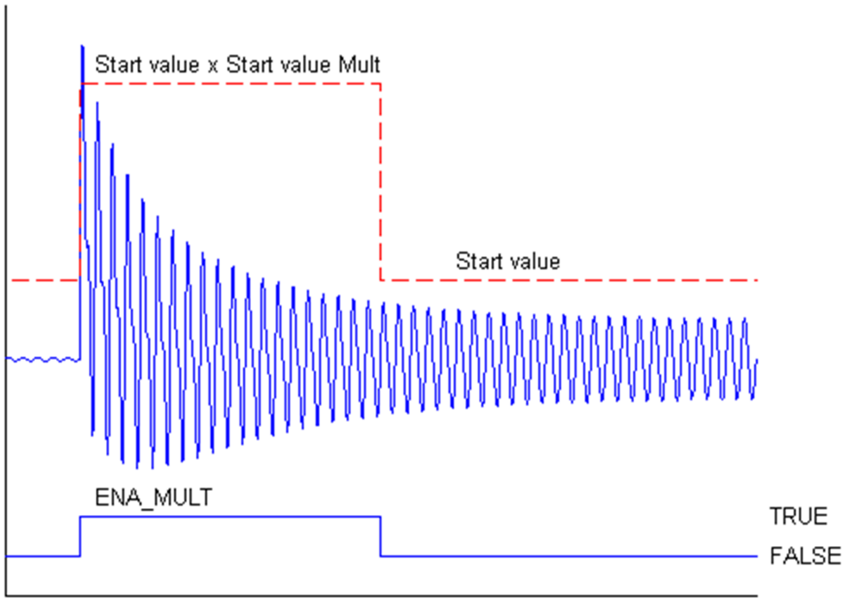



*Figure 10: Start value behavior with* `ENA_MULT` *input activated*

### 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 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 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. 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 user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the General function block features section in this manual.

The timer calculates the start duration value START_DUR which indicates the percentual 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 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 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 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.

## 4.1.1.5 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 44: Measurement modes supported by PHxPTOC stages*

| Measurement mode | Supported measurement modes | | |
|---|---|---|---|
| | PHLPTOC | PHHPTOC | PHIPTOC |
| RMS | x | x | |
| DFT | x | x | |
| Peak-to-Peak | x | x | |
| P-to-P + backup | | | x |

For a detailed description of the measurement modes, see the General function block features section in this manual.

### 4.1.1.6 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 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 45: Timer characteristics supported by different stages*

| Operating curve type | Supported by | |
|---|---|---|
| | PHLPTOC | PHHPTOC |
| (1) ANSI Extremely Inverse | x | x |
| (2) ANSI Very Inverse | x | |
| (3) ANSI Normal Inverse | x | x |
| (4) ANSI Moderately Inverse | x | |
| (5) ANSI Definite Time | x | x |
| (6) Long Time Extremely Inverse | x | |
| (7) Long Time Very Inverse | x | |
| (8) Long Time Inverse | x | |
| (9) IEC Normal Inverse | x | x |
| (10) IEC Very Inverse | x | x |

Table continues on next page

| Operating curve type | Supported by | |
|---|---|---|
| | PHLPTOC | PHHPTOC |
| (11) IEC Inverse | x | |
| (12) IEC Extremely Inverse | x | x |
| (13) IEC Short Time Inverse | x | |
| (14) IEC Long Time Inverse | x | |
| (15) IEC Definite Time | x | x |
| (17) User programmable | x | x |
| (18) RI type | x | |
| (19) RD type | x | |

PHIPTOC supports only definite time characteristic.

For a detailed description of timers, see the General function block features section in this manual.

*Table 46: Reset time characteristics supported by different stages*

| Reset curve type | Supported by | | |
|---|---|---|---|
| | PHLPTOC | PHHPTOC | Note |
| (1) Immediate | x | x | Available for all operate time curves |
| (2) Def time reset | x | x | Available for all operate time curves |
| (3) Inverse reset | x | x | Available only for ANSI and user programmable curves |

The *Type of reset curve* setting does not apply to PHIPTOC or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

### 4.1.1.7 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
- Back-up 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 back-up protection

PHxPTOC is used for single-phase, two-phase and three-phase non-directional overcurrent and short-circuit protection. Typically, overcurrent protection is used for clearing two and three-phase short circuits. Therefore, the user can choose how many phases, at minimum, must have currents above the start level for the function to operate. When the number of start-phase settings is set to "1 out of 3", the operation of PHxPTOC is enabled with the presence of high current in one-phase.

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

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

- Low PHLPTOC
- High PHHPTOC
- Instantaneous PHIPTOC.

PHLPTOC is used for overcurrent protection. The function contains several types of time-delay characteristics. PHHPTOC and PHIPTOC are used for fast clearance of very high overcurrent situations.

### Transformer and busbar overcurrent protection with reverse blocking principle

By implementing a full set of overcurrent protection stages and blocking channels between the protection stages of the incoming feeders, bus-tie and outgoing feeders, it is possible to speed up the operation of overcurrent protection in the busbar and transformer LV-side faults without impairing the selectivity. Also, the security degree of busbar protection is increased, because there is now a dedicated, selective and fast busbar protection functionality, which is based on the blockable overcurrent protection principle. The additional time selective stages on the transformer HV- and LV-sides provide increased security degree of back-up 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 11 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 47: Proposed functionality of numerical transformer and busbar over current 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 in 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.

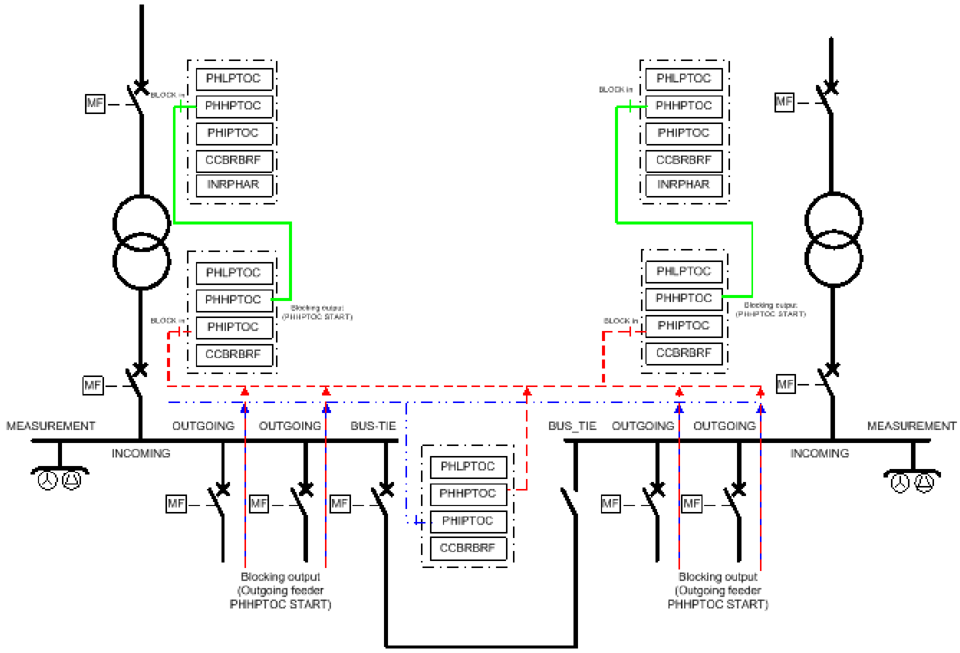



*Figure 11: Numerical overcurrent protection functionality for a typical sub-transmission/distribution substation (feeder protection not shown). Blocking output = digital output signal from the start of a protection stage, Blocking in = digital input signal to block the operation of a protection stage*

The operating times of the time selective stages are very short, because the grading margins between successive protection stages can be kept short. This is mainly due to the advanced measuring principle allowing a certain degree of CT saturation, good operating accuracy and short retardation times of the numerical units. So, for example, a grading margin of 150 ms in the DT mode of operation can be used, provided that the circuit breaker interrupting time is shorter than 60 ms.

The sensitivity and speed of the current-selective stages become as good as possible due to the fact that the transient overreach is practically zero. Also, the effects of switching inrush currents on the setting values can be reduced by using the IED logic, which recognizes the transformer energizing inrush current and blocks the operation or multiplies the current start value setting of the selected overcurrent stage with a predefined multiplier setting.

Finally, a dependable trip of the overcurrent protection is secured by both a proper selection of the settings and an adequate ability of the measuring transformers to reproduce the fault current. This is important in order to maintain selectivity and also for the protection to operate without additional time delays. For additional information about available measuring modes and current transformer requirements, refer to section where general function block features are described in the IED technical 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 a multiple-stage over current units. Figure 12 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 over current protection, where the low-set stage PHLPTOC operates in IDMT-mode and the two higher stages PHHPTOC and PHIPTOC in DT-mode. Also the thermal withstand of the line types along the feeder and maximum expected inrush currents of the feeders are shown. Faults occurring near the station, where the fault current levels are the highest, are cleared rapidly by the instantaneous stage in order to minimize the effects of severe short circuit faults. The influence of the inrush current is taken into consideration by connecting the inrush current detector to the start value multiplying input of the instantaneous stage. By this way the start value is multiplied with a predefined setting during the inrush situation and nuisance tripping can be avoided.

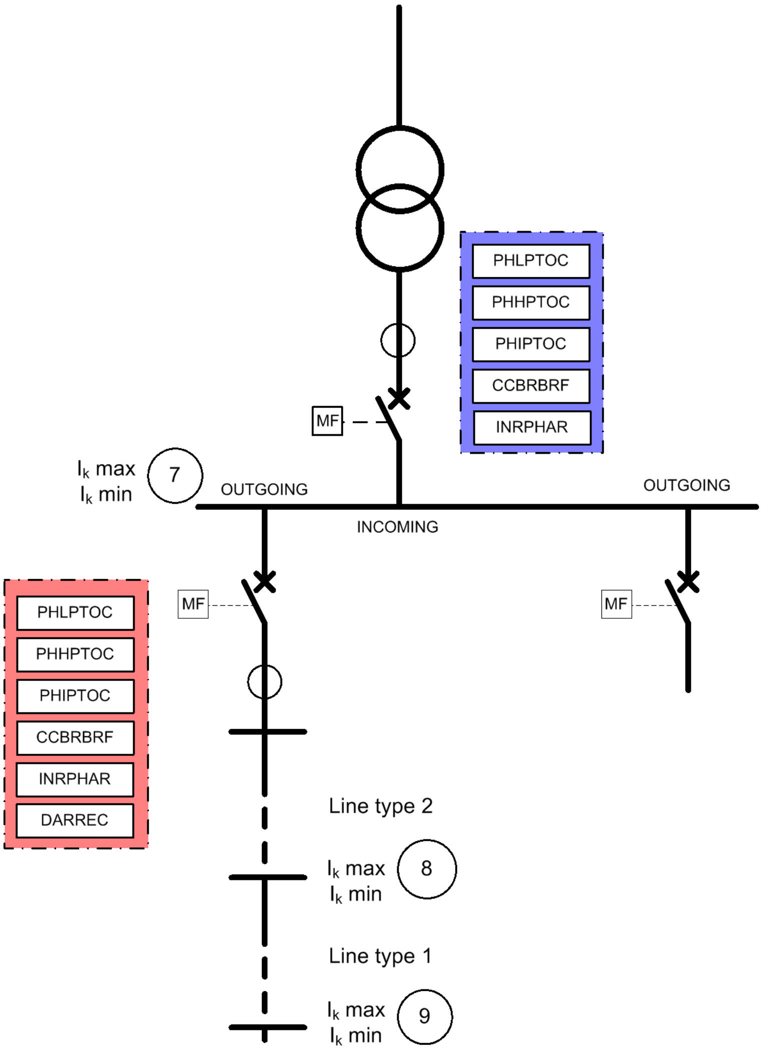



*Figure 12: Functionality of numerical multiple-stage overcurrent protection*

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 simultaneusly in a coordination plan. In Figure 13 the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

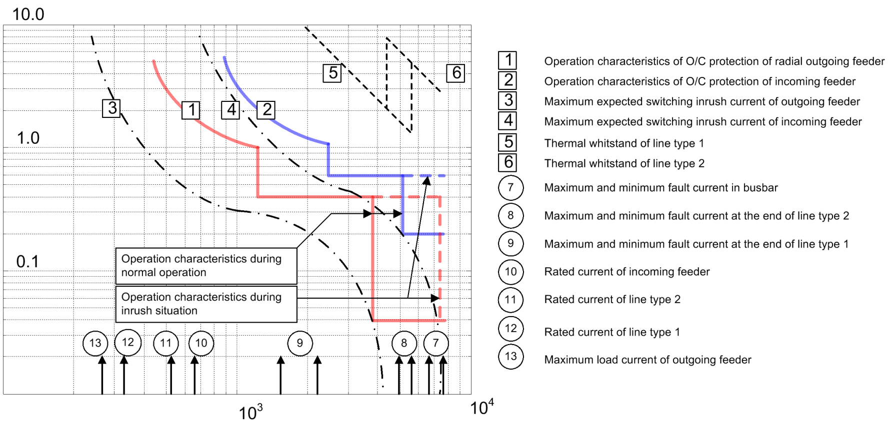



*Figure 13: Example coordination of numerical multiple-stage overcurrent protection*

### 4.1.1.8 Signals

*Table 48: 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 49: 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 50: 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 51: PHLPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

*Table 52: PHHPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

*Table 53: PHIPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.1.1.9 Settings

*Table 54: PHLPTOC Group settings*

| 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 | | 0.05 | 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.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Programmable<br>18=RI type<br>19=RD type | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset | | | 1=Immediate | Selection of reset curve type |

Table 55: *PHLPTOC Non group settings*

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

Table 56: *PHHPTOC Group settings*

| 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 | | 0.05 | 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.<br>3=ANSI Norm. inv.<br>5=ANSI Def. Time<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>12=IEC Ext. inv.<br>15=IEC Def. Time<br>17=Programmable | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset | | | 1=Immediate | Selection of reset curve type |

*Table 57: PHHPTOC Non group settings*

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

*Table 58: PHIPTOC Group settings*

| 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 59: PHIPTOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 | | | 1=1 out of 3 | Number of phases required for operate activation |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |

### 4.1.1.10 Monitored data

*Table 60: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

*Table 61: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

*Table 62: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.1.1.11 Technical data

*Table 63: PHxPTOC Technical data*

| Characteristic | | Value |
|---|---|---|
| Operation accuracy | | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | PHLPTOC | ±1.5% of the set value or ±0.002 x $I_n$ |
| | PHHPTOC<br>and<br>PHIPTOC | ±1.5% of set value or ±0.002 x $I_n$<br>(at currents in the range of 0.1…10 x $I_n$)<br>±5.0% of the set value<br>(at currents in the range of 10…40 x $I_n$) |
| Table continues on next page | | |

| Characteristic | | Value | | |
|---|---|---|---|---|
| Start time 1)2) | | Minimum | Typical | Maximum |
| | PHIPTOC:<br>$I_{Fault}$ = 2 x set *Start value*<br>$I_{Fault}$ = 10 x set *Start value* | 16 ms<br>11 ms | 19 ms<br>12 ms | 23 ms<br>14 ms |
| | PHHPTOC and PHLPTOC:<br>$I_{Fault}$ = 2 x set *Start value* | 22 ms | 24 ms | 25 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 0.96 | | |
| Retardation time | | < 30 ms | | |
| Operate time accuracy in definite time mode | | ±1.0% of the set value or ±20 ms | | |
| Operate time accuracy in inverse time mode | | ±5.0% of the theoretical value or ±20 ms 3) | | |
| Suppression of harmonics | | RMS: No suppression<br>DFT: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5,…<br>Peak-to-Peak: No suppression<br>P-to-P+backup: No suppression | | |

1) *Measurement mode* = default (depends on stage), current before fault = 0.0 x $I_n$, $f_n$ = 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 x $I_n$, *Start value* multiples in range of 1.5 to 20

### 4.1.1.12 Technical revision history

*Table 64: PHIPTOC Technical revision history*

| Technical revision | Change |
|---|---|
| C | Minimum and default values changed to 20 ms for the *Operate delay time* setting.<br>Minimum value changed to 1.00 x $I_n$ for the *Start value* setting. |

*Table 65: PHHPTOC Technical revision history*

| Technical revision | Change |
|---|---|
| C | *Measurement mode* "P-to-P + backup" replaced with "Peak-to-Peak" |

*Table 66: PHLPTOC Technical revision history*

| Technical revision | Change |
|---|---|
| B | Minimum and default values changed to 40 ms for the *Operate delay time* setting |

## 4.1.2 Three-phase directional overcurrent protection DPHxPDOC

### 4.1.2.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Three-phase directional overcurrent protection - Low stage | DPHLPDOC | 3I> -> | 67-1 |
| Three-phase directional overcurrent protection - High stage | DPHHPDOC | 3I>> -> | 67-2 |

### 4.1.2.2 Function block

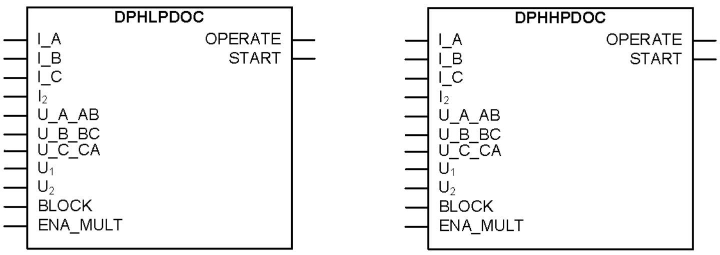



*Figure 14: Function block symbol*

### 4.1.2.3 Functionality

The three-phase overcurrent protection DPHxPDOC is used as one-phase, two-phase or three-phase directional overcurrent and short-circuit protection for feeders.

DPHxPDOC starts when the value of the current exceeds the set limit and directional criterion is fulfilled. The operate time characteristics for low stage DPHLPDOC and high stage DPHHPDOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

### 4.1.2.4 Operation principle

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

The operation of directional overcurrent protection can be described using a module diagram. All the blocks in the diagram are explained in the next sections.

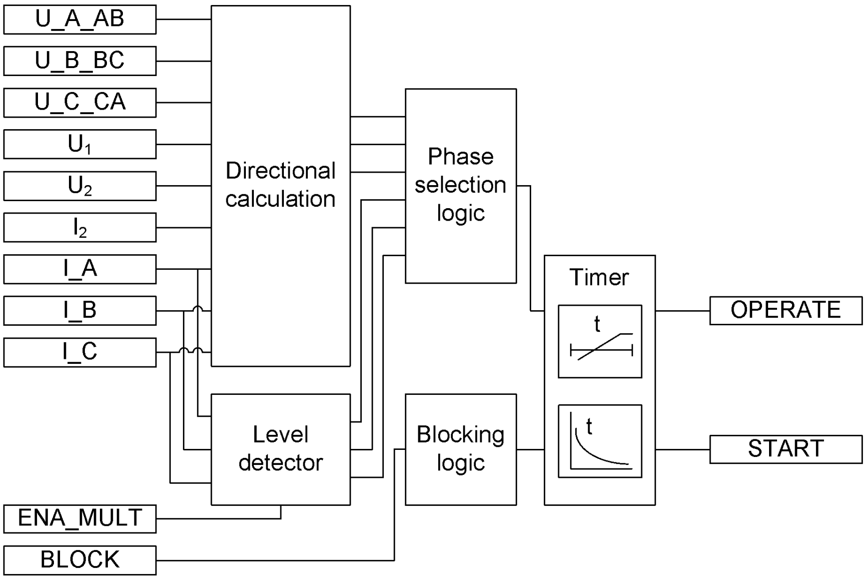



*Figure 15: Functional module diagram*

## Directional calculation

The directional calculation compares the current phasors to the polarizing phasor. The user can select the suitable one from 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 67: 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 IED operation in case of a close short circuit or an earth fault characterized by an extremely low voltage. At sudden loss of the polarization quantity, the angle difference is calculated on the basis of a fictive voltage. The fictive voltage is calculated using the 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 voltage memory arises and these are kept frozen until the time set with *Voltage Mem time* elapses.

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.

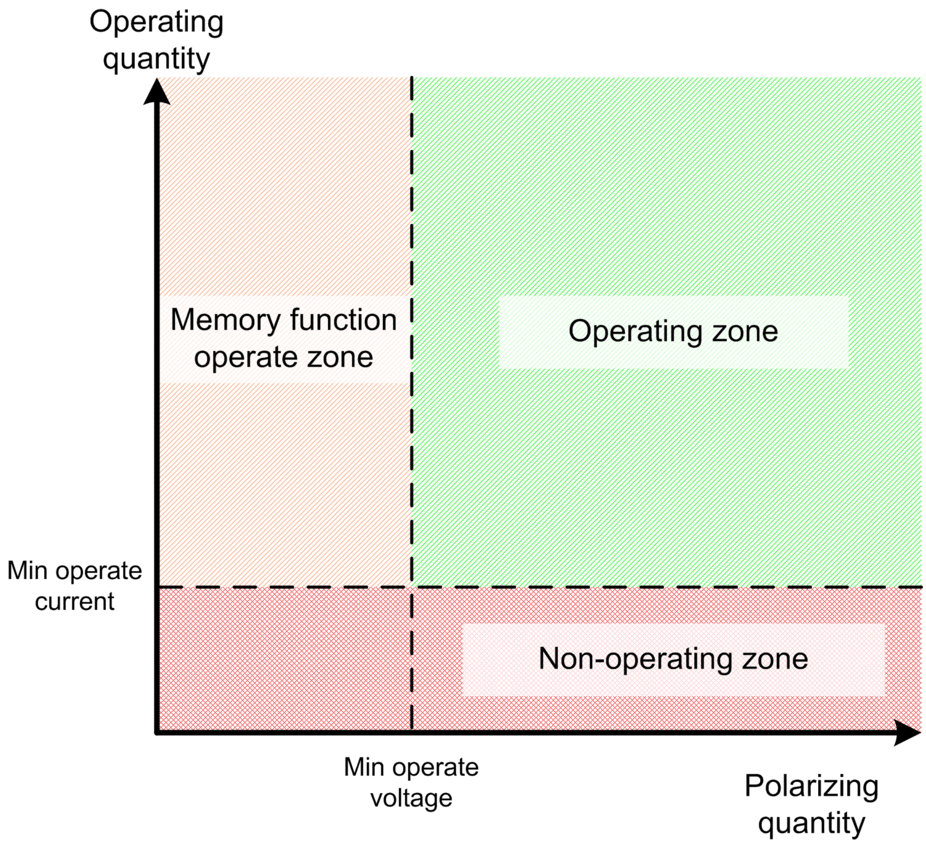



*Figure 16: Operating zones at minimum magnitude levels*

### Level detector

The measured phase currents are compared phase-wise with 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. See more details on the inrush detection function in the relevant chapter.

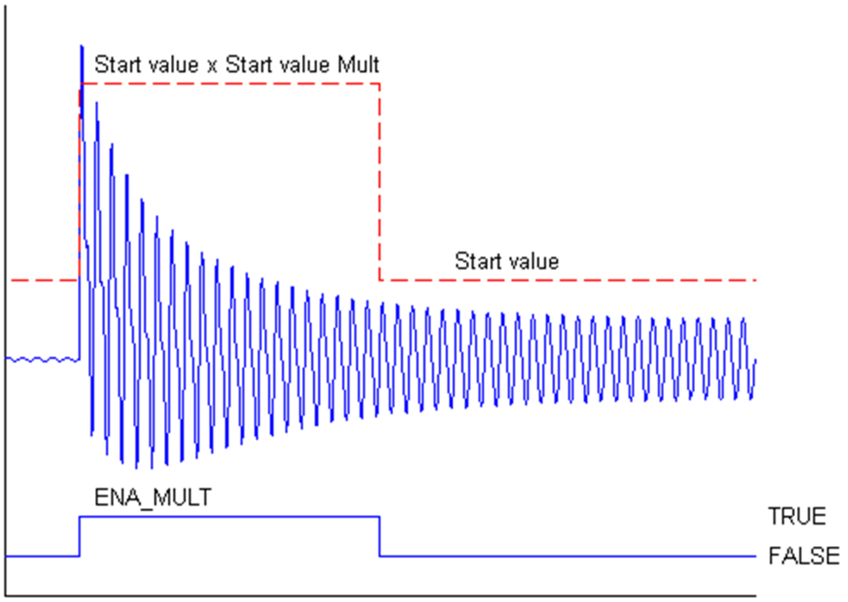



*Figure 17: Start value behavior with* `ENA_MULT` *input activated*

## 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 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 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. 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 user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the General function block features section in this manual.

The timer calculates the start duration value START_DUR which indicates the percentual 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 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 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 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.

## 4.1.2.5 Measuring modes

The function operates on three alternative measurement modes: “RMS”, “DFT” and “Peak-to-Peak” . The measurement mode is selected with the *Measurement mode* setting.

*Table 68: Measurement modes supported by DPHxPDOC stages*

| Measurement mode | Supported measurement modes | |
|---|---|---|
| | DPHLPDOC | DPHHPDOC |
| RMS | x | x |
| DFT | x | x |
| Peak-to-Peak | x | x |

## 4.1.2.6 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 reverse operation area, the *Max reverse angle* setting gives the counterclockwise sector and the *Min reverse angle* setting gives the corresponding clockwise sector, measured from the complement of the *Characteristic angle* setting, for example, 180 degrees phase shift.

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.

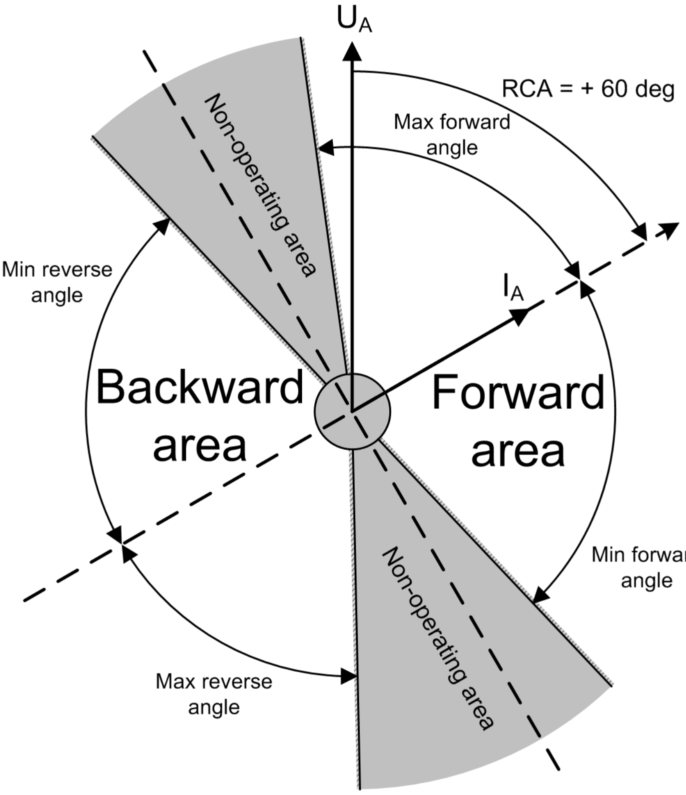



*Figure 18: Configurable operating sectors*

*Table 69: 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 70: 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 71: Equations for calculating angle difference for self polarizing method*

| Faulted phases | Used fault current | Used polarizing voltage | Angle difference |
|---|---|---|---|
| A | $I_A$ | $U_A$ | $ANGLE\_A = \varphi(U_A) - \varphi(I_A) - \varphi_{RCA}$ |
| B | $I_B$ | $U_B$ | $ANGLE\_B = \varphi(U_B) - \varphi(I_B) - \varphi_{RCA}$ |
| C | $I_C$ | $U_C$ | $ANGLE\_C = \varphi(U_C) - \varphi(I_C) - \varphi_{RCA}$ |
| A - B | $\underline{I}_A - \underline{I}_B$ | $U_{AB}$ | $ANGLE\_A = \varphi(U_{AB}) - \varphi(\overline{I_A} - \overline{I_B}) - \varphi_{RCA}$ |
| B - C | $\underline{I}_B - \underline{I}_C$ | $U_{BC}$ | $ANGLE\_B = \varphi(U_{BC}) - \varphi(\overline{I_B} - \overline{I_C}) - \varphi_{RCA}$ |
| C - A | $\underline{I}_C - \underline{I}_A$ | $U_{CA}$ | $ANGLE\_C = \varphi(U_{CA}) - \varphi(\overline{I_C} - \overline{I_A}) - \varphi_{RCA}$ |

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.

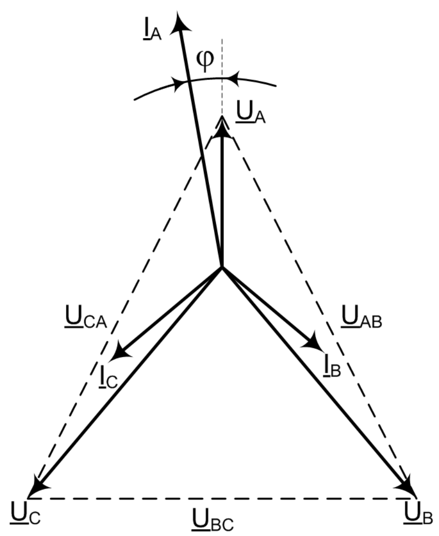



*Figure 19: Single-phase earth fault, phase A*

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.

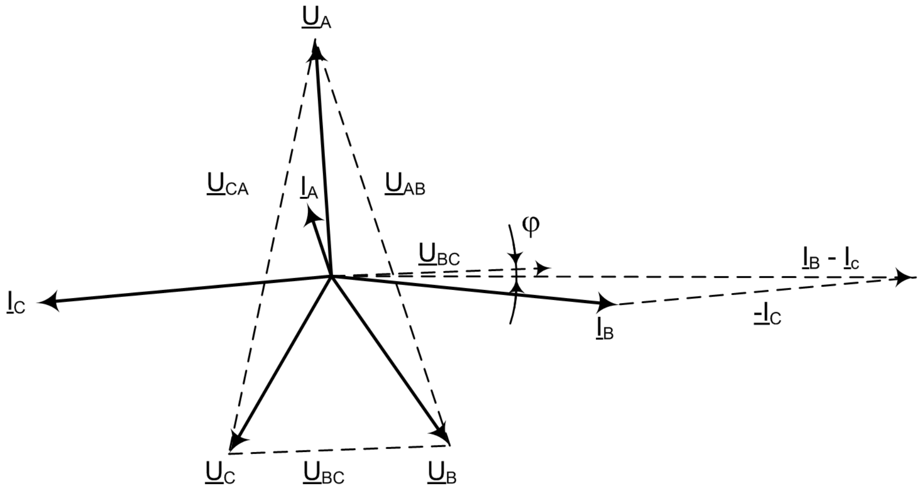



*Figure 20: Two-phase short circuit, short circuit is between phases B and C*

## Cross polarizing as polarizing quantity

*Table 72: Equations for calculating angle difference for cross polarizing method*

| Faulted phases | Used fault current | Used polarizing voltage | Angle difference |
|---|---|---|---|
| A | $I_A$ | $U_{BC}$ | $ANGLE\_A = \varphi(U_{BC}) - \varphi(I_A) - \varphi_{RCA} + 90^o$ |
| B | $I_B$ | $U_{CA}$ | $ANGLE\_B = \varphi(U_{CA}) - \varphi(I_B) - \varphi_{RCA} + 90^o$ |
| C | $I_C$ | $U_{AB}$ | $ANGLE\_C = \varphi(U_{AB}) - \varphi(I_C) - \varphi_{RCA} + 90^o$ |
| A - B | $\underline{I}_A$ - $\underline{I}_B$ | $\underline{U}_{BC}$ - $\underline{U}_{CA}$ | $ANGLE\_A = \varphi(\overline{U_{BC}} - \overline{U_{CA}}) - \varphi(\overline{I_A} - \overline{I_B}) - \varphi_{RCA} + 90^o$ |
| B - C | $\underline{I}_B$ - $\underline{I}_C$ | $\underline{U}_{CA}$ - $\underline{U}_{AB}$ | $ANGLE\_B = \varphi(\overline{U_{CA}} - \overline{U_{AB}}) - \varphi(\overline{I_B} - \overline{I_C}) - \varphi_{RCA} + 90^o$ |
| C - A | $\underline{I}_C$ - $\underline{I}_A$ | $\underline{U}_{AB}$ - $\underline{U}_{BC}$ | $ANGLE\_C = \varphi(\overline{U_{AB}} - \overline{U_{BC}}) - \varphi(\overline{I_C} - \overline{I_A}) - \varphi_{RCA} + 90^o$ |

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.

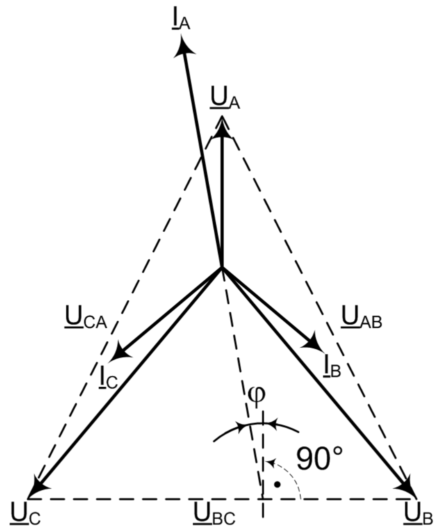



*Figure 21: Single-phase earth fault, phase A*

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.

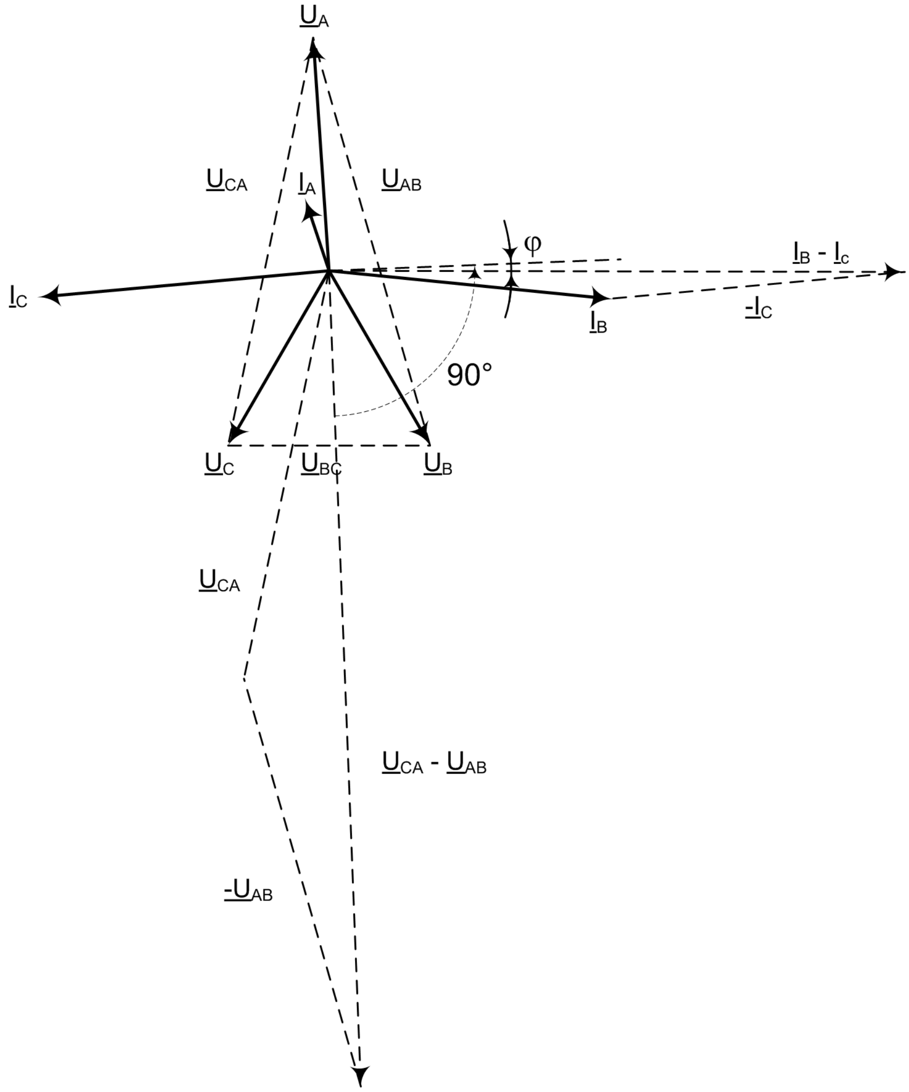



*Figure 22: Two-phase short circuit, short circuit is between phases B and C*

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:

$$ANGLE\_X = \varphi(-\overline{U2}) - \varphi(\overline{I2}) - \varphi_{RCA}$$

(Equation 1)

This means that the actuating polarizing quantity is -U2.

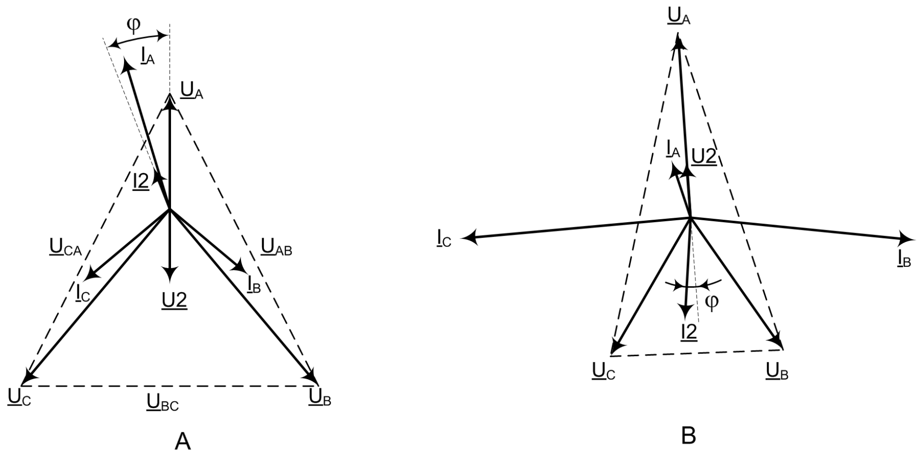



*Figure 23: Phasors in a single-phase earth fault, phases A-N, and two-phase short circuit, phases B and C, when the actuating polarizing quantity is the negative sequence voltage -U2*

## Positive sequence voltage as polarizing quantity

*Table 73: Equations for calculating angle difference for positive sequence quantity polarizing method*

| Faulted phases | Used fault current | Used polarizing voltage | Angle difference |
|---|---|---|---|
| A | $I_A$ | U1 | $ANGLE\_A = \varphi(U1) - \varphi(I_A) - \varphi_{RCA}$ |
| B | $I_B$ | U1 | $ANGLE\_B = \varphi(U1) - \varphi(I_B) - \varphi_{RCA} - 120^{\circ}$ |
| C | $I_C$ | U1 | $ANGLE\_C = \varphi(U1) - \varphi(I_C) - \varphi_{RCA} + 120^{\circ}$ |
| A - B | $I_A$ - $I_B$ | U1 | $ANGLE\_A = \varphi(U1) - \varphi(\overline{I_A} - \overline{I_B}) - \varphi_{RCA} + 30^{\circ}$ |
| B - C | $I_B$ - $I_C$ | U1 | $ANGLE\_B = \varphi(U1) - \varphi(\overline{I_B} - \overline{I_C}) - \varphi_{RCA} - 90^{\circ}$ |
| C - A | $I_C$ - $I_A$ | U1 | $ANGLE\_C = \varphi(U1) - \varphi(\overline{I_C} - \overline{I_A}) - \varphi_{RCA} + 150^{\circ}$ |

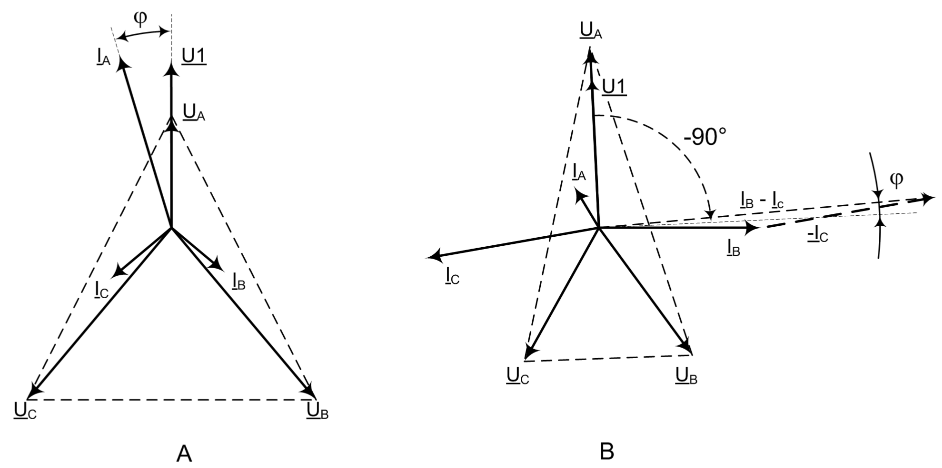



*Figure 24: Phasors in a single-phase earth fault, phase A to ground, and two-phase short circuit, phases B-C are short circuited, when the polarizing quantity is the positive sequence voltage U1*

## Network rotating direction

Typically, the network rotating direction is counter-clockwise and defined as "ABC". If the network rotating direction is reversed, meaning clockwise, that is, "ACB", the equations for calculating the angle difference needs to be changed. The network rotating direction is defined with a system parameter *Phase rotation*. The change in the network rotating direction affects the phase-to-phase voltages polarization method where the calculated angle difference needs to be rotated 180 degrees. Also, when the sequence components are used, which are, the positive sequence voltage or negative sequence voltage components, the calculation of the components are affected but the angle difference calculation remains the same. When the phase-to-ground voltages are used as the polarizing method, the network rotating direction change has no effect on the direction calculation.

The network rotating direction is set in the IED using the parameter in the HMI menu: **Configuration/System/Phase rotation**. The default parameter value is "ABC".

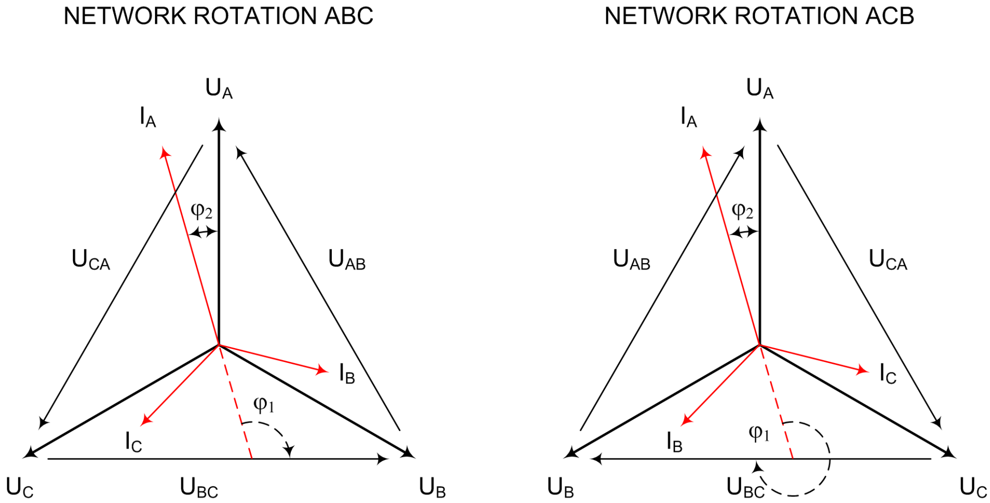



*Figure 25: Examples of network rotating direction*

## 4.1.2.7 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, the phase overcurrent 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 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 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 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.

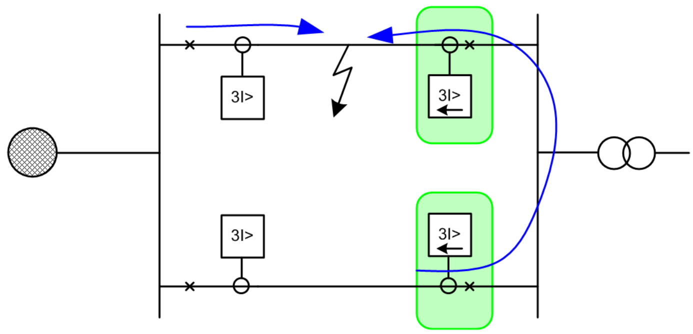



*Figure 26: Overcurrent protection of parallel lines using directional relays*

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.

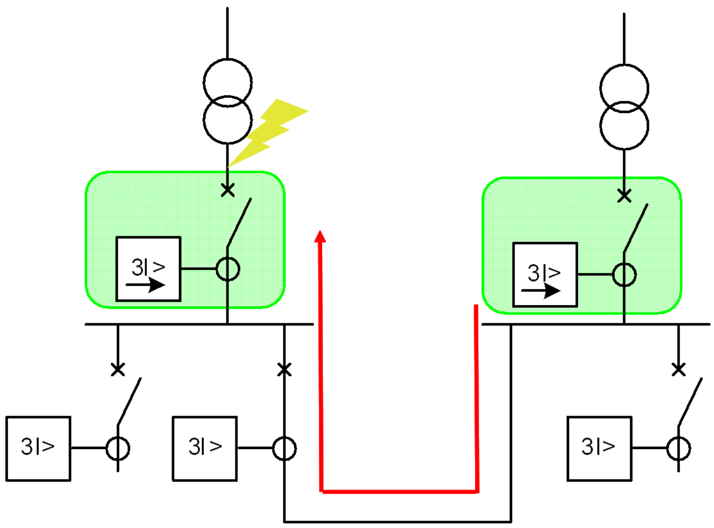



*Figure 27: Overcurrent protection of parallel operating transformers*

### 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 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.

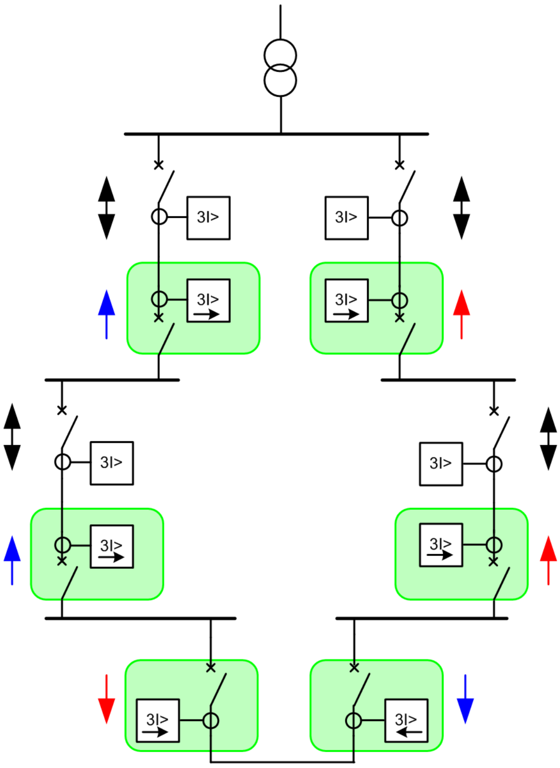



*Figure 28: Closed ring network topology where feeding lines are protected with directional overcurrent relays*

## 4.1.2.8 Signals

### Input signals

*Table 74: 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 |
| Table continues on next page | | | |

| Name | Type | Default | Description |
|---|---|---|---|
| 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 | Enable signal for current multiplier |

## Input signals

*Table 75: 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 | Enable signal for current multiplier |

*Table 76: DPHLPDOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

*Table 77: DPHHPDOC Output signals*

| Name | Type | Description |
|---|---|---|
| START | BOOLEAN | Start |
| OPERATE | BOOLEAN | Operate |

## 4.1.2.9 Settings

*Table 78: DPHLPDOC Group settings*

| 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 | | 0.05 | 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.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Programmable<br>18=RI type<br>19=RD type | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset | | | 1=Immediate | Selection of reset curve type |
| Voltage Mem time | 0...3000 | ms | 1 | 40 | Voltage memory time |
| Directional mode | 1=Non-directional<br>2=Forward<br>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 |
| Pol quantity | -2=Pos. seq. volt.<br>1=Self pol<br>4=Neg. seq. volt.<br>5=Cross pol | | | 5=Cross pol | Reference quantity used to determine fault direction |

*Table 79: DPHLPDOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 | | | 1=1 out of 3 | Number of phases required for operate activation |
| 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<br>2=DFT<br>3=Peak-to-Peak | | | 2=DFT | Selects used measurement mode |
| Curve parameter A | 0.0086...120.0000 | | | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120 | | | 0.1217 | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00 | | | 2.00 | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00 | | | 29.10 | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0 | | | 1.0 | Parameter E for customer programmable curve |
| Allow Non Dir | 0=False<br>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 80: DPHHPDOC Group settings*

| 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<br>2=Forward<br>3=Reverse | | | 2=Forward | Directional mode |
| Time multiplier | 0.05...15.00 | | 0.05 | 1.00 | Time multiplier in IEC/ANSI IDMT curves |
| Operating curve type | 1=ANSI Ext. inv.<br>3=ANSI Norm. inv.<br>5=ANSI Def. Time<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>12=IEC Ext. inv.<br>15=IEC Def. Time<br>17=Programmable | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset | | | 1=Immediate | Selection of reset curve type |
| Operate delay time | 40...200000 | ms | 10 | 40 | Operate delay time |
| Characteristic angle | -179...180 | deg | 1 | 60 | Characteristic angle |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| 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 |
| Voltage Mem time | 0...3000 | ms | 1 | 40 | Voltage memory time |
| Pol quantity | -2=Pos. seq. volt.<br>1=Self pol<br>4=Neg. seq. volt.<br>5=Cross pol | | | 5=Cross pol | Reference quantity used to determine fault direction |

*Table 81: DPHHPDOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| 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<br>1=True | | | 0=False | Allows prot activation as non-dir when dir info is invalid |
| Measurement mode | 1=RMS<br>2=DFT<br>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 |
| Curve parameter A | 0.0086...120.0000 | | | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120 | | | 0.1217 | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00 | | | 2.00 | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00 | | | 29.10 | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0 | | | 1.0 | Parameter E for customer programmable curve |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 | | | 1=1 out of 3 | Number of phases required for operate activation |

### 4.1.2.10 Monitored data

*Table 82: 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<br>1=forward<br>2=backward<br>3=both | | Detected fault direction |
| DIRECTION | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Direction information |
| DIR_A | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Direction phase A |
| DIR_B | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Direction phase B |
| DIR_C | Enum | 0=unknown<br>1=forward<br>2=backward<br>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 |
| DPHLPDOC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

*Table 83: 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<br>1=forward<br>2=backward<br>3=both | | Detected fault direction |
| DIRECTION | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Direction information |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| DIR_A | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Direction phase A |
| DIR_B | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Direction phase B |
| DIR_C | Enum | 0=unknown<br>1=forward<br>2=backward<br>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 |
| DPHHPDOC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 4.1.2.11 Technical data

*Table 84: DPHxPDOC Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the current/ voltage measured: $f_n$ ±2Hz | | |
| | DPHLPDOC | Current:<br>±1.5% of the set value or ±0.002 x $I_n$<br>Voltage:<br>±1.5% of the set value or ±0.002 x $U_n$<br>Phase angle:<br>±2° | | |
| | DPHHPDOC | Current:<br>±1.5% of the set value or ±0.002 x $I_n$ (at currents in the range of 0.1…10 x $I_n$)<br>±5.0% of the set value (at currents in the range of 10…40 x $I_n$)<br>Voltage:<br>±1.5% of the set value or ±0.002 x $U_n$<br>Phase angle:<br>±2° | | |
| Start time[1)2)] | | Minimum | Typical | Maximum |
| | $I_{Fault}$ = 2.0 x set *Start value* | 37 ms | 40 ms | 42 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 0.96 | | |
| Retardation time | | < 35 ms | | |

Table continues on next page

| 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 x $f_n$, where n = 2, 3, 4, 5,… |

1) *Measurement mode* and *Pol quantity* = default, current before fault = 0.0 x $I_n$, voltage before fault = 1.0 x $U_n$, $f_n$ = 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 x $I_n$, *Start value* multiples in range of 1.5 to 20

## 4.1.3 Three-phase thermal overload protection for overhead lines and cables T1PTTR

### 4.1.3.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Three-phase thermal overload protection for overhead lines and cables | T1PTTR | 3Ith> | 49F |

### 4.1.3.2 Function block

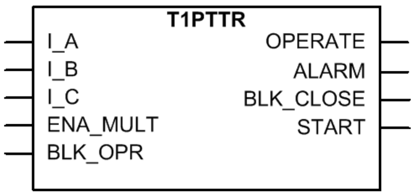



*Figure 29: Function block symbol*

### 4.1.3.3 Functionality

The increased utilization of power systems closer to the thermal limits has generated a need for a thermal overload function also for power lines.

A thermal overload is in some cases not detected by other protection functions, and the introduction of the thermal overload function T1PTTR allows the protected circuit to operate closer to the thermal limits.

An alarm level gives an early warning to allow operators to take action before the line trips. The early warning is based on the three-phase current measuring function using a thermal model with first order thermal loss with the settable time constant. If the temperature rise continues the function will operate based on the thermal model of the line.

Re-energizing of the line after the thermal overload operation can be inhibited during the time the cooling of the line is in progress. The cooling of the line is estimated by the thermal model.

### 4.1.3.4 Operation principle

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

The operation of three-phase thermal protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

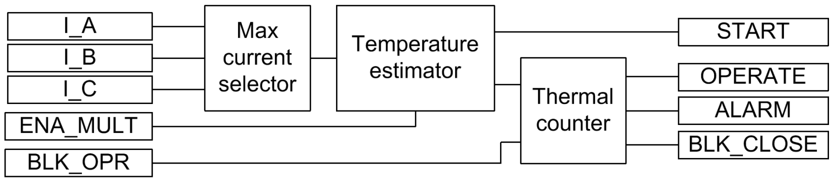



*Figure 30: Functional module diagram. I_A, I_B and I_C represent phase currents.*

#### Max current selector

The sampled analogue phase currents are pre-processed and the RMS value of each phase current is derived for each phase current. These phase current values are fed to the function.

The max current selector of the function continuously checks the highest phase current value. The selector reports the highest value to the temperature estimator.

#### Temperature estimator

From the largest of the three-phase currents, a final temperature is calculated according to the expression:

$$\Theta_{final} = \left( \frac{I}{I_{ref}} \right)^2 \cdot T_{ref}$$

(Equation 2)

| | |
|---|---|
| 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 estimation, and the ambient temperature value used in the calculation is also available in the monitored data as TEMP_AMB. 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 3)

| | |
|---|---|
| $\Theta_n$ | calculated present temperature |
| $\Theta_{n-1}$ | calculated temperature at previous time step |
| $\Theta_{final}$ | calculated final temperature with actual current |
| $\Delta t$ | time step between calculation of actual temperature |
| $\tau$ | thermal time constant for the protected device (line or cable), set *Time constant* |

The actual temperature of the protected component (line or cable) is calculated by adding the ambient temperature to the calculated temperature, as shown above. The ambient temperature can be given a constant value. The calculated component temperature can be monitored as it is exported from the function as a real figure.

When the component temperature reaches the set alarm level *Alarm value*, the output signal ALARM is set. When the component temperature reaches the set trip level *Maximum temperature*, the OPERATE output is activated. The OPERATE signal pulse length is fixed to 100 ms

There is also a calculation of the present time to operation with the present current. This 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 4)

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 2 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 5)

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 *Env temperature Set* setting is used to define the ambient temperature.

The temperature calculation is initiated from the value defined with the *Initial temperature* setting parameter. This is done in case the IED is powered up, the function is turned "Off" and back "On" or reset through the Clear menu. The temperature is also stored in the nonvolatile memory and restored in case the IED is restarted.

The thermal time constant of the protected circuit is given in minutes with the *Time constant* setting. Please see cable manufacturers manuals for further details.

### 4.1.3.5 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.
- In cables the insulation can be damaged as a consequence of overtemperature, and therefore phase-to-phase or phase-to-earth faults can occur.

In stressed situations in the power system, the lines and cables may be required to be overloaded for a limited time. This should be done without any risk for the above-mentioned risks.

The thermal overload protection provides information that makes temporary overloading of cables and lines possible. The thermal overload protection estimates the conductor temperature continuously. This estimation is made by using a thermal model of the line/cable that is based on the current measurement.

If the temperature of the protected object reaches a set warning level, a signal is given to the operator. This enables actions in the power system to be done before dangerous temperatures are reached. If the temperature continues to increase to the maximum allowed temperature value, the protection initiates a trip of the protected line.

### 4.1.3.6 Signals

*Table 85: T1PTTR 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 |
| ENA_MULT | BOOLEAN | 0=False | Enable Current multiplier |
| BLK_OPR | BOOLEAN | 0=False | Block signal for operate outputs |

*Table 86: T1PTTR Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |
| ALARM | BOOLEAN | Thermal Alarm |
| BLK_CLOSE | BOOLEAN | Thermal overload indicator. To inhibite reclose. |

### 4.1.3.7 Settings

*Table 87: T1PTTR Group settings*

| 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 multiplier | 1...5 | | 1 | 1 | Current multiplier when function is used for parallel lines |
| 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 |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| 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 88: T1PTTR Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Initial temperature | -50.0...100.0 | °C | 0.1 | 0.0 | Temperature raise above ambient temperature at startup |

### 4.1.3.8 Monitored data

*Table 89: 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...600000 | ms | Estimated time to operate |
| T_ENA_CLOSE | INT32 | 0...600000 | ms | Estimated time to deactivate BLK_CLOSE |
| TEMP_AMB | FLOAT32 | -99...999 | °C | The ambient temperature used in the calculation |
| T1PTTR | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 4.1.3.9 Technical data

*Table 90: T1PTTR Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | 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 |

1) Overload current > 1.2 x Operate level temperature

## 4.1.3.10 Technical revision history

*Table 91: T1PTTR Technical revision history*

| Technical revision | Change |
|---|---|
| C | Removed the *Sensor available* setting parameter |

# 4.1.4 Three-phase thermal overload protection, two time constants T2PTTR

## 4.1.4.1 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 | 49T |

## 4.1.4.2 Function block

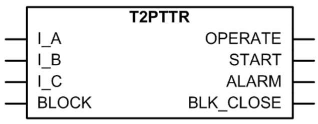



*Figure 31: Function block symbol*

## 4.1.4.3 Functionality

The three-phase thermal overload, two time constant protection function T2PTTR protects the transformer mainly from short-time overloads. The transformer is protected from long-time overloads with the oil temperature detector included in its equipment.

The alarm signal gives an early warning to allow the operators to take action before the transformer trips. The early warning is based on the three-phase current measuring function using a thermal model with two settable time constants. If the temperature rise continues, T2PTTR operates based on the thermal model of the transformer.

After a thermal overload operation, the re-energizing of the transformer is inhibited during the transformer cooling time. The transformer cooling is estimated with a thermal model.

## 4.1.4.4 Operation principle

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

The operation of three-phase thermal overload, 2 time constant protection can be described using a module diagram. All the blocks in the diagram are explained in the next sections.

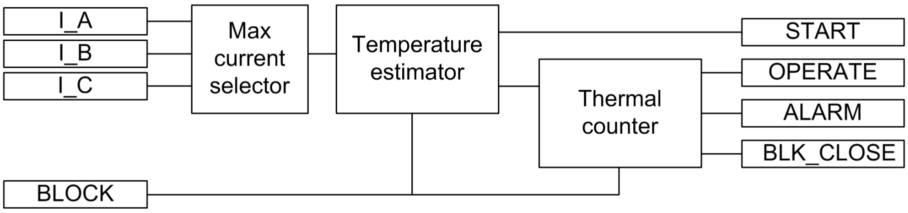



*Figure 32: Functional module diagram*

### Max current selector

The sampled analog phase currents are pre-processed and the TRMS value of the phase current is derived for each phase current. These phase current values are fed to the function. The max current selector of T2PTTR checks continuously the highest phase current value and reports the highest value to the thermal counter.

### Temperature estimator

The final temperature 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 6)

| | |
|---|---|
| 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 value. 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 7)

| | |
|---|---|
| ΔΘ | calculated temperature rise (°C) in transformer |
| I | measured phase current with the highest TRMS value |
| Iref | the set value of the *Current reference* setting (rated current of the protected object) |
| Tref | the set value of the *Temperature rise* (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 calculation of actual temperature |
| $\tau_1$ | the set value of the *Short time constant* (the short heating / cooling time constant) |
| $\tau_2$ | the set value of the *Long time constant* (the long heating / cooling time constant) |

The warming and cooling following the two time-constant thermal curve is a characteristic of transformers. The thermal time constants of the protected transformer are given in seconds with the *Short time constant* and *Long time constant* settings. The *Short time constant* setting describes the warming of the transformer with respect to windings. The *Long time constant* setting describes the warming of the transformer with respect to the oil. Using the two time-constant model, the IED is able to follow both fast and slow changes in the temperature of the protected object.

The *Weighting factor p* setting is the weighting factor between *Short time constant* $\tau_1$ and *Long time constant* $\tau_2$. 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.

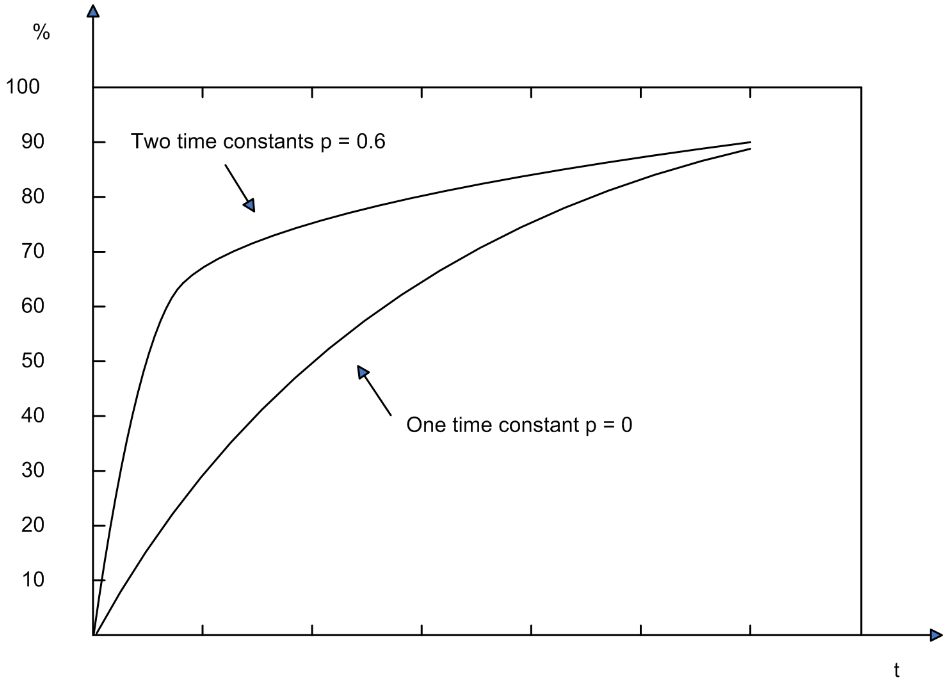



*Figure 33: Effect of the Weighting factor p factor and the difference between the two time-constant and one time-constant models*

The actual temperature of the transformer is calculated by adding the ambient temperature to the calculated temperature.

$$\Theta = \Delta\Theta + \Theta_{amb}$$

(Equation 8)

| | |
|---|---|
| $\Theta$ | temperature in transformer (°C) |
| $\Delta\Theta$ | calculated temperature rise (°C) in transformer |
| $\Theta_{amb}$ | set *Env temperature Set* |

The *Env temperature Set* setting is used to define the ambient temperature.

The temperature calculation is initiated from the value defined with the *Initial temperature* setting. This is done when the IED is powered up, the function is turned off and back on or reset through the Clear menu. The temperature is stored in a nonvolatile memory and restored if the IED is restarted.

The *Max temperature* setting defines the maximum temperature of the transformer in degrees Celsius (°C). The value of the *Max temperature* setting is usually given by transformer manufacturers. The actual alarm, operating and lockout temperatures for T2PTTR are given as 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. The `T_OPERATE` is only calculated if the final temperature is calculated to be above the operation temperature. The value is available through the Monitored data view.

After operating, due to the thermal overload protection function, there can be a lockout to reconnect the tripped circuit. 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 through the Monitored data view.

### 4.1.4.5 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 age 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 92: 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 |

Table continues on next page

| Single time constant (min) | *Short time constant* (min) | *Long time constant* (min) | *Weighting factor p* |
|---|---|---|---|
| 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.

### 4.1.4.6 Signals

*Table 93: 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 |

*Table 94: 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. |

### 4.1.4.7 Settings

*Table 95: T2PTTR Group settings*

| 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 | 78.0 | End temperature rise above ambient |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| 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 |
| Reclose temperature | 40.0...100.0 | % | 0.1 | 60.0 | Temperature for reset of block reclose after operate |
| Short time constant | 6...60000 | | 1 | 450 | Short time constant in seconds |
| Long time constant | 60...60000 | | 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 96: T2PTTR Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Initial temperature | 0.0...100.0 | % | 0.1 | 80.0 | Initial temperature, percent value |

## 4.1.4.8 Monitored data

*Table 97: 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 in seconds |
| T_ENA_CLOSE | INT32 | 0...60000 | s | Estimated time to deactivate BLK_CLOSE in seconds |
| TEMP_AMB | FLOAT32 | -99...999 | °C | The ambient temperature used in the calculation |
| T2PTTR | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.1.4.9 Technical data

*Table 98: T2PTTR Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | 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 |

1) Overload current > 1.2 x Operate level temperature

## 4.1.5 Motor stall protection JAMPTOC

### 4.1.5.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Motor stall protection | JAMPTOC | Ist> | 51LR |

### 4.1.5.2 Function block

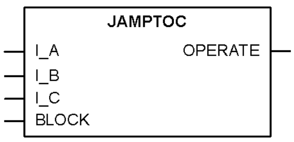



*Figure 34: Function block symbol*

### 4.1.5.3 Functionality

The stalled motor protection JAMPTOC is used for protecting the motor in stall or mechanical jam situations during the running state.

When the motor is started, a separate function is used for the startup protection and JAMPTOC is normally blocked during the startup period. When the motor has passed the starting phase, JAMPTOC monitors the magnitude of phase currents. The function starts when the measured current exceeds the breakdown torque level, that is, above the set limit. The operation characteristic is definite time.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

## 4.1.5.4 Operation principle

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

The operation of the stalled motor protection can be described using a module diagram. All the blocks in the diagram are explained in the next sections.

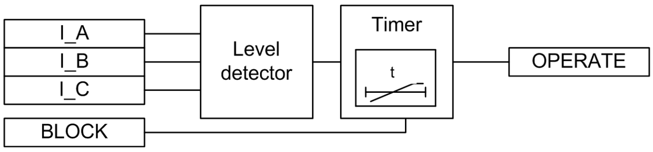



*Figure 35: Functional module diagram*

### 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 operate time is still counting, the reset timer is activated. If the drop-off time exceeds the set *Reset delay time*, the operate timer is reset.

The timer calculates the start duration value START_DUR which indicates the percentual ratio of the start situation and the set operate time. The value is available through the Monitored data view.

## 4.1.5.5 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.

### 4.1.5.6 Signals

*Table 99: 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 100: JAMPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |

### 4.1.5.7 Settings

*Table 101: JAMPTOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>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 |
| Reset delay time | 0...60000 | ms | 1 | 100 | Reset delay time |

### 4.1.5.8 Monitored data

*Table 102: JAMPTOC Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| START | BOOLEAN | 0=False<br>1=True | | Start |
| START_DUR | FLOAT32 | 0.00...100.00 | % | Ratio of start time / operate time |
| JAMPTOC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.1.5.9 Technical data

*Table 103: JAMPTOC Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: fn ±2Hz |
| | ±1.5% of the set value or ±0.002 x $I_n$ |
| Reset time | < 40 ms |
| Reset ratio | Typical 0.96 |
| Retardation time | < 35 ms |
| Operate time accuracy in definite time mode | ±1.0% of the set value or ±20 ms |

## 4.1.6 Loss of load protection LOFLPTUC

### 4.1.6.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Loss of load protection | LOFLPTUC | 3I< | 37 |

### 4.1.6.2 Function block

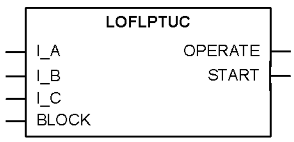



*Figure 36: Function block symbol*

### 4.1.6.3 Functionality

The loss of load protection LOFLPTUC is used to detect a sudden load loss which is considered as a fault condition.

LOFLPTUC starts when the current is less than the set limit. It operates with the definite time (DT) characteristics, which means that the function operates after a predefined operate time and resets when the fault current disappears.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

### 4.1.6.4 Operation principle

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

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

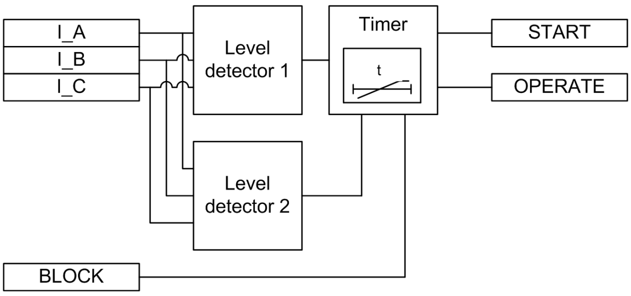



*Figure 37: Functional module diagram*

#### 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 percentual ratio of the start situation and the set operate time. The value is available through the Monitored data view.

The BLOCK signal blocks the operation of the function and resets the timer.

### 4.1.6.5 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.

### 4.1.6.6 Signals

*Table 104: 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 105: LOFLPTUC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

#### 4.1.6.7 Settings

*Table 106: LOFLPTUC Group settings*

| 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 107: LOFLPTUC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |

#### 4.1.6.8 Monitored data

*Table 108: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

#### 4.1.6.9 Technical data

*Table 109: LOFLPTUC Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | ±1.5% of the set value or ±0.002 x $I_n$ |
| Start time | Typical 300 ms |
| Reset time | < 40 ms |
| Reset ratio | Typical 0.96 |
| Retardation time | < 35 ms |
| Operate time accuracy in definite time mode | ±1.0% of the set value or ±20 ms |

## 4.1.7 Three-phase thermal overload protection for motors MPTTR

### 4.1.7.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Three-phase thermal overload protection for motors | MPTTR | 3Ith>M | 49M |

### 4.1.7.2 Function block

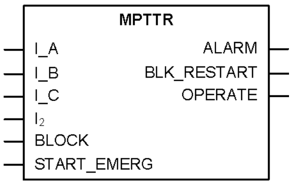



*Figure 38: Function block symbol*

### 4.1.7.3 Functionality

The motor thermal overload protection function MPTTR protects the electric motors from overheating. MPTTR models the thermal behavior of motor on the basis of the measured load current and disconnects the motor when the thermal content reaches 100 percent. The thermal overload conditions are the most often encountered abnormal conditions in industrial motor applications. The thermal overload conditions are typically the result of an abnormal rise in the motor running current, which produces an increase in the thermal dissipation of the motor and temperature or reduces cooling. MPTTR prevents an electric motor from drawing excessive current and overheating, which causes the premature insulation failures of the windings and, in worst cases, burning out of the motors.

### 4.1.7.4 Operation principle

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

The operation of the motor thermal overload protection function can be described using a module diagram. All the blocks in the diagram are explained in the next sections.

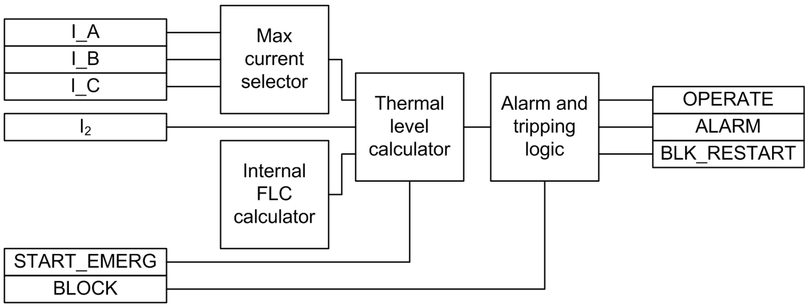



*Figure 39: Functional module diagram*

### Max current selector

The max current selector selects the highest phase current and reports it to the thermal level calculator.

### Internal FLC calculator

The 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, it appears that the motor is loaded beyond its rating. 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 decides 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, internal FLC is calculated based on the ambient temperature taken as input through the *Env temperature Set* setting.

*Table 110: 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 through the monitored data view from the TEMP_AMB output. The activation of the BLOCK input does not affect the TEMP_AMB 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 phase current level. The equations used for the heating up calculations are:

$$\theta_B = \left[ \left( \frac{I}{k \times I_r} \right)^2 + K_2 \times \left( \frac{I_2}{k \times I_r} \right)^2 \right] \times \left( 1 - e^{-t/\tau} \right) \times p\%$$

(Equation 9)

$$\theta_A = \left[ \left( \frac{I}{k \times I_r} \right)^2 + K_2 \times \left( \frac{I_2}{k \times I_r} \right)^2 \right] \times \left( 1 - e^{-t/\tau} \right) \times 100\%$$

(Equation 10)

| | |
|---|---|
| I | TRMS value of the measured max of phase currents |
| $I_r$ | set *Rated current*, FLC or internal FLC |
| $I_2$ | measured negative sequence current |
| k | set value of *Overload factor* |
| $K_2$ | set value of *Negative Seq factor* |
| p | set value of *Weighting factor* |
| τ | time constant |

The equation $\theta_B$ is used when the values of all the phase currents are below the overload limit, that is, k x $I_r$. The equation $\theta_A$ 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 $\theta_B$ in background, and when the overload ends the thermal level is brought linearly from $\theta_A$ to $\theta_B$ 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 11)

$\theta_{02}$ initial thermal level when cooling begins

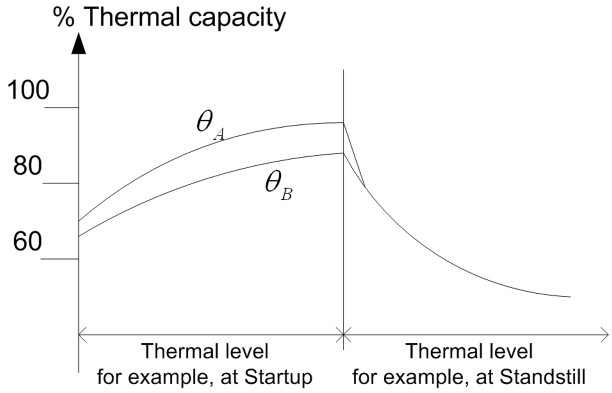



*Figure 40: Thermal behavior*

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 optimal thermal load, 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 111: 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 $\theta_A$ and $\theta_B$.

The thermal level at the powerup of the IED 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 IED 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 startup condition of a motor and at the end of the startup condition is available through 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 startup is available through the monitored data view from the T_ENARESTART output. The T_ENARESTART output estimates the time for the BLK_RESTAR deactivation considering as if the motor is stopped.

When the value of the emergency start signal START_EMERG increases, the thermal level is set to a value below the thermal restart inhibit level. This allows at least one motor startup, even though the thermal level has exceeded the restart inhibit level.

When the thermal content reaches 100 percent, the OPERATE output is activated. The OPERATE output is deactivated when the value of the measured current falls below 12 percent of *Rated current* or the thermal content drops below 100 percent.

The activation of the BLOCK input blocks the ALARM, BLK_RESTART and OPERATE outputs.

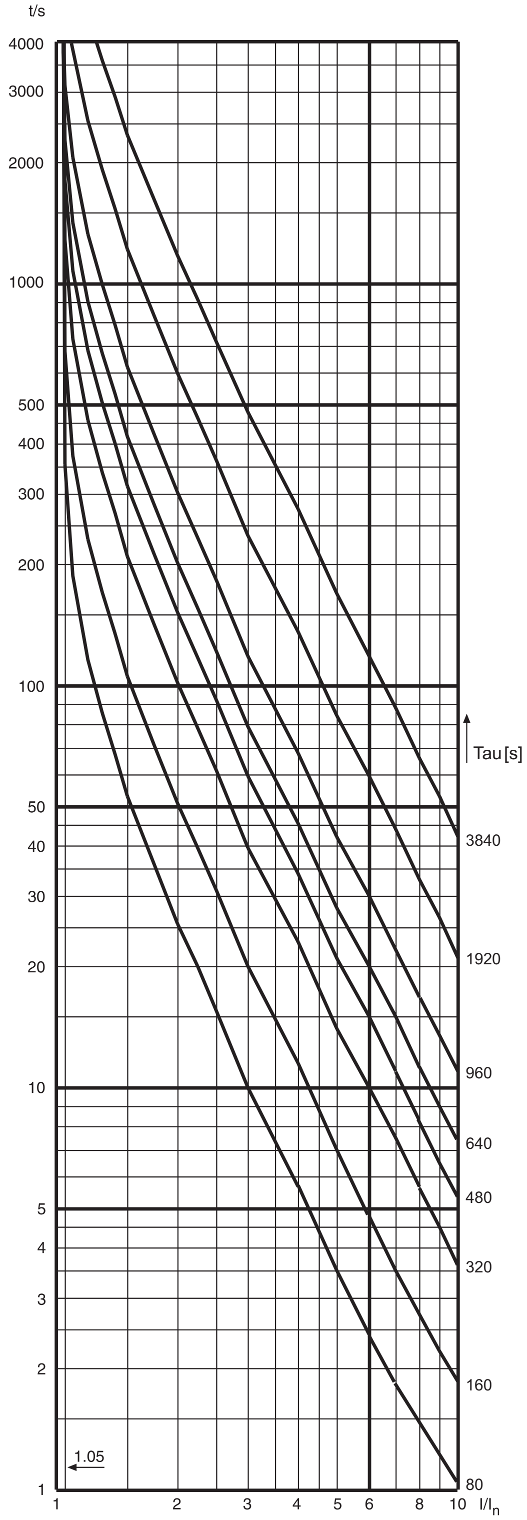



*Figure 41: Trip curves when no prior load and p=20...100 %. Overload factor = 1.05.*

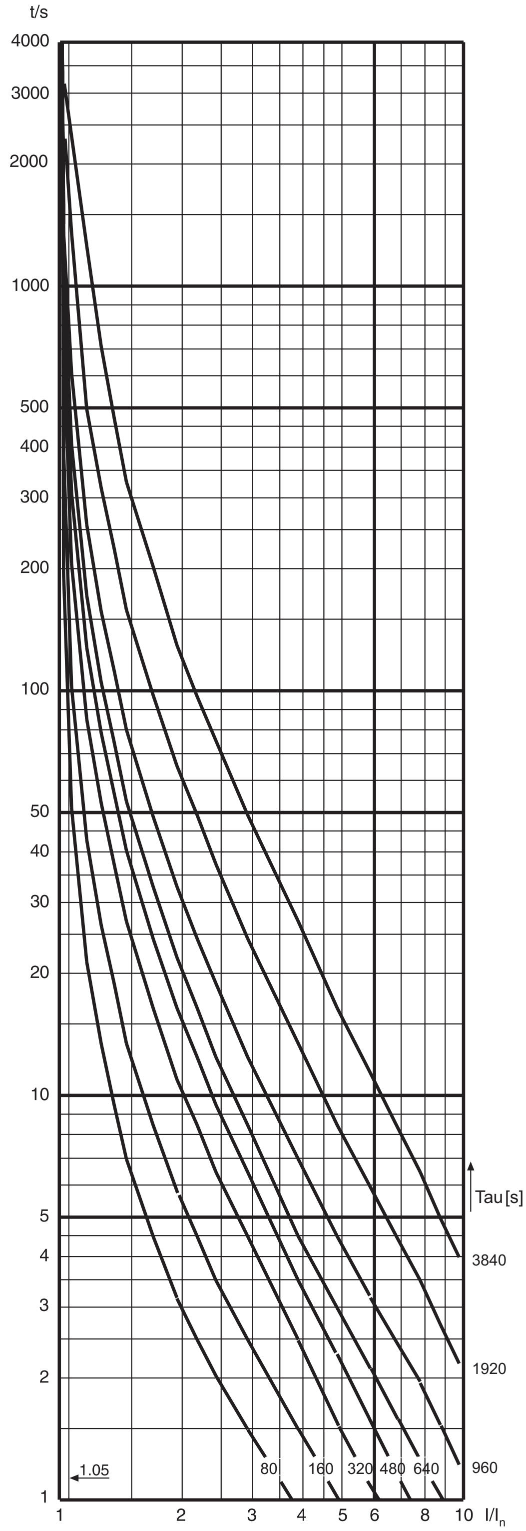



*Figure 42: Trip curves at prior load 1 x FLC and p=100 %, Overload factor = 1.05.*

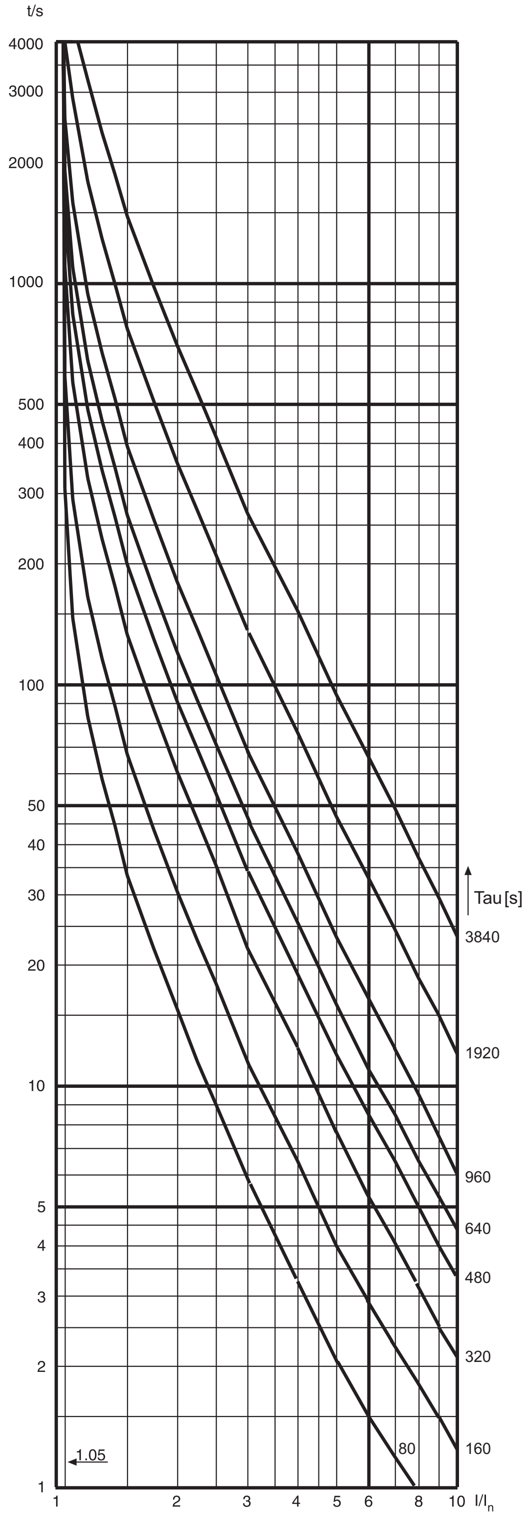



*Figure 43: Trip curves at prior load 1 x FLC and p=50 %. Overload factor = 1.05.*

## 4.1.7.5 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 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.

The "*Weighting factor p* = to 100 percent", it produces a pure single time constant thermal unit, which is used for application with the cables. As presented in Figure 44, the hot curve with the value of "*Weighting factor p* = 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* = 50 percent", the IED notifies a 45 to 50 percent thermal capacity use at full load.

For direct-on-line started motors with hot spot tendencies, the value of *Weighting factor p* is typically set to "50 percent", which will properly distinguish between short-time thermal stress and long-time thermal history. After a short period of thermal stress, for example a motor startup, the thermal level starts to decrease quite sharply, simulating the leveling out of the hot spots. Consequently, the probability of successive allowed startups increases.

When protecting the objects without hot spot tendencies, for example motors started with soft starters, and cables, the value of *Weighting factor p* is set to "100 percent". With the value of *Weighting factor p* set to "100 percent", the thermal level decreases slowly after a heavy load condition. This makes the protection suitable for applications where no hot spots are expected. Only in special cases where the thermal overload protection is required to follow the characteristics of the object to be protected more closely and the thermal capacity of the object is very well known, a value between "50" and "100 percent" is required.

For motor applications where, for example, two hot starts are allowed instead of three cold starts, the value of the setting "*Weighting factor p*= 40 percent" has proved 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 sufficiently been taken into account.

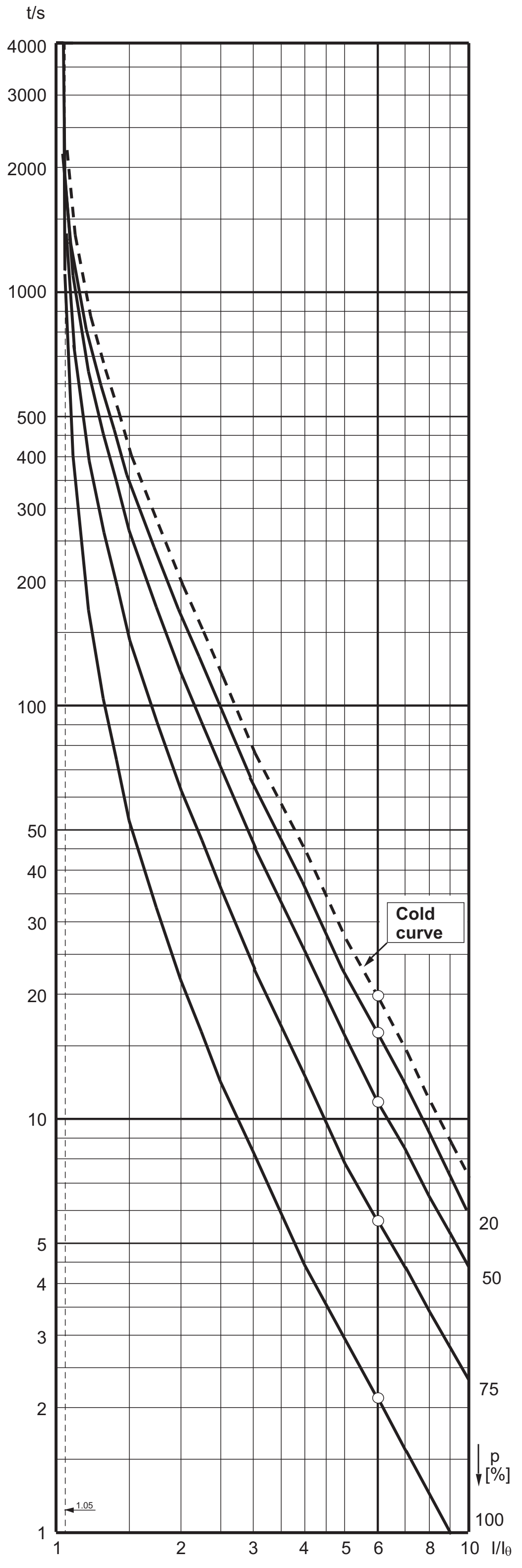



*Figure 44: The influence of Weighting factor p at prior load 1xFLC, timeconstant = 640 sec, and Overload factor = 1.05*

### Setting the overload factor

The value of the *Overload factor* allows utilization of the entire thermal capacity of the motor. Typically, value 1.05 is used. The value of the *Overload factor* should be high for a motor to take higher overload without tripping.

### Setting the negative sequence factor

During the unbalance condition, the symmetry of the stator currents is disturbed and a counter-rotating negative phase sequence (NPS) current is set up. An increased stator current causes additional heating in the stator and the NPS 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 12)

$R_{R2}$ rotor positive sequence resistance

$R_{R1}$ rotor negative sequence resistance

A conservative estimate for the setting can be calculated:

$$Negative\,Seq\;factor = \frac{175}{I_{LR}^2}$$

$I_{LR}$ locked rotor current (multiple of set *Rated current*). The same as the startup current at the beginning of the motor startup.

For example, if the rated current of a motor is 230 A, startup current is 5.7 x $I_r$,

$$Negative\,Seq\;factor = \frac{175}{5.7^2} = 5.4$$

### Setting the thermal restart level

The restart disable level can be calculated as follows:

$$\theta_i = 100\% - \left( \frac{startup\ time\ of\ the\ motor}{operate\ time\ when\ no\ prior\ load} \times 100\% + margin \right)$$

(Equation 13)

For instance, if the startup time of the motor is 11 seconds and the calculated operate time of the thermal protection stage with no prior load is 25 seconds, one motor startup uses 11/25 ≈ 45 percent of the thermal capacity of the motor. Therefore, the restart disable level must be set to below 100 percent - 45 percent = 55 percent, for example to 50 percent (100 percent - (45 percent + margin), where margin is 5 percent).

### Setting the thermal alarm level

Tripping due to high overload is avoided by reducing the load of the motor on a prior alarm.

The value of *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.

## 4.1.7.6 Signals

*Table 112: 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 |

*Table 113: MPTTR Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| ALARM | BOOLEAN | Thermal Alarm |
| BLK_RESTART | BOOLEAN | Thermal overload indicator, to inhibit restart |

### 4.1.7.7 Settings

*Table 114: MPTTR Group settings*

| 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 |
| Time constant start | 80...4000 | s | 1 | 320 | Motor time constant during the start of motor |
| Time constant stop | 80...8000 | s | 1 | 500 | Motor time constant during the standstill condition of motor |
| Env temperature mode | 1=FLC Only<br>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 115: MPTTR Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Rated current | 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 |

### 4.1.7.8 Monitored data

*Table 116: 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 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |
| Therm-Lev | FLOAT32 | 0.00...9.99 | | Thermal level of protected object (1.00 is the operate level) |

### 4.1.7.9 Technical data

*Table 117: MPTTR Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | 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 |

1) Overload current > 1.2 x 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 | I0> | 51N-1 |
| Non-directional earth-fault protection - High stage | EFHPTOC | I0>> | 51N-2 |
| Non-directional earth-fault protection - Instantaneous stage | EFIPTOC | I0>>> | 50N/51N |

### 4.2.1.2 Function block

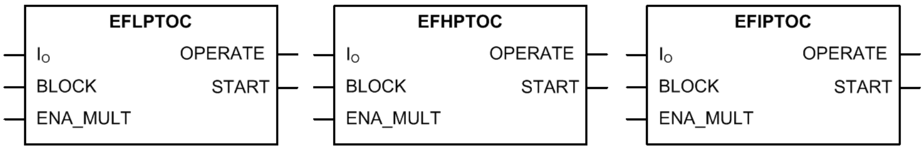



*Figure 45: Function block symbol*

## 4.2.1.3 Functionality

The earth-fault function EFxPTOC is used as non-directional earth-fault protection for feeders.

The function starts and operates when the residual current exceeds the set limit. The operate time characteristic for low stage EFLPTOC and high stage EFHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage EFIPTOC always operates with the DT characteristic.

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

## 4.2.1.4 Operation principle

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

The operation of non-directional earth-fault protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

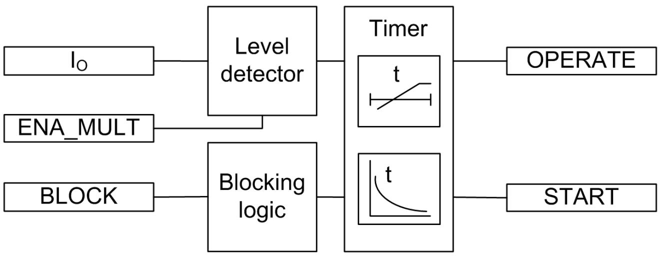



*Figure 46: Functional module diagram. $I_0$ represents the residual current.*

### Level detector

The measured residual current is compared with 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 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. See more details on the inrush detection function in the relevant chapter.

### 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 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 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. 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 user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the General function block features section in this manual.

The timer calculates the start duration value START_DUR which indicates the percentual 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 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 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 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.

## 4.2.1.5 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 118: Measurement modes supported by EFxPTOC stages*

| Measurement mode | Supported measurement modes | | |
|---|---|---|---|
| | EFLPTOC | EFHPTOC | EFIPTOC |
| RMS | x | x | |
| DFT | x | x | |
| Peak-to-Peak | x | x | x |

For a detailed description of the measurement modes, see the General function block features section in this manual.

## 4.2.1.6 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 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 119: Timer characteristics supported by different stages*

| Operating curve type | Supported by | |
|---|---|---|
| | EFLPTOC | EFHPTOC |
| (1) ANSI Extremely Inverse | x | x |
| (2) ANSI Very Inverse | x | |
| (3) ANSI Normal Inverse | x | x |
| (4) ANSI Moderately Inverse | x | |
| (5) ANSI Definite Time | x | x |
| (6) Long Time Extremely Inverse | x | |
| (7) Long Time Very Inverse | x | |
| (8) Long Time Inverse | x | |
| (9) IEC Normal Inverse | x | x |
| (10) IEC Very Inverse | x | x |
| (11) IEC Inverse | x | |
| (12) IEC Extremely Inverse | x | x |
| (13) IEC Short Time Inverse | x | |
| (14) IEC Long Time Inverse | x | |
| (15) IEC Definite Time | x | x |
| (17) User programmable curve | x | x |
| (18) RI type | x | |
| (19) RD type | x | |

EFIPTOC supports only definite time characteristics.

For a detailed description of timers, see the General function block features section in this manual.

*Table 120: Reset time characteristics supported by different stages*

| Reset curve type | Supported by | | Note |
|---|---|---|---|
| | EFLPTOC | EFHPTOC | |
| (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 back-up 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

*Table 121: EFLPTOC Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $I_0$ | 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 |

*Table 122: EFHPTOC Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $I_0$ | 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 |

*Table 123: EFIPTOC Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $I_0$ | 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 |

*Table 124: EFLPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

*Table 125: EFHPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

*Table 126: EFIPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.2.1.9 Settings

*Table 127: EFLPTOC Group settings*

| 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 |
| Time multiplier | 0.05...15.00 | | 0.05 | 1.00 | Time multiplier in IEC/ANSI IDMT curves |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operate delay time | 40...200000 | ms | 10 | 40 | Operate delay time |
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Programmable<br>18=RI type<br>19=RD type | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset | | | 1=Immediate | Selection of reset curve type |

*Table 128: EFLPTOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| 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<br>2=DFT<br>3=Peak-to-Peak | | | 2=DFT | Selects used measurement mode |
| Curve parameter A | 0.0086...120.0000 | | | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120 | | | 0.1217 | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00 | | | 2.00 | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00 | | | 29.10 | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0 | | | 1.0 | Parameter E for customer programmable curve |

*Table 129: EFHPTOC Group settings*

| 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 | | 0.05 | 1.00 | Time multiplier in IEC/ANSI IDMT curves |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operate delay time | 40...200000 | ms | 10 | 40 | Operate delay time |
| Operating curve type | 1=ANSI Ext. inv.<br>3=ANSI Norm. inv.<br>5=ANSI Def. Time<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>12=IEC Ext. inv.<br>15=IEC Def. Time<br>17=Programmable | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset | | | 1=Immediate | Selection of reset curve type |

*Table 130: EFHPTOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| 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<br>2=DFT<br>3=Peak-to-Peak | | | 2=DFT | Selects used measurement mode |
| Curve parameter A | 0.0086...120.0000 | | | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120 | | | 0.1217 | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00 | | | 2.00 | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00 | | | 29.10 | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0 | | | 1.0 | Parameter E for customer programmable curve |

*Table 131: EFIPTOC Group settings*

| 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 132: EFIPTOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |

### 4.2.1.10 Monitored data

*Table 133: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

*Table 134: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

*Table 135: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.2.1.11 Technical data

*Table 136: EFxPTOC Technical data*

| Characteristic | | Value |
|---|---|---|
| Operation accuracy | | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | EFLPTOC | ±1.5% of the set value or ±0.002 x $I_n$ |
| | EFHPTOC and EFIPTOC | ±1.5% of set value or ±0.002 x $I_n$<br>(at currents in the range of 0.1…10 x $I_n$)<br>±5.0% of the set value<br>(at currents in the range of 10…40 x $I_n$) |
| Table continues on next page | | |

| Characteristic | | Value | | |
|---|---|---|---|---|
| Start time 1)2) | | Minimum | Typical | Maximum |
| | EFIPTOC:<br>$I_{Fault}$ = 2 x set *Start value*<br>$I_{Fault}$ = 10 x set *Start value* | 16 ms<br>11 ms | 19 ms<br>12 ms | 23 ms<br>14 ms |
| | EFHPTOC and EFLPTOC:<br>$I_{Fault}$ = 2 x set *Start value* | 22 ms | 24 ms | 25 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 0.96 | | |
| Retardation time | | < 30 ms | | |
| Operate time accuracy in definite time mode | | ±1.0% of the set value or ±20 ms | | |
| Operate time accuracy in inverse time mode | | ±5.0% of the theoretical value or ±20 ms 3) | | |
| Suppression of harmonics | | RMS: No suppression<br>DFT: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5,…<br>Peak-to-Peak: No suppression | | |

1) *Measurement mode* = default (depends on stage), current before fault = 0.0 x $I_n$, $f_n$ = 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 x $I_n$, *Start value* multiples in range of 1.5 to 20

## 4.2.1.12 Technical revision history

*Table 137: EFIPTOC Technical revision history*

| Technical revision | Change |
|---|---|
| C | Minimum and default values changed to 20 ms for the *Operate delay time* setting<br>Minimum value changed to 1.00 x $I_n$ for the *Start value* setting. |

*Table 138: EFHPTOC Technical revision history*

| Technical revision | Change |
|---|---|
| B | Minimum and default values changed to 40 ms for the *Operate delay time* setting |

*Table 139: EFLPTOC Technical revision history*

| Technical revision | Change |
|---|---|
| C | *Start value* step changed to 0.005 |

# 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 | I0>-> | 67N-1 |
| Directional earth-fault protection - High stage | DEFHPDEF | I0>>-> | 67N-2 |

## 4.2.2.2 Function block

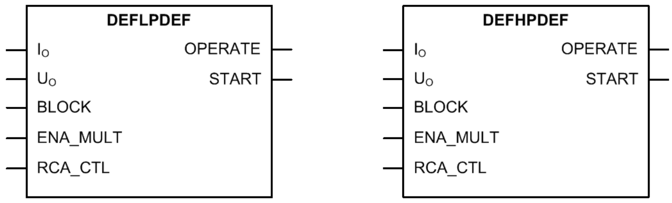



*Figure 47: Function block symbol*

## 4.2.2.3 Functionality

The earth-fault function DEFxPDEF is used as directional earth-fault protection for feeders.

The function starts and operates when the residual current and residual voltage (-$U_0$) exceed the set limits and the angle between them is inside the set operating sector. The operate time characteristic for low stage (DEFLPDEF) and high stage (DEFHPDEF) can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

## 4.2.2.4 Operation principle

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

The operation of directional earth-fault protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

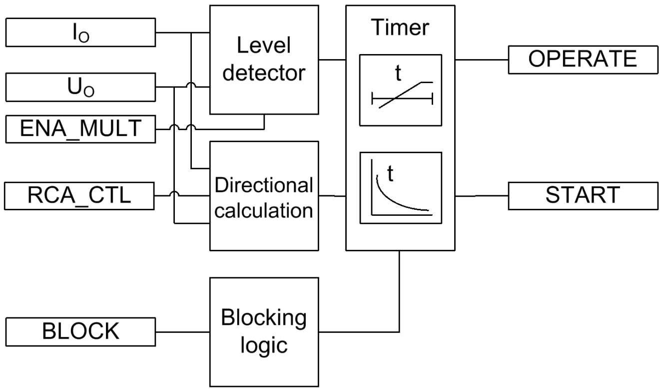



*Figure 48: Functional module diagram. $I_0$ and $U_0$ represent the residual current and residual voltage.*

## Level detector

The measured residual current is compared with the set *Start value*. For directional operation, the residual voltage (-Uo) also needs to be compared with the set *Voltage start value*. If both limits are exceeded, the level detector sends an enable-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 residual current. 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. See more details on the inrush detection function in the relevant chapter.

## Directional calculation

The directional calculation module monitors the angle between the measured residual current and residual voltage (-Uo). When the angle is in the operation sector, the module sends the enable-signal to the timer module.

For defining the operation sector, there are five modes available through the *Operation mode* setting.

*Table 140: 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 the mathematical expression has a positive value and "reverse" when the value is negative |
| 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. |

The directional operation can be selected with the *Directional mode* setting. The user can select either "Non-directional", "Forward" or "Reverse" operation. The operation criterion is selected with the *Operation mode* setting. By setting *Allow Non Dir* to "True", non-directional operation is allowed when directional information is invalid.

The *Characteristic angle* setting is used in "Phase angle" mode to adjust the operation according to the method of neutral point earthing so that in an isolated network the *Characteristic angle* ($\varphi_{RCA}$) = -90° and in a compensated network $\varphi_{RCA}$ = 0°. In addition, the characteristic angle can be changed via the control signal RCA_CTL, in which case the alternatives are -90° and 0°. The operation of RCA_CTL depends on the *Characteristic angle* setting.

The *Correction angle* setting can be used to improve selectivity when there are inaccuracies due to measurement transformers. The setting decreases the operation sector. The correction can only be used with the "IoCos" or "IoSin" modes.

The minimum signal level which allows directional operation can be set by using the *Min operate current* and *Min operate voltage* settings.

When polarizing quantity (residual voltage (-Uo)) is inverted because of switched voltage measurement cables, the correction can be done by setting the *Pol reversal* to "True" which turns polarizing quantity by 180 degrees.

For definitions of different directional earth-fault characteristics, see the Directional earth-fault characteristics section in this manual.

The directional calculation module calculates several values which are presented in the monitored data.

*Table 141: 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 $U_0$ (polarizing quantity) and $I_0$ (operating quantity). |
| 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 neutral current. If the *Operation mode* setting is "IoSin", I_OPER is calculated as follows I_OPER = $I_0$ x sin(ANGLE). If the *Operation mode* setting is "IoCos", I_OPER is calculated as follows I_OPER = $I_0$ 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 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 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. 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 user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the General function block features section in this manual.

The timer calculates the start duration value START_DUR which indicates the percentual 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 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 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 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.

## 4.2.2.5 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 $I_0$ into account. This is done by comparing the phase angle of $I_0$ to that of the residual voltage ($-U_0$).

### Relay characteristic angle

The *Characteristic angle*, also known as Relay Characteristic Angle (RCA), Relay Base Angle or Maximum Torque Angle (MTA), is used in the "Phase angle" mode to turn the directional characteristic, if the expected fault current angle does not coincide with the polarizing quantity to produce the maximum torque. That is, RCA is the angle between the maximum torque line and polarizing quantity. If the polarizing quantity is in phase with the maximum torque line, RCA is 0 degrees.

The angle is positive if operating current lags the polarizing quantity and negative if it leads the polarizing quantity.

**Example 1.**

The "Phase angle" mode is selected, compensated network (φRCA = 0 deg)

=> *Characteristic angle* = 0 deg

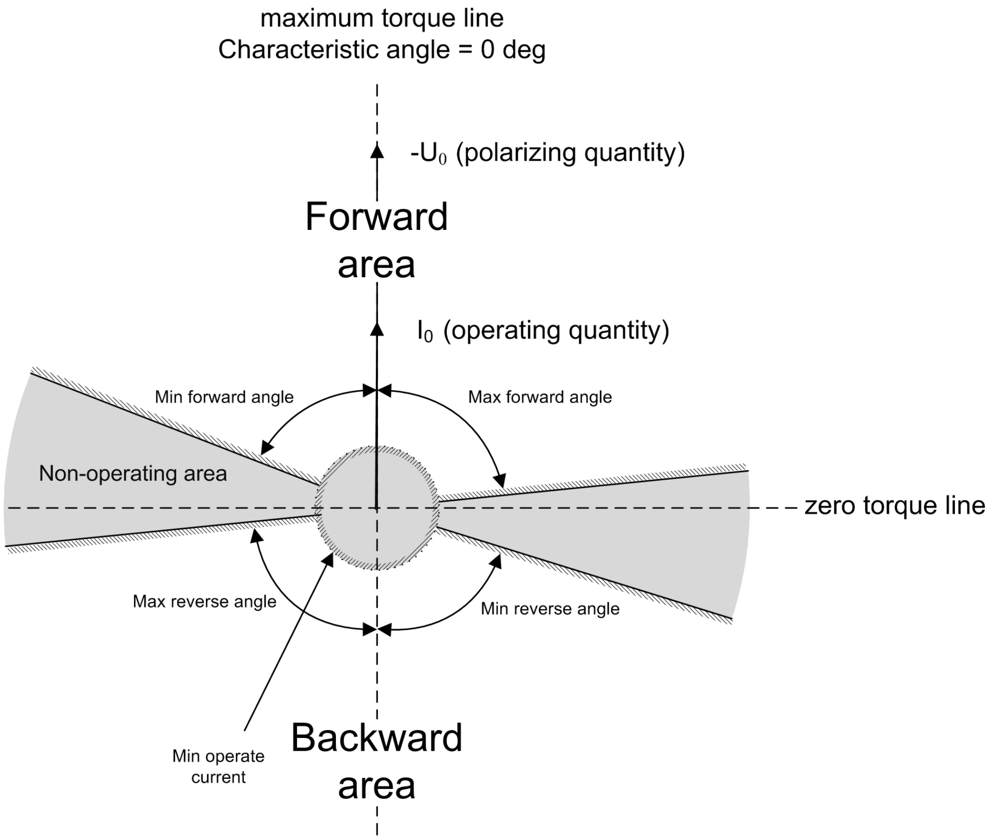



*Figure 49: Definition of the relay characteristic angle, RCA=0 degrees in a compensated network*

**Example 2.**

The "Phase angle" mode is selected, solidly earthed network (φRCA = +60 deg)

=> *Characteristic angle* = +60 deg

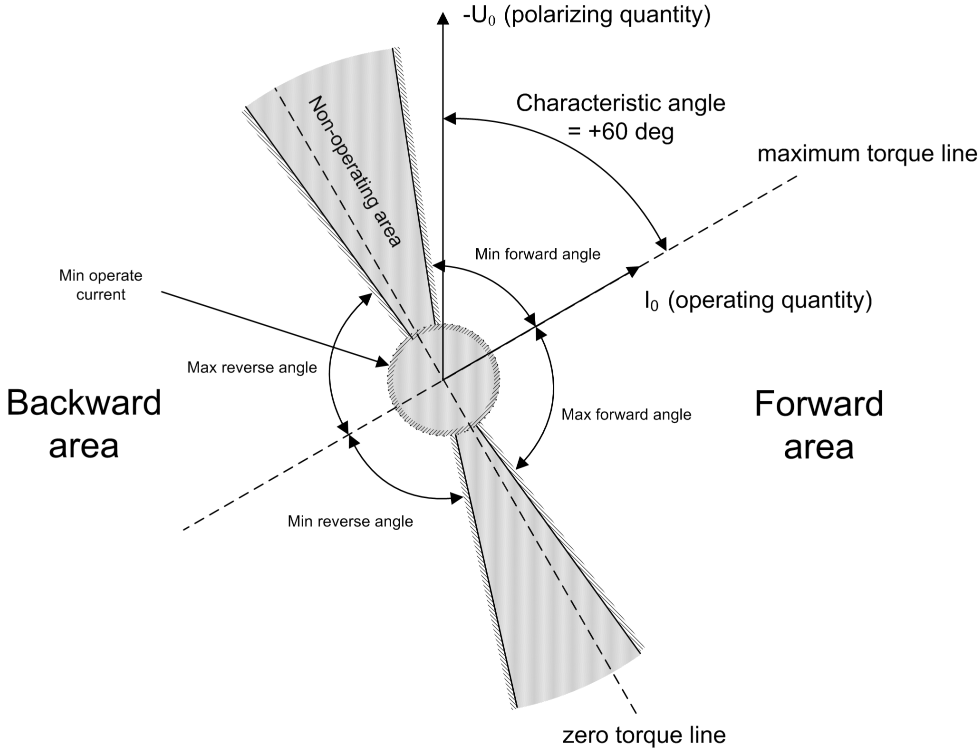



*Figure 50: Definition of the relay characteristic angle, RCA=+60 degrees in a solidly earthed network*

**Example 3.**

The "Phase angle" mode is selected, isolated network (φRCA = -90 deg)

=> *Characteristic angle* = -90 deg

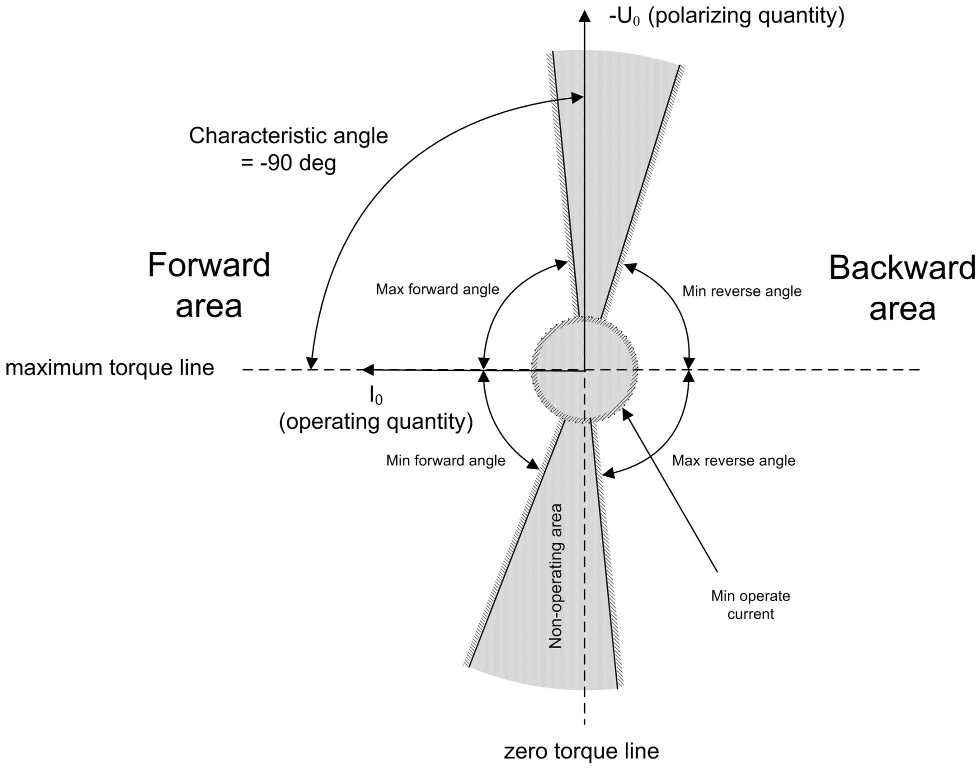



*Figure 51: Definition of the relay characteristic angle, RCA=–90 degrees in an isolated network*

## 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 line-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 residual voltage ($-U_0$). Consequently, the relay characteristic angle (RCA) should be set to -90 degrees and the operation criteria to $I_0\sin(\varphi)$ 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*. The figure below describes how earth fault current is defined in isolated neutral networks.

For definitions of different directional earth-fault characteristics, refer to the Technical manual.

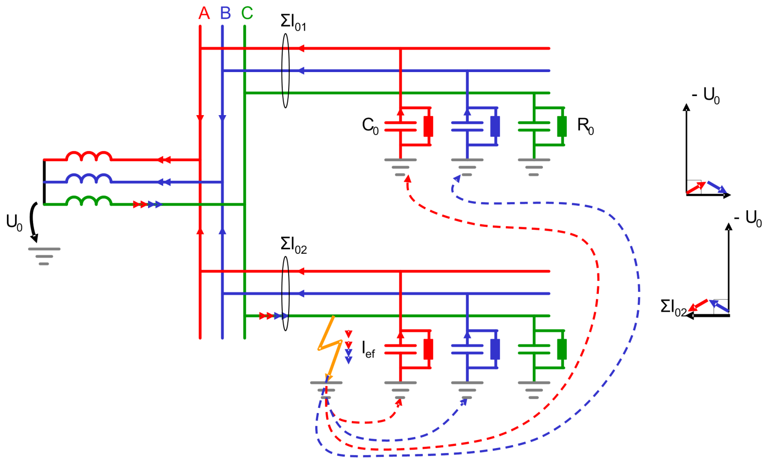



*Figure 52: Earth-fault situation in an isolated network*

### Directional earth-fault protection in a compensated network

In compensated networks, the capacitive fault current and the inductive resonance coil current compensate each other. The protection cannot be based on the reactive current measurement, since the current of the compensation coil would disturb the operation of the relays. In this case, the selectivity is based on the measurement of the active current component. The magnitude of this component is often small and must be increased by means of a parallel resistor in the compensation equipment. When measuring the resistive part of the residual current, the relay characteristic angle (RCA) should be set to 0 degrees and the operation criteria to $I_0\cos(\varphi)$ or phase angle. The figure below describes how earth fault current is defined in compensated neutral networks.

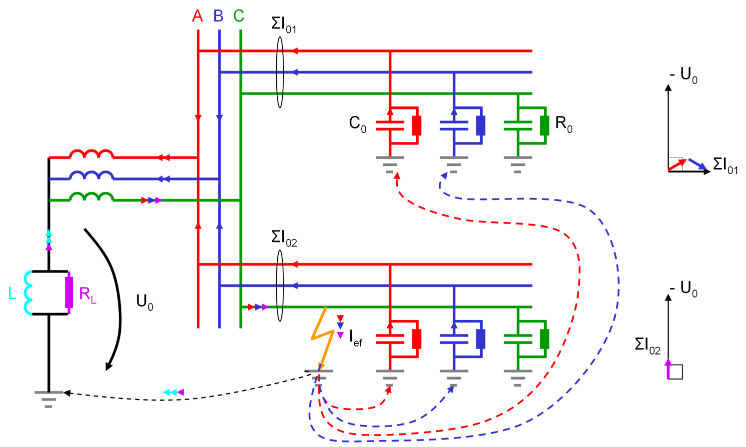



*Figure 53: Earth-fault situation in a compensated network*

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 is done with an auxiliary input in the relay which receives a signal from an auxiliary switch of the disconnector of the Petersen coil in compensated networks or of the earthing resistor in earthed 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 $I_0$ characteristic:

*Table 142: Relay characteristic angle control in $I_0$sin(φ) and $I_0$cos(φ) operation criteria*

| Operation criteria setting: | RCA_CTL = FALSE | RCA_CTL = TRUE |
|---|---|---|
| $I_0$sin(φ) | Actual operation criteria: $I_0$sin(φ) | Actual operation criteria: $I_0$cos(φ) |
| $I_0$cos(φ) | Actual operation criteria:$I_0$cos(φ) | Actual operation criteria: $I_0$sin(φ) |

*Table 143: Characteristic angle control in phase angle operation mode*

| *Characteristic angle* setting | RCA_CTL = FALSE | RCA_CTL = TRUE |
|---|---|---|
| -90° | φRCA = -90° | φRCA = 0° |
| 0° | φRCA = 0° | φRCA = -90° |

### Usage of the extended phase angle characteristic

In addition to the RCA_CTL input, the extended phase angle characteristic can be used when the compensation coil is temporarily disconnected in compensated networks. When the extended operation area is used, the operation area is wide enough to detect earth faults selectively in compensated networks regardless of whether the compensation coil is connected or not. Therefore, the RCA_CTL input is not required if the extended operation area is used.

Sometimes the distance between the start point and the IED is long which makes it impractical to apply the scheme based on signal wiring between the relay and the Petersen coil or the earthing resistor. This is the case for instance, when a directional earth-fault relay is used in an MV-switching substation some kilometers from the HV/MV -substation in which the earthing facilities are located. Another example is when HV/MV-substations are connected in parallel but located far from each other.

It is easy to give the tripping sector such a width that all possible directions of the $I_0$-phasors of a faulty line are covered by one and the same sector. Thus, the problem of setting the characteristic angle according to the earthing status of the network is easily solved. There is no need to change any settings when a Petersen coil or an earthing resistor is switched on or off. Auxiliary switches and other pieces of extra hardware are no longer required for ensuring the selectivity of the directional earth-fault protection.

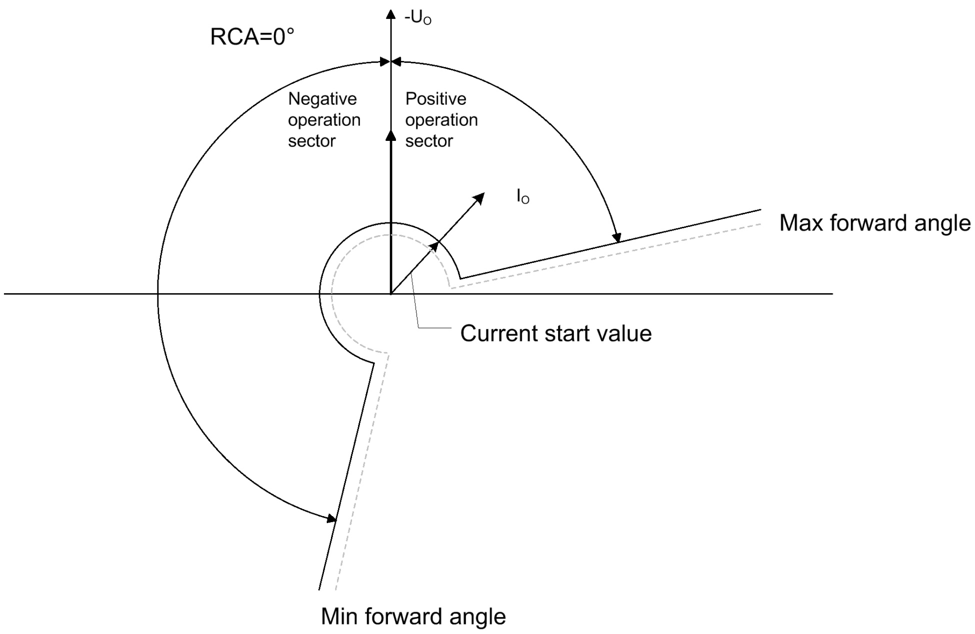



*Figure 54: Extended operation area in directional earth-fault protection*

### 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 144: Measurement modes supported by DEFxPDEF stages*

| Measurement mode | Supported measurement modes | |
|---|---|---|
| | DEFLPDEF | DEFHPDEF |
| RMS | x | x |
| DFT | x | x |
| Peak-to-Peak | x | x |

For a detailed description of the measurement modes, see the General function block features section in this manual.

### 4.2.2.7 Timer characteristics

DEFxPDEF supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* setting.

The 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 145: Timer characteristics supported by different stages*

| Operating curve type | Supported by | |
|---|---|---|
| | DEFLPDEF | DEFHPDEF |
| (1) ANSI Extremely Inverse | x | x |
| (2) ANSI Very Inverse | x | |
| (3) ANSI Normal Inverse | x | x |
| (4) ANSI Moderately Inverse | x | |
| (5) ANSI Definite Time | x | x |
| (6) Long Time Extremely Inverse | x | |
| (7) Long Time Very Inverse | x | |
| (8) Long Time Inverse | x | |
| (9) IEC Normal Inverse | x | |
| (10) IEC Very Inverse | x | |
| (11) IEC Inverse | x | |
| (12) IEC Extremely Inverse | x | |
| (13) IEC Short Time Inverse | x | |
| (14) IEC Long Time Inverse | x | |
| (15) IEC Definite Time | x | x |
| (17) User programmable curve | x | x |
| (18) RI type | x | |
| (19) RD type | x | |

For a detailed description of the timers, see the General function block features section in this manual.

*Table 146: Reset time characteristics supported by different stages*

| Reset curve type | Supported by | | |
|---|---|---|---|
| | DEFLPDEF | DEFHPDEF | Note |
| (1) Immediate | x | x | Available for all operate time curves |
| (2) Def time reset | x | x | Available for all operate time curves |
| (3) Inverse reset | x | x | Available only for ANSI and user programmable curves |

## 4.2.2.8 Directional earth-fault characteristics

### Phase angle characteristic with an additional operating sector

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 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 anti-clockwise 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 anti-clockwise 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.

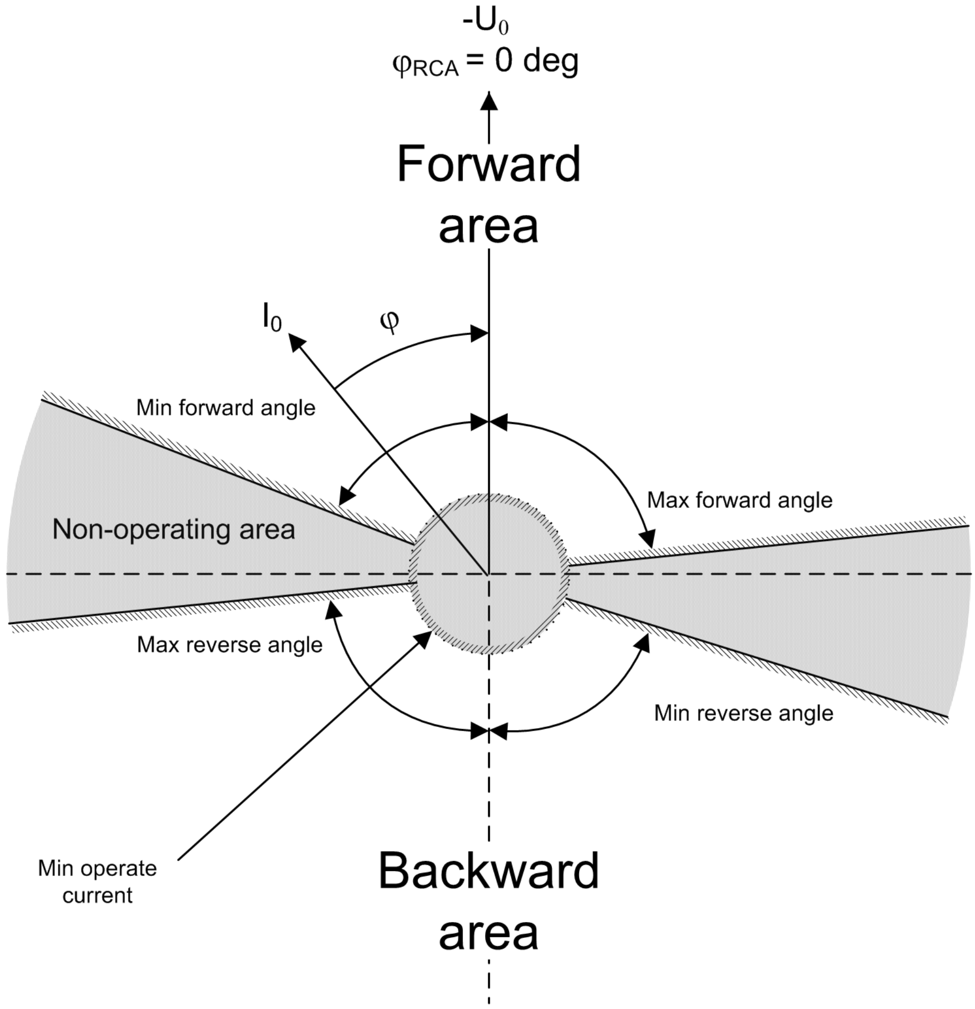



*Figure 55: Configurable operating sectors in phase angle characteristic*

*Table 147: 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 |

Directional operation is not allowed (the setting *Allow non dir* is "False") when the measured polarizing or operating quantities are not valid, 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.

The RCA_CTL input is used in compensated networks where the compensation coil sometimes can be disconnected. When the coil is disconnected, the compensated network becomes isolated and the *Characteristic angle* setting (φRCA) must be changed. This can be done automatically with the RCA_CTL input. Note that the RCA_CTL input only works when the *Characteristic angle* setting is set to exactly -90 degrees or 0 degrees. The value of the input affects the *Characteristic angle* setting in the following way:

*Table 148: Characteristic angle control in phase angle operation mode*

| *Characteristic angle* setting | RCA_CTL = "False" | RCA_CTL = "True" |
|---|---|---|
| -90° | φRCA = -90° | φRCA = 0° |
| 0° | φRCA = 0° | φRCA = -90° |

### $I_0$sin(φ) and $I_0$cos(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 $I_0$sin(φ) characteristic is used in an isolated network, measuring the reactive component of the fault current caused by the earth capacitance. The $I_0$cos(φ) characteristic is used in a compensated network, measuring the active component of the fault current.

The operation criteria $I_0$sin(φ) and $I_0$cos(φ) are selected with the *Operation mode* setting using the values "IoSin" or "IoCos", respectively.

In isolated networks, $I_0$sin(φ) does not differ from the phase angle criterion, since the phase angle of the operating quantity is fairly close to -90 degrees. Furthermore, in completely compensated networks the fault current is usually mostly resistive. Therefore, the phase angle and $I_0$cos(φ) criteria are equally sensitive. However, if the fault is in the background network, the fault current of a sound and healthy line is almost fully capacitive and its phase angle is close to the operation area of the component. Therefore, the $I_0$cos(φ) characteristic is recommended, since the risk of faulty operation is smaller than with the phase angle criterion.

The angle correction setting can be used to improve selectivity. The setting decreases the operation sector. The correction can only be used with the $I_0$sin(φ) or $I_0$cos(φ) criterion. The RCA_CTL input is used to change the $I_0$ characteristic:

*Table 149: Relay characteristic angle control in $I_0$sin(φ) and $I_0$cos(φ) operation criterion*

| Operation criteria: | RCA_CTL = "False" | RCA_CTL = "True" |
|---|---|---|
| $I_0$sin(φ) | Actual operation criterion: $I_0$sin(φ) | Actual operation criterion: $I_0$cos(φ) |
| $I_0$cos(φ) | Actual operation criterion: $I_0$cos(φ) | Actual operation criterion: $I_0$sin(φ) |

When the $I_0$sin(φ) or $I_0$cos(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 $I_0$sin(φ) or $I_0$cos(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. Otherwise, the value of a current in a reverse area is negative.

The following examples show the characteristics of the different operation criteria:

**Example 1.**

$I_0$sin(φ) criterion selected, forward-type fault

=> FAULT_DIR = 1

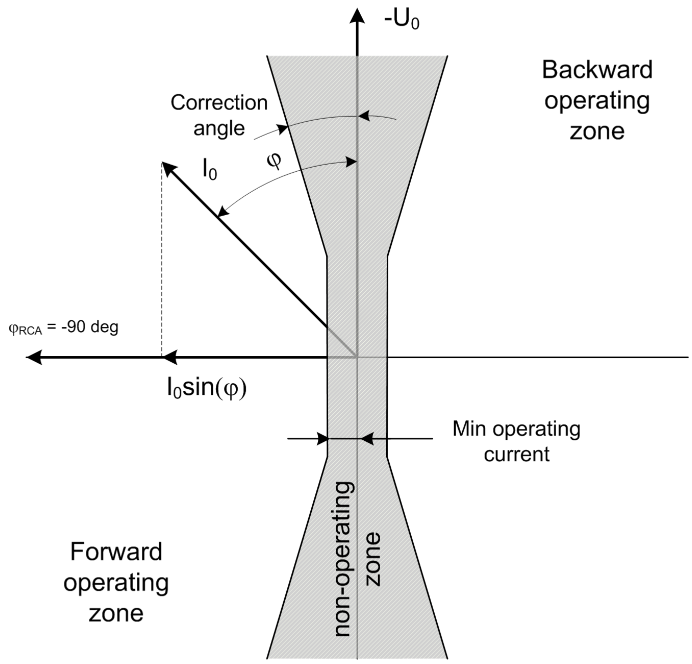



*Figure 56: Operating characteristic $I_0sin(φ)$ in forward fault*

The operating sector is limited by Angle correction, that is, the operating sector is 180 degrees - 2*(Angle correction).

**Example 2.**

$I_0$sin(φ) criterion selected, reverse-type fault

```
=> FAULT_DIR = 2
```

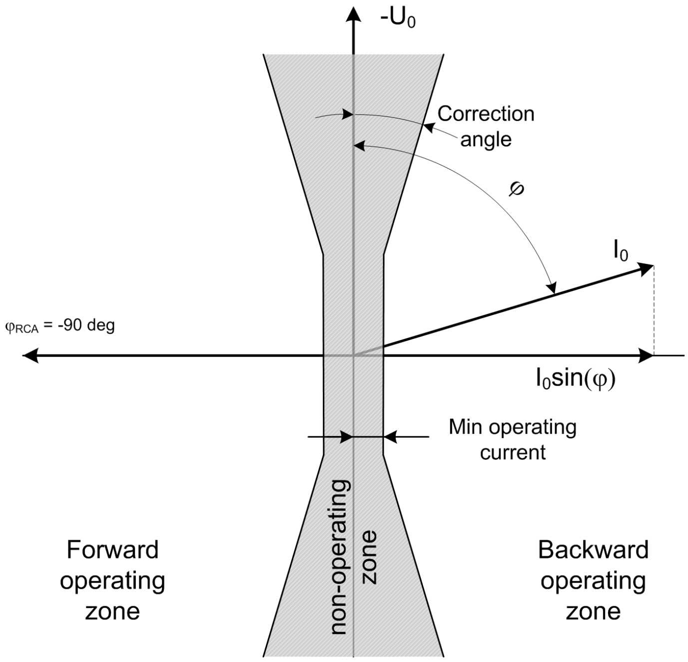



*Figure 57: Operating characteristic $I_0 sin(\varphi)$ in reverse fault*

**Example 3.**

$I_0cos(\varphi)$ criterion selected, forward-type fault

`=> FAULT_DIR = 1`

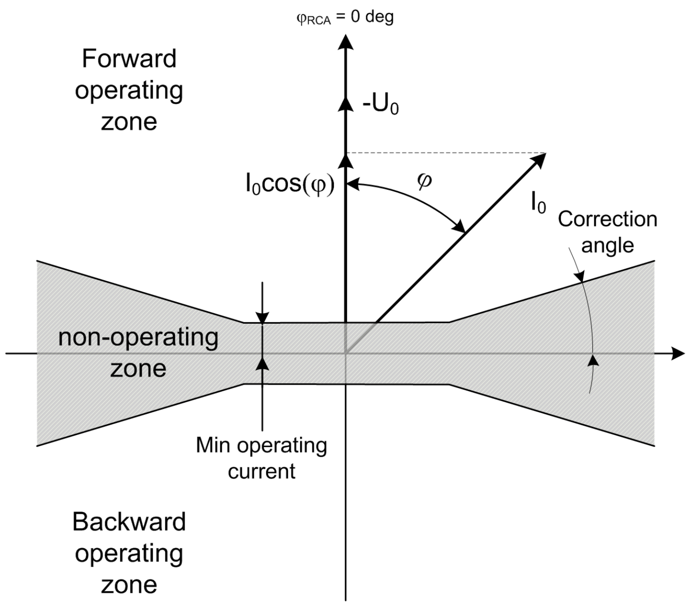



*Figure 58: Operating characteristic $I_0 cos(\varphi)$ in forward fault*

**Example 4.**

$I_0\cos(\varphi)$ criterion selected, reverse-type fault

=> FAULT_DIR = 2

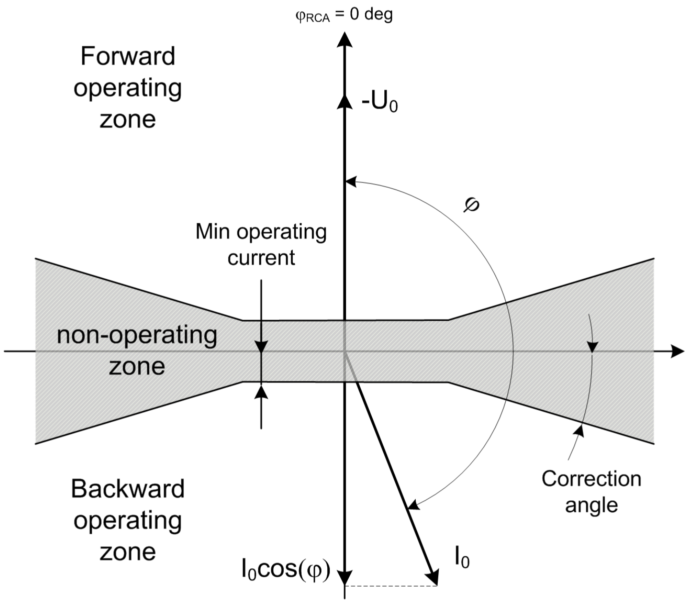



*Figure 59: Operating characteristic $I_0\cos(\varphi)$ in reverse fault*

## Phase angle, classic 80

The operation criterion phase angle classic 80 is selected with the *Operation mode* setting using the value "Phase angle 80".

Phase angle classic 80 implements the same functionality as the phase angle, but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings are not settable but 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.

If the current amplitude falls below one percent of the nominal current, the direction enters the non-directional area.

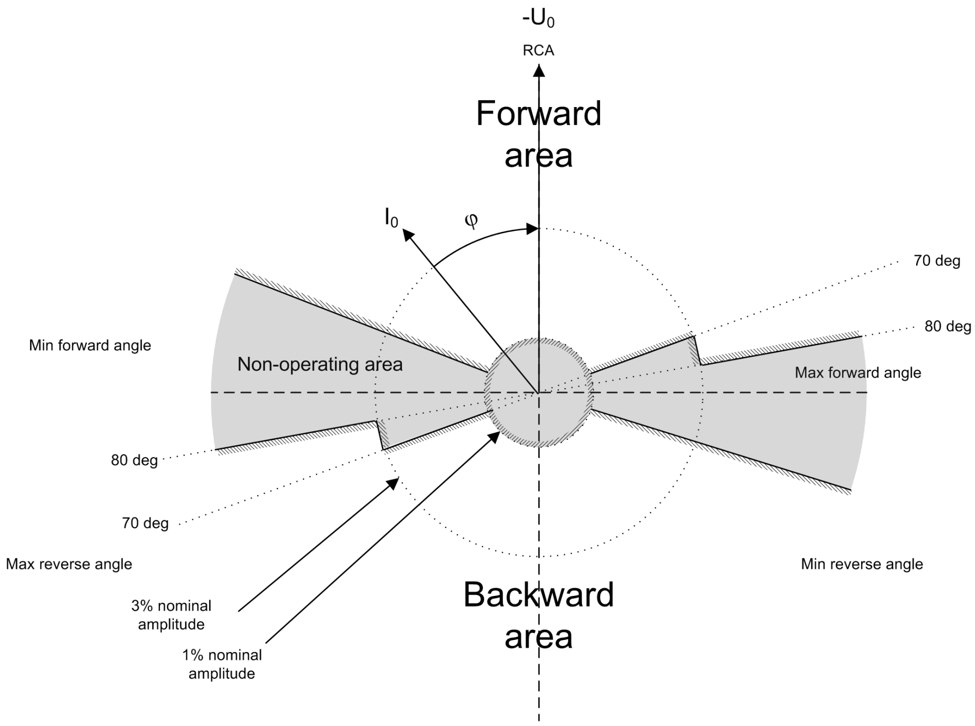



*Figure 60: Operating characteristic for phase angle classic 80*

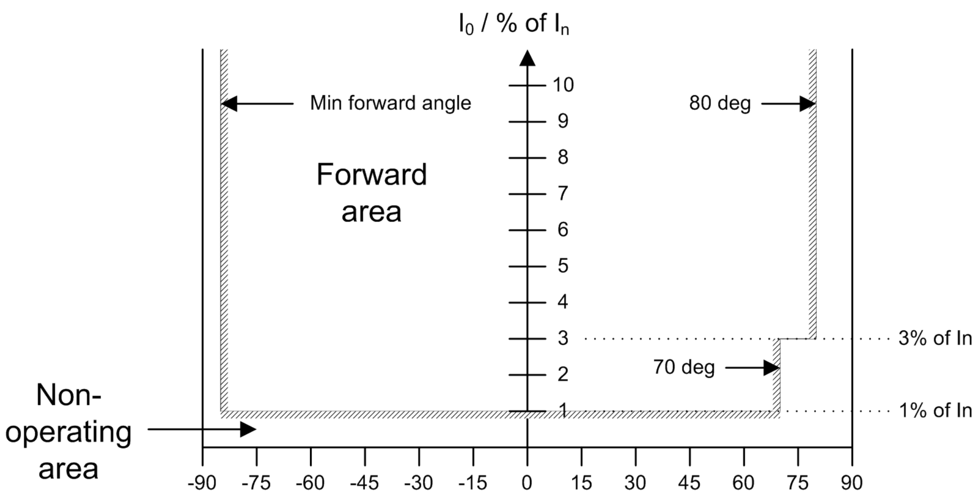



*Figure 61: Phase angle classic 80 amplitude*

### Phase angle, classic 88

The operation criterion phase angle classic 88 is selected with the *Operation mode* setting using the value "Phase angle 88".

Phase angle classic 88 implements the same functionality as the phase angle, but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings are not settable, but have a fixed value of 88 degrees
- The sector limits of the fixed sectors are rounded.

Sector rounding in the phase angle classic 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 1...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.

If the current amplitude falls below one percent of the nominal current, the direction enters the non-directional area.

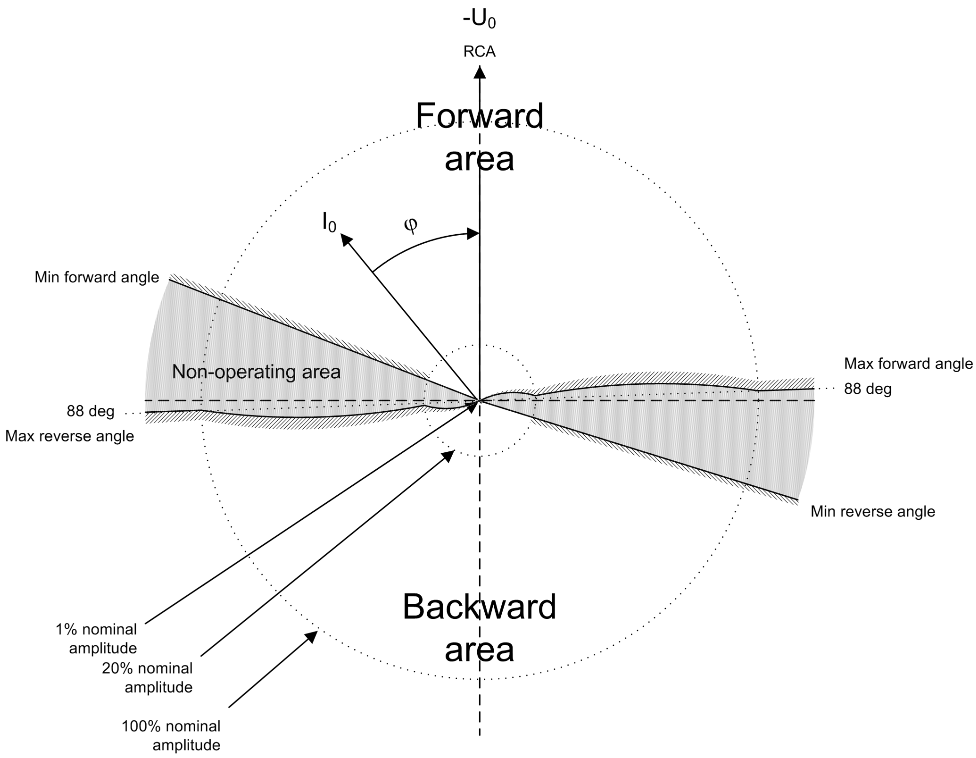



*Figure 62: Operating characteristic for phase angle classic 88*

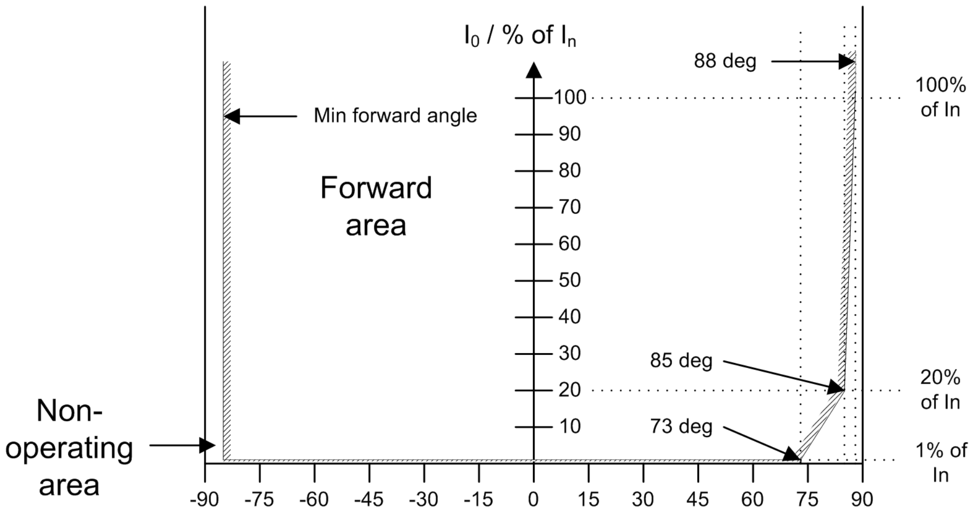



*Figure 63: Phase angle classic 88 amplitude*

## 4.2.2.9 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 $I_0\sin(\varphi)$ or the active part $I_0\cos(\varphi)$ 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 $I_0\cos(\varphi)$ or $I_0\sin(\varphi)$ according to the earthing method, where φ is the angle between the residual current and the reference residual voltage ($-U_0$). 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 ($-U_0$). 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 ($-U_0$) 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, $I_0\cos(\varphi)$ operation can be used.

In solidly earthed networks, the *Characteristic angle* is typically set to +60 degrees for the phase angle. Alternatively, $I_0\sin(\varphi)$ 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 $I_0\sin(\varphi)$ 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 $I_0$ 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 ($-U_0$), the poles of the measuring transformers must match each other and also the fault current direction. Also the earthing of the cable sheath must be taken into notice when using core balance current transformers. The following figure describes how measuring transformers can be connected to the IED.

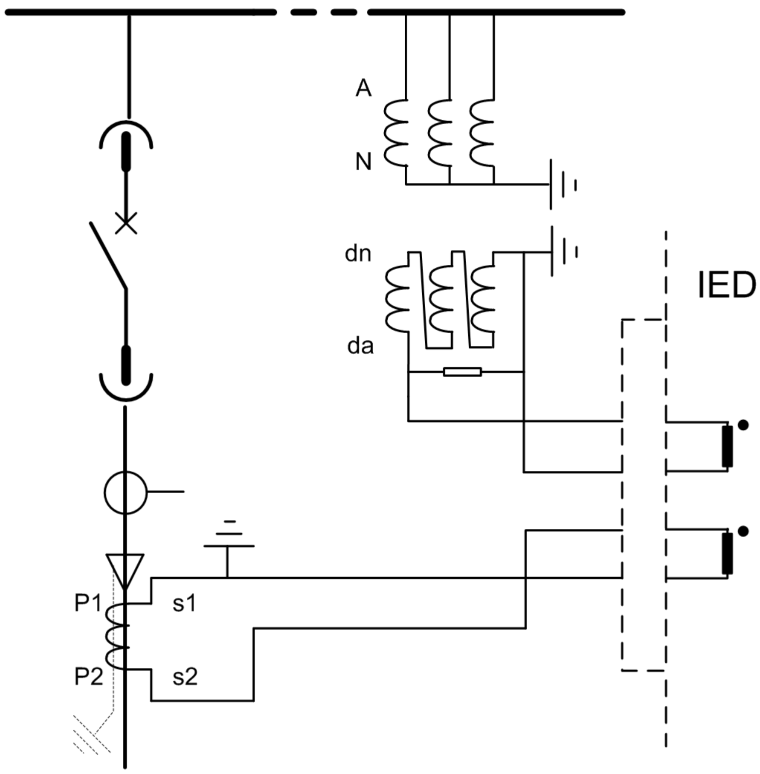



*Figure 64: Connection of measuring transformers*

## 4.2.2.10 Signals

*Table 150: DEFLPDEF Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $I_0$ | SIGNAL | 0 | Residual current |
| $U_0$ | 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 |

*Table 151: DEFHPDEF Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $I_0$ | SIGNAL | 0 | Residual current |
| $U_0$ | 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 |

*Table 152: DEFLPDEF Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

*Table 153: DEFHPDEF Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.2.2.11 Settings

*Table 154: DEFLPDEF Group settings*

| 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<br>2=Forward<br>3=Reverse | | | 2=Forward | Directional mode |
| Time multiplier | 0.05...15.00 | | 0.05 | 1.00 | Time multiplier in IEC/ANSI IDMT curves |
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Programmable<br>18=RI type<br>19=RD type | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset | | | 1=Immediate | Selection of reset curve type |
| Operate delay time | 60...200000 | ms | 10 | 60 | Operate delay time |
| Operation mode | 1=Phase angle<br>2=IoSin<br>3=IoCos<br>4=Phase angle 80<br>5=Phase angle 88 | | | 1=Phase angle | Operation criteria |
| Characteristic angle | -179...180 | deg | 1 | -90 | Characteristic angle |
| Max forward angle | 0...180 | deg | 1 | 88 | Maximum phase angle in forward direction |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Max reverse angle | 0...180 | deg | 1 | 88 | Maximum phase angle in reverse direction |
| Min forward angle | 0...180 | deg | 1 | 88 | Minimum phase angle in forward direction |
| Min reverse angle | 0...180 | deg | 1 | 88 | Minimum phase angle in reverse direction |
| Voltage start value | 0.010...1.000 | xUn | 0.001 | 0.010 | Voltage start value |
| Enable voltage limit | 0=False<br>1=True | | | 1=True | Enable voltage limit |

*Table 155: DEFLPDEF Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |
| Minimum operate time | 60...60000 | ms | 1 | 60 | Minimum operate time for IDMT curves |
| Allow Non Dir | 0=False<br>1=True | | | 0=False | Allows prot activation as non-dir when dir info is invalid |
| Measurement mode | 1=RMS<br>2=DFT<br>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<br>1=True | | | 0=False | Rotate polarizing quantity |
| Curve parameter A | 0.0086...120.0000 | | | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120 | | | 0.1217 | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00 | | | 2.00 | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00 | | | 29.10 | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0 | | | 1.0 | Parameter E for customer programmable curve |

*Table 156: DEFHPDEF Group settings*

| 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<br>2=Forward<br>3=Reverse | | | 2=Forward | Directional mode |
| Time multiplier | 0.05...15.00 | | 0.05 | 1.00 | Time multiplier in IEC/ANSI IDMT curves |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operating curve type | 1=ANSI Ext. inv.<br>3=ANSI Norm. inv.<br>5=ANSI Def. Time<br>15=IEC Def. Time<br>17=Programmable | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset | | | 1=Immediate | Selection of reset curve type |
| Operate delay time | 60...200000 | ms | 10 | 60 | Operate delay time |
| Operation mode | 1=Phase angle<br>2=IoSin<br>3=IoCos<br>4=Phase angle 80<br>5=Phase angle 88 | | | 1=Phase angle | Operation criteria |
| Characteristic angle | -179...180 | deg | 1 | -90 | Characteristic angle |
| Max forward angle | 0...180 | deg | 1 | 88 | Maximum phase angle in forward direction |
| Max reverse angle | 0...180 | deg | 1 | 88 | Maximum phase angle in reverse direction |
| Min forward angle | 0...180 | deg | 1 | 88 | Minimum phase angle in forward direction |
| Min reverse angle | 0...180 | deg | 1 | 88 | Minimum phase angle in reverse direction |
| Voltage start value | 0.010...1.000 | xUn | 0.001 | 0.010 | Voltage start value |
| Enable voltage limit | 0=False<br>1=True | | | 1=True | Enable voltage limit |

*Table 157: DEFHPDEF Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |
| Minimum operate time | 60...60000 | ms | 1 | 60 | Minimum operate time for IDMT curves |
| Allow Non Dir | 0=False<br>1=True | | | 0=False | Allows prot activation as non-dir when dir info is invalid |
| Measurement mode | 1=RMS<br>2=DFT<br>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<br>1=True | | | 0=False | Rotate polarizing quantity |
| Curve parameter A | 0.0086...120.0000 | | | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120 | | | 0.1217 | Parameter B for customer programmable curve |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Curve parameter C | 0.02...2.00 | | | 2.00 | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00 | | | 29.10 | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0 | | | 1.0 | Parameter E for customer programmable curve |

## 4.2.2.12 Monitored data

*Table 158: DEFLPDEF Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| FAULT_DIR | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Detected fault direction |
| START_DUR | FLOAT32 | 0.00...100.00 | % | Ratio of start time / operate time |
| DIRECTION | Enum | 0=unknown<br>1=forward<br>2=backward<br>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 | | Calculated operating current |
| DEFLPDEF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

*Table 159: DEFHPDEF Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| FAULT_DIR | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Detected fault direction |
| START_DUR | FLOAT32 | 0.00...100.00 | % | Ratio of start time / operate time |
| DIRECTION | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Direction information |
| ANGLE_RCA | FLOAT32 | -180.00...180.00 | deg | Angle between operating angle and characteristic angle |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| ANGLE | FLOAT32 | -180.00...180.00 | deg | Angle between polarizing and operating quantity |
| I_OPER | FLOAT32 | 0.00...40.00 | | Calculated operating current |
| DEFHPDEF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 4.2.2.13 Technical data

*Table 160: DEFxPDEF Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the current measured: $f_n$ ±2Hz | | |
| | DEFLPDEF | Current:<br>±1.5% of the set value or ±0.002 x $I_n$<br>Voltage<br>±1.5% of the set value or ±0.002 x $U_n$<br>Phase angle:<br>±2° | | |
| | DEFHPDEF | Current:<br>±1.5% of the set value or ±0.002 x $I_n$<br>(at currents in the range of 0.1…10 x $I_n$)<br>±5.0% of the set value<br>(at currents in the range of 10…40 x $I_n$)<br>Voltage:<br>±1.5% of the set value or ±0.002 x $U_n$<br>Phase angle:<br>±2° | | |
| Start time [1)2)] | | Minimum | Typical | Maximum |
| | DEFHPDEF and DEFLPTDEF:<br>$I_{Fault}$ = 2 x set *Start value* | 61 ms | 64 ms | 66 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 0.96 | | |
| Retardation time | | < 30 ms | | |
| Operate time accuracy in definite time mode | | ±1.0% of the set value or ±20 ms | | |
| Operate time accuracy in inverse time mode | | ±5.0% of the theoretical value or ±20 ms [3)] | | |
| Suppression of harmonics | | RMS: No suppression<br>DFT: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5,…<br>Peak-to-Peak: No suppression | | |

1) *Measurement mode* = default (depends on stage), current before fault = 0.0 x $I_n$, $f_n$ = 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 x $I_n$, *Start value* multiples in range of 1.5 to 20

### 4.2.2.14 Technical revision history

*Table 161: DEFHPDEF Technical revision history*

| Technical revision | Change |
|---|---|
| B | Maximum value changed to 180 deg for the *Max forward angle* setting |

*Table 162: DEFLPDEF Technical revision history*

| Technical revision | Change |
|---|---|
| B | Maximum value changed to 180 deg for the *Max forward angle* setting.<br>*Start value* step changed to 0.005 |

## 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 | I0> ->IEF | 67NIEF |

### 4.2.3.2 Function block

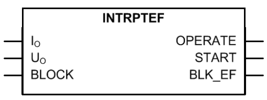



*Figure 65: Function block symbol*

### 4.2.3.3 Functionality

The transient/intermittent earth-fault protection (INTRPTEF) is a sample based function designed for the protection and clearance of intermittent and transient earth faults 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.

The operate time characteristics are according to definite time (DT).

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

## 4.2.3.4 Operation principle

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

The operation of transient/intermittent earth-fault protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

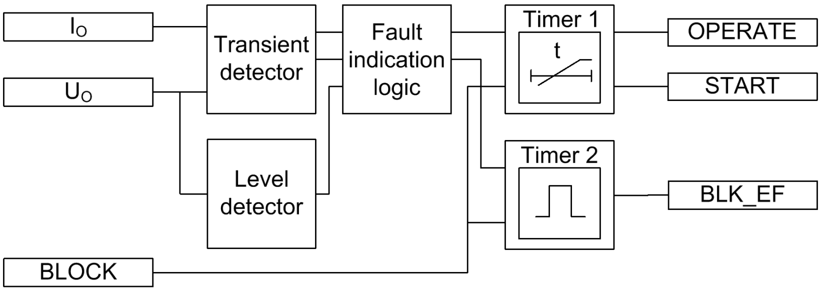



*Figure 66: Functional module diagram. $I_0$ and $U_0$ stand for residual current and residual voltage.*

### Level detector

The level detector module is used only when selected *Operation mode* is "Transient EF". The module compares the measured residual voltage with the set *Voltage start value*. If the measured value exceeds the set *Voltage start value*, the module reports the exceeding of the value to the fault indication logic.

### Transient detector

The transient detector module is used for detecting transients in the residual current and residual voltage signals. There are predefined criteria for $I_0$ and $U_0$ signals for detecting transients and their direction. The found transients that fulfil the criteria are reported to the fault indication logic separately for $I_0$ and $U_0$.

### 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.

Traditional earth fault protection should always be used in parallel with "Transient EF" mode.

The fault indication logic module checks that the detected transients match the directional criteria set by the *Directional mode* setting. When the setting value "Forward" is used, meaning that the fault is in the fed cable from the relay point of view, the matching can be done only if the direction of the transients in $I_0$ and $U_0$ are both positive or negative. When the setting value "Reverse" is used, meaning that respectively the fault is in the background network, the matching is done only if the direction of the transients is not equal (one positive and one negative). If the direction has no importance, the value "Non-directional" can be selected.

The detected fault direction (FAULT_DIR) is available through the Monitored data view on the LHMI or through tools via communications.

In the "Transient EF" mode, when the start transient of the fault is detected and the $U_0$ level exceeds the set *Voltage start value*, Timer 1 is activated. Timer 1 is kept activated until the $U_0$ 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 a required amount of intermittent earth-fault transients set with the *Peak counter limit* setting are detected without the function being reset (depends on the drop-off time set with the *Reset delay time* setting), Timer 1 is activated. Timer 1 is kept activated as long as transients are occurring during the drop-off time *Reset delay time*.

### Timer 1

Once activated, the timer activates the START output. The time characteristic is according to DT. When the timer has reached the value set by *Operate delay time* and in the "Intermittent EF" mode at least one transient is detected during the drop-off cycle, the OPERATE output of the function is activated. In the "Transient EF" mode, the OPERATE output is activated after operate time if the residual voltage exceeds the set *Voltage start value*. The activation of the BLOCK input resets the timer and the START and OPERATE outputs are 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.

### 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 during *Block EF reset time*, the BLK_EF output is deactivated. The BLK_EF output is activated only in the "Intermittent EF" mode.

The activation of the BLOCK input resets the timer and the BLK_EF output is deactivated.

## 4.2.3.5 Application

INTRPTEF is a dedicated earth-fault function to operate in intermittent and transient earth faults occurring in distribution and sub-transmission networks. The function has selectable modes for corresponding fault types. As the function has a dedicated purpose for these 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 extinguishes mostly itself as the fault current zero for the first time. As a result, very short transients, that is, rapid changes in form of spikes in residual current ($I_0$) and in residual voltage ($U_0$), can be repeatedly measured. Typically, the fault resistance in case of an intermittent earth fault is only a few ohms.

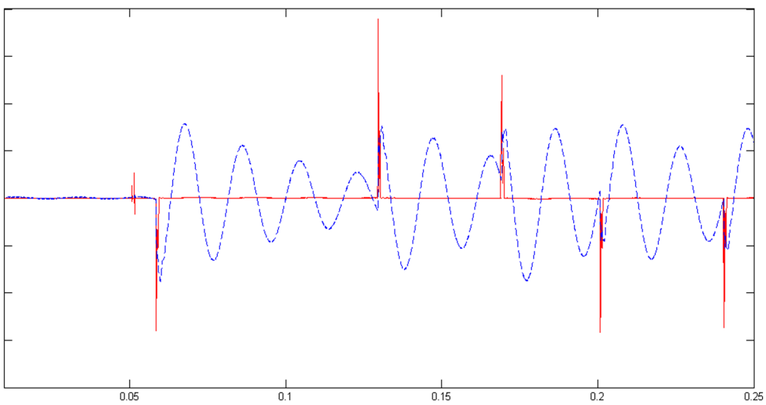



*Figure 67: Typical intermittent earth-fault characteristics*

### 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.

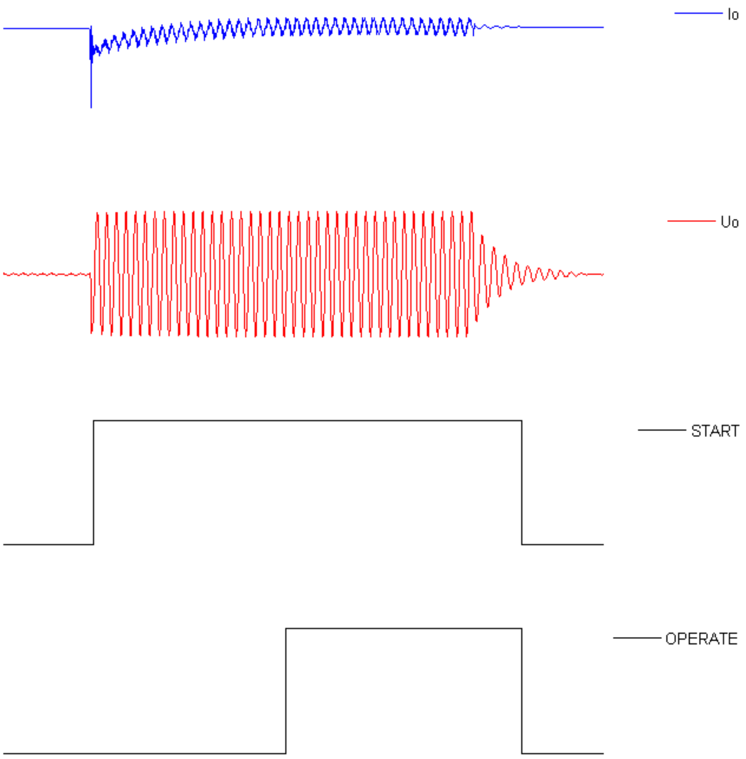



*Figure 68: Transient earth-fault situation and operation of INTRPTEF during a fault*

## 4.2.3.6 Signals

*Table 163: INTRPTEF Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $I_0$ | SIGNAL | 0 | Residual current |
| $U_0$ | SIGNAL | 0 | Residual voltage |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

*Table 164: INTRPTEF Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |
| BLK_EF | BOOLEAN | Block signal for EF to indicate oposite direction peaks |

### 4.2.3.7 Settings

*Table 165: INTRPTEF Group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Directional mode | 1=Non-directional<br>2=Forward<br>3=Reverse | | | 2=Forward | Directional mode, Non-directional / Forward / Reverse |
| Operate delay time | 40...1200000 | ms | 10 | 500 | Operate delay time |
| Voltage start value | 0.01...0.50 | xUn | 0.01 | 0.01 | Voltage start value for transient EF |

*Table 166: INTRPTEF Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Operation mode | 1=Intermittent EF<br>2=Transient EF | | | 1=Intermittent EF | Operation criteria |
| Reset delay time | 0...60000 | ms | 1 | 500 | Reset delay time |
| Peak counter limit | 2...20 | | | 2 | Min requirement for peak counter before start in IEF mode |

### 4.2.3.8 Monitored data

*Table 167: INTRPTEF Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| FAULT_DIR | Enum | 0=unknown<br>1=forward<br>2=backward<br>3=both | | Detected fault direction |
| START_DUR | FLOAT32 | 0.00...100.00 | % | Ratio of start time / operate time |
| INTRPTEF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.2.3.9 Technical data

*Table 168: INTRPTEF Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy ($U_0$ criteria with transient protection) | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | ±1.5% of the set value or ±0.002 x $U_n$ |
| Operate time accuracy | ±1.0% of the set value or ±20 ms |
| Suppression of harmonics | DFT: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5 |

### 4.2.3.10 Technical revision history

*Table 169: INTRPTEF Technical revision history*

| Technical revision | Change |
|---|---|
| B | Minimum and default values changed to 40 ms for the *Operate delay time* setting |

# 4.3 Differential protection

## 4.3.1 Line differential protection LNPLDF

### 4.3.1.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Line differential protection | LNPLDF | 3dI>L | 87L |

### 4.3.1.2 Function block

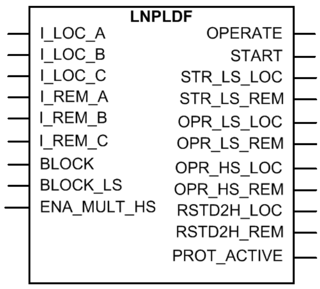



*Figure 69: Function block symbol*

### 4.3.1.3 Functionality

The phase segregated line differential protection LNPLDF is used as feeder differential protection for the distribution network lines and cables. LNPLDF includes low, stabilized and high, non-stabilized stages.

The stabilized low stage provides a fast clearance of faults while remaining stable with high currents passing through the protected zone increasing errors on current measuring. Second harmonic restraint insures that the low stage does not operate due to the startup of the tapped transformer. The high stage provides a very fast clearance of severe faults with a high differential current regardless of their harmonics.

The operating time characteristic for the low stage can be selected to be either definite time (DT) or inverse definite time (IDMT). The direct inter-trip ensures both ends are always operated, even without local criteria.

### 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 function can also be set into test mode by setting the *Operation* setting to “Test/ blocked”.

The operation of line differential protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

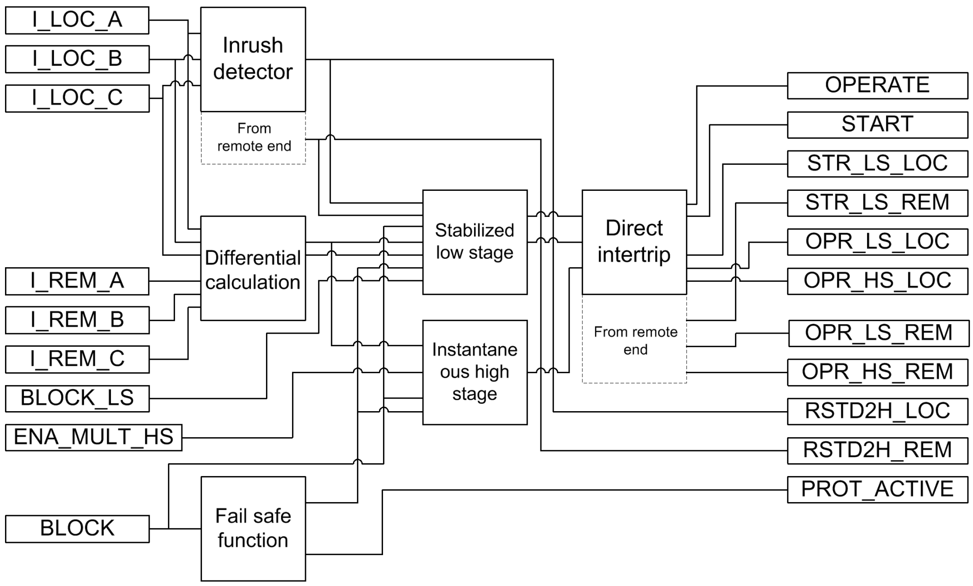



*Figure 70: Functional module diagram. I_LOC_x stands for current of the local end and I_REM_x for phase currents of the remote ends.*

#### Inrush detector

The transformer inrush currents cause high degrees of second harmonic to the measured phase currents. The inrush detector detects inrush situations in transformers. The second harmonic based local blocking is selected into use with the *Restraint mode* parameter. The blocking for the low stage on the local end is issued when the second harmonic blocking is selected and the inrush is detected.

The inrush detector calculates the ratio of the second harmonic current `I_2H_LOC_A` and the fundamental frequency current `I_1H_LOC_A`. The calculated value is compared with the parameter value of the *Start value 2.H* setting. If the calculated value exceeds the set value and the fundamental frequency current `I_1H_LOC_A` is more that seven percent of the nominal current, the output signal BLK2H_A is activated. The inrush detector handles the other phases the same way.

The locally detected transformer inrush is also transferred to the remote end as a binary indication signal independently of the local *Restraint mode* setting parameter value. When the internal blocking of the stabilized low stage is activated, the RSTD2H_LOC and RSTD2H_REM outputs will also be activated at the same time depending on whether the inrush has been detected on local or remote end or on both ends.

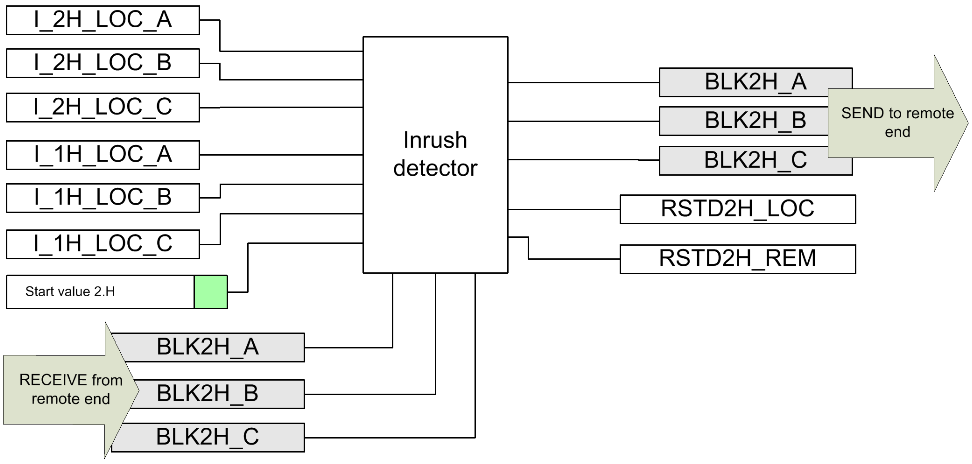



*Figure 71: Inrush current detection logic*

## Differential calculation

The operating principle is to calculate on both ends differential current from currents entering and leaving the protection zone by utilizing the digital communication channels for data exchange. The differential currents are almost zero on normal operation. The differential protection is phase segregated and the differential currents are calculated on both ends separately.

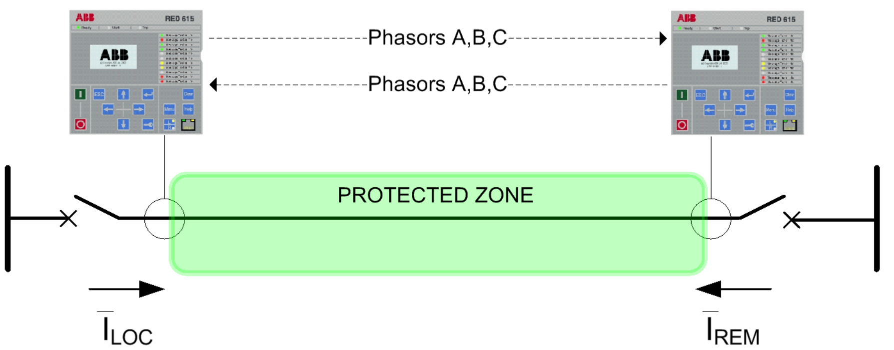



*Figure 72: Basic protection principle*

The differential current IΔ ($I_d$) of the IED is obtained on both ends with the formula:

$$I_d = \left| \bar{I}_{LOC} + \bar{I}_{REM} \right|$$

(Equation 14)

The stabilizing current $I_{bias}$ ($I_b$) of the IED is obtained on both ends with the formula:

$$I_b = \frac{\left| \bar{I}_{LOC} - \bar{I}_{REM} \right|}{2}$$

(Equation 15)

Depending on the location of the star points of the current transformers, the polarity of the local end remote currents may be different causing malfunction of the calculation algorithms. The CT transformation ratio may be different and this needs to be compensated to provide a correct differential current calculation result on both ends.

The operation characteristics related settings are given in units as percentage of the current transformer secondary nominal current on each line end IED. For the actual primary setting, the corresponding CT ratio on each line end has to be considered. An example of how the *CT ratio correction* parameter values should be selected on both line ends in the example case to compensate the difference in the nominal levels can be presented. For example, 160A in the primary circuit would equal 160A/800Ax100% = 20% as the setting value for IED (A) and 160A/400Ax100% = 40% for IED (B). The *CT ratio correction* setting parameter is provided in case current transformers with different ratios are used in the two IEDs. This has no effect on the actual protection stage settings.

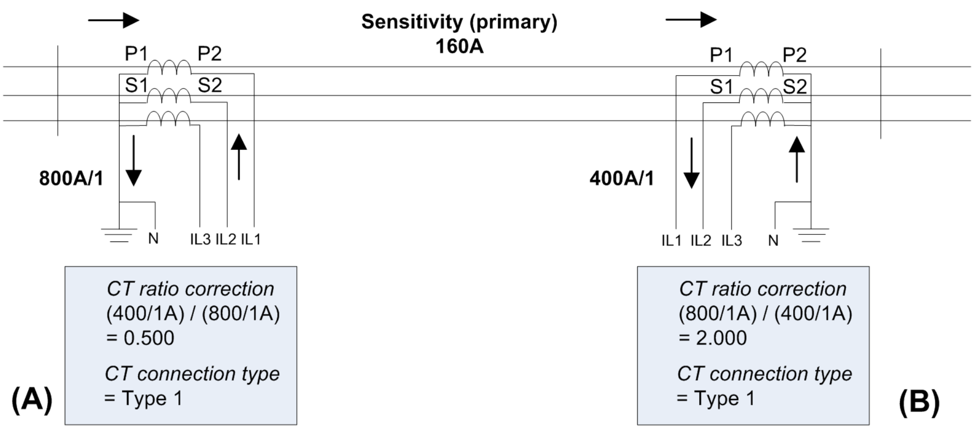



*Figure 73: Example of differential current during external fault*

*CT connection type* is chosen based on two possibilities:

- "Type 1" is selected on both ends when the secondary current direction for local and remote secondary is the opposite (default). "Type 1" should be used when the star point of the current transformer is located on the bus bar side on

both line end IEDs or alternatively, when the star point of the current transformer is located on the line side on both line end IEDs
- "Type 2" is selected on both ends when the secondary current directions for local and remote secondary is the same. "Type 2" should be used when the star point of the current transformer is located on the line side on one line end IED and on the bus bar side on the other line end IED

### Fail safe function

To prevent malfunction during communication interference, the operation of LNPLDF is blocked when the protection communication supervision detects severe interference in the communication channel. The timer reset stage is activated in case the stabilized stage is started during a communication interruption.

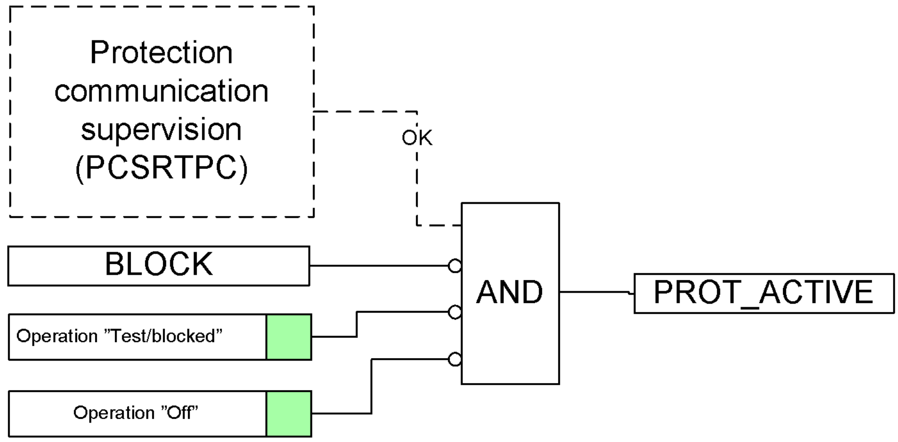



*Figure 74: Operation logic of the fail safe function*

The function can also be set into "Test/blocked" state with the *Operation* setting. This can also be utilized during the commissioning.

The `BLOCK` input is provided for blocking the function with the logic. When the function is blocked, the monitored data and measured values are still available but the binary outputs are blocked. When the function is blocked, the direct inter-trip is also blocked.

The `PROT_ACTIVE` output is always active when the protection function is capable of operating. `PROT_ACTIVE` can be used as a blocking signal for backup protection functions.

### Stabilized low stage

In the stabilized low stage, the higher the load current increases, the higher the differential current required for tripping is. This happens on normal operation or during external faults. When an internal fault occurs, the currents on both sides of the protected object flow towards the fault and cause the stabilizing current to be considerably lower. This makes the operation more sensitive during internal faults. The low stage includes a timer delay functionality.

The characteristic of the low stage taking the apparent differential current into account is influenced by various factors:

- Small tapped loads within the protection zone
- Current transformer errors
- Current transformer saturation
- Small asymmetry of the communication channel go and return paths
- Small steady state line charging current.

The timer is activated according to the calculated differential, stabilizing current and the set differential characteristic.

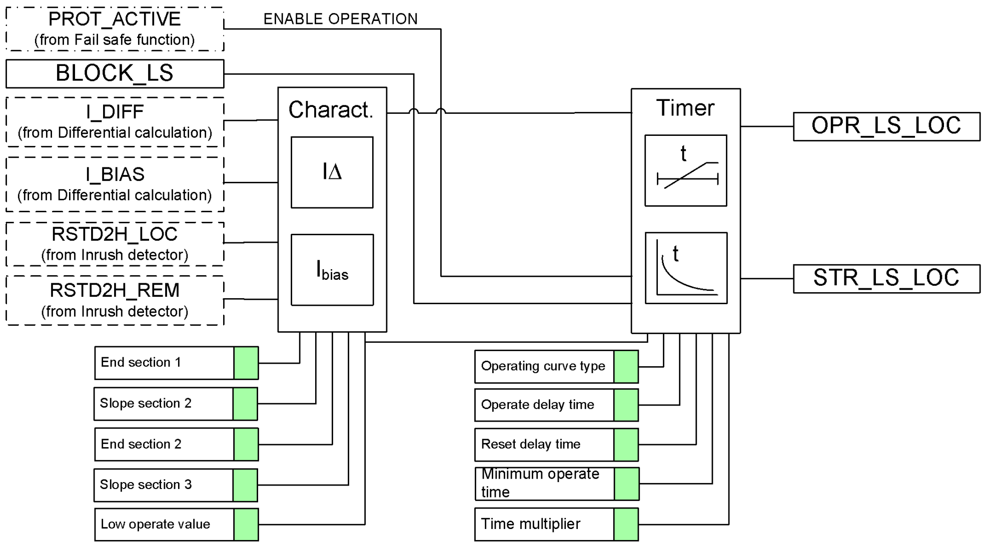



*Figure 75: Operation logic of the stabilized low stage*

The stabilization affects the operation of the function.

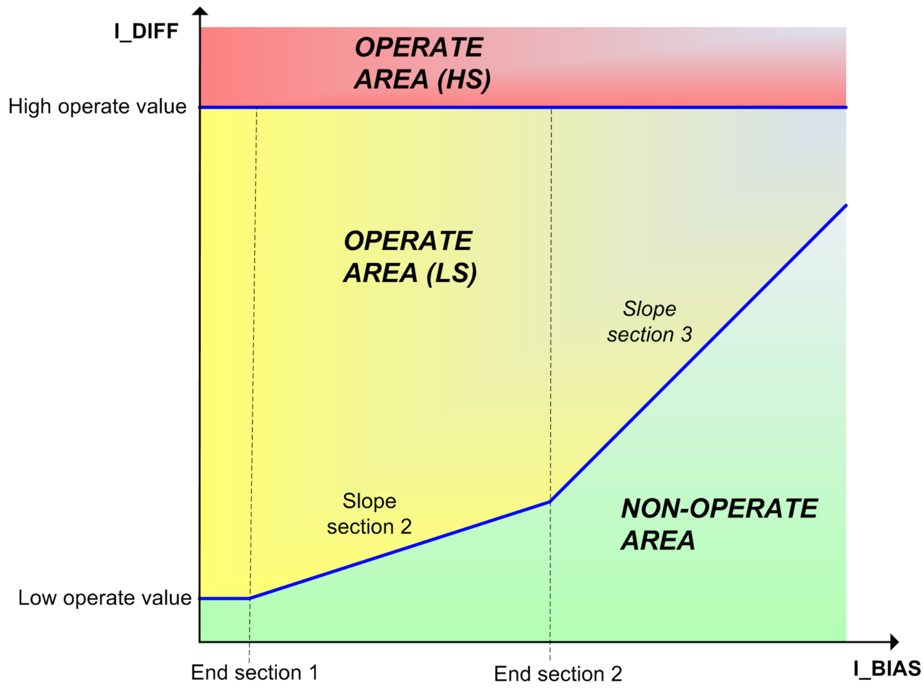



*Figure 76: Operating characteristics of the protection. (LS) stands for the low stage and (HS) for the high stage.*

The slope of the operating characteristic curve of the differential function varies in the different sections of the range:

- 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 basic setting (*Low operate value*) selected for the function. The basic setting allows the appearance of the no-load current of the line, the load current of the tapped load and minor inaccuracies of the current transformers. 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*. This is called the influence area of the starting ratio. In this section, the variations in the starting ratio affect the slope of the characteristic. That is, how big change is required for tripping in the differential current in comparison with the change in the load current. The starting ratio should consider CT errors.
- Section 3 where *End section 2* $< I_b/I_n$. By setting the slope in this section, attention can be paid to prevent unnecessary operation of the protection when there is an external fault, and the differential current is mainly produced by saturated current transformers.

The operation of the differential protection is based on the fundamental frequency components. The operation is accurate and stable and the DC component and the harmonics of the current do not cause unwanted operations.

### Timer

Once activated, the timer activates the STR_LS_LOC output. Depending on the value of the set *Operating curve type*, the timer characteristics are according to DT or IDMT. When the operation timer has reached the value set with the *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPR_LS_LOC output is activated. When the operation mode is according to IDMT, *Low operate value* is used as reference value (Start value) in the IDMT equations presented in the Standard inverse-time characteristics section.

A timer reset state is activated when a drop-off situation happens. The reset is according to the DT characteristics.

For a detailed description of the timer characteristics, see the General function block features section in this manual.

### Instantaneous high stage

In addition to the stabilized low stage, LNPLDF has an instantaneous high stage. The stabilizing is not done with the instantaneous high stage. The instantaneous high stage operates immediately when the differential current amplitude is higher than the set value of the *High operate value* setting. If the ENA_MULT_HS input is active, the *High operate value* setting is internally multiplied by the *High Op value Mult* setting.

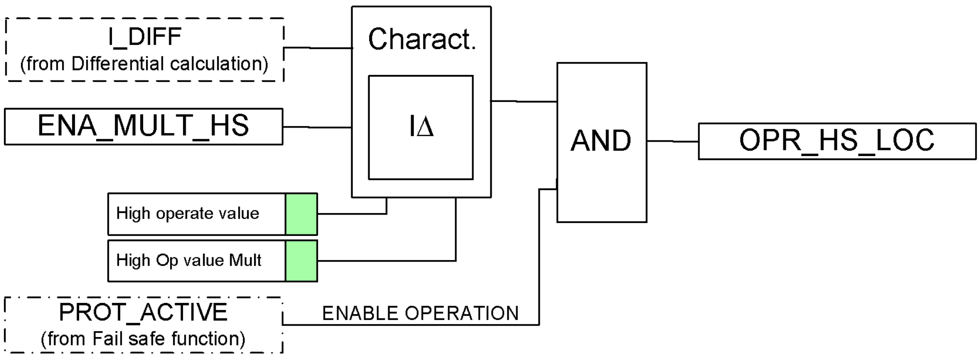



*Figure 77: Operation logic of instantaneous high stage*

### Direct inter-trip

Direct inter-trip is used to ensure the simultaneous opening of the circuit breakers at both ends of the protected line when a fault is detected. Both start and operate signals are sent to the remote end via communication. The direct-intertripping of the line differential protection is included into LNPLDF. The OPERATE output combines the operate signals from both stages, local and remote, so that it can be used for the direct inter-trip signal locally.

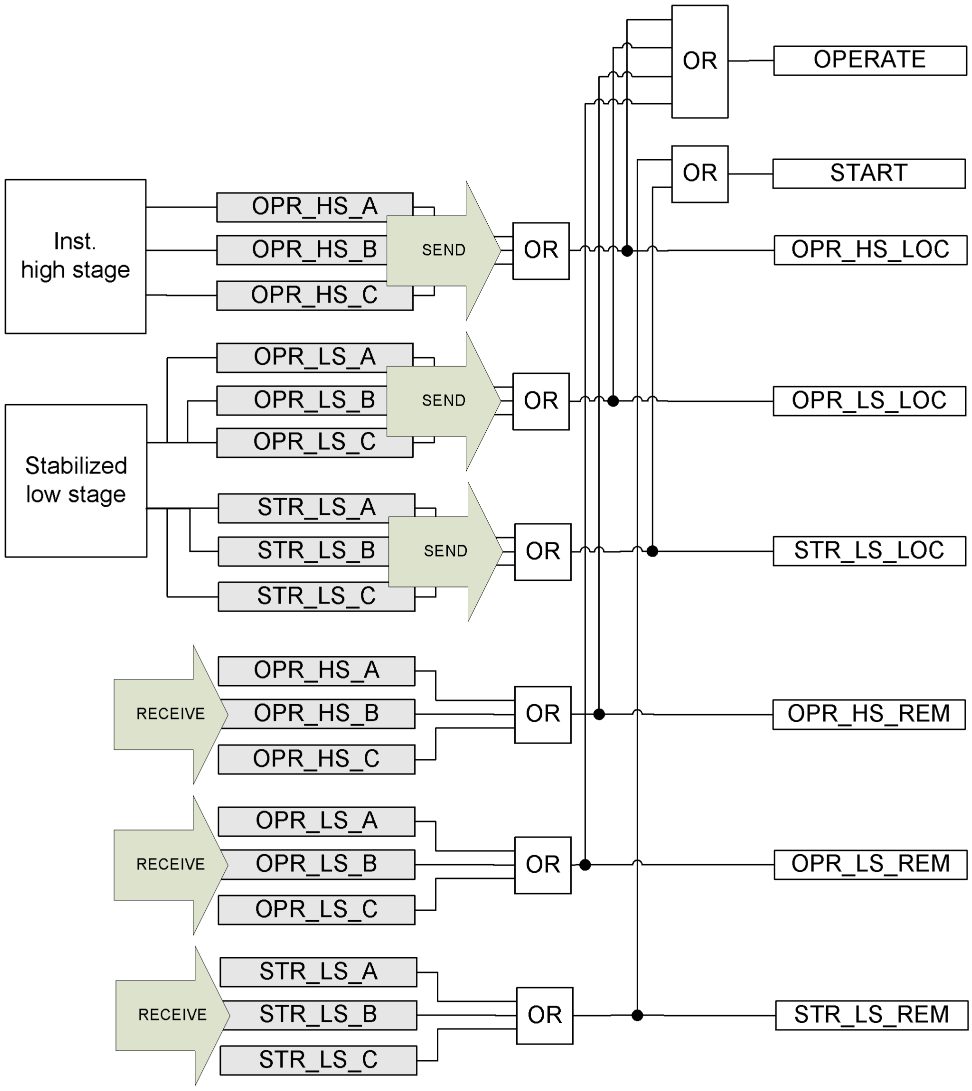



*Figure 78: Operation logic of the direct intertrip function*

The start and operate signals are provided separately for the low and high stages, and in local and remote.

## Blocking functionality

There are two independent inputs that can be used for blocking the function: BLOCK and BLOCK_LS. The difference between these inputs is that BLOCK_LS (when TRUE) blocks only the stabilized low stage leaving the instantaneous high stage operative. BLOCK (when TRUE) blocks both stages and also the PROT_ACTIVE output is updated according to the BLOCK input status, as described in the Fail safe function chapter.

The BLOCK and BLOCK_LS input statuses affect only the behavior of the local protection instance. When a line differential protection stage (stabilized low or instantaneous high) is blocked, also the received remote signals related to the corresponding stage are ignored (received direct inter-trip signals from the remote end). The binary signal transfer functionality should therefore be used for transferring the possible additional blocking information between the local and remote terminals whenever the blocking logic behavior needs to be the same on both line ends.

### Test mode

The line differential function in one IED can be set to test mode, that is, the *Operation* setting is set to “Test/blocked”. This blocks the line differential protection outputs in the IED and sets the remote IED to a remote test mode, such that the injected currents are echoed back with the shifted phase and settable amplitude. It is also possible that both IEDs are simultaneously in the test mode. When the line differential protection function is in the test mode:

- The remote end IED echoes locally injected current samples back with the shifted phase and settable amplitude.
- The operation of both stages (stabilized low or instantaneous high) are blocked, and also the direct inter-trip functionality is blocked (both receive and send) in the IED where the test mode is active.
- The remote end line differential protection function that is in the normal mode (On) is not affected by the local end being in the test mode. This means that the remote end function is operative but, at the same time, it ignores the received current samples from the other end IED which is in the test mode.
- The `PROT_ACTIVE` output is false only in the IED that is currently in the test mode.

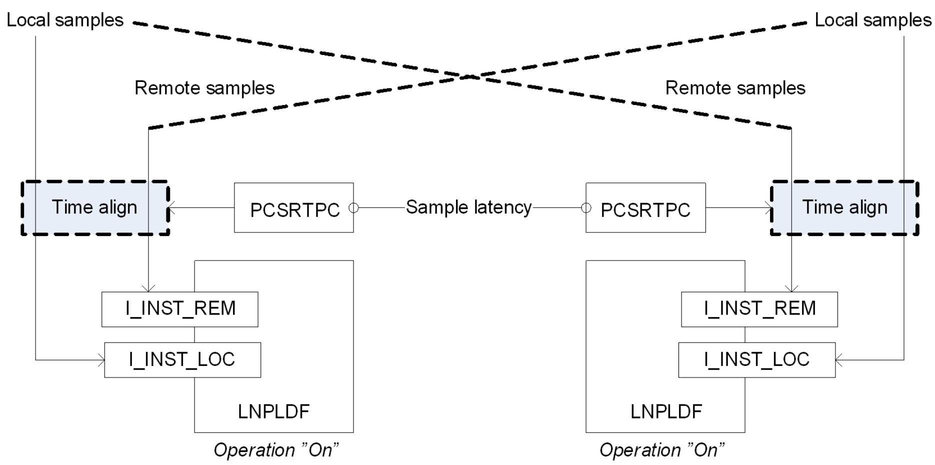



*Figure 79: Operation during the normal operation of the line differential protection*

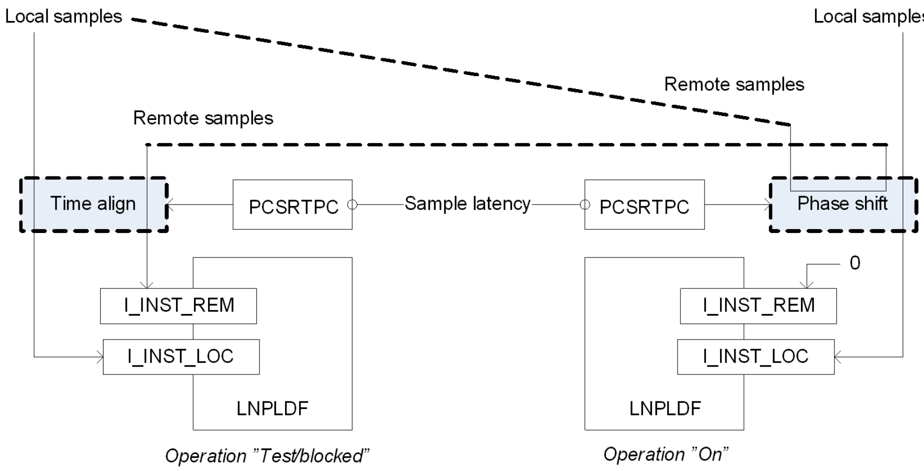



*Figure 80: Operation during test operation of the line differential protection*

### 4.3.1.5 Commissioning

The commissioning of the line differential protection scheme would be difficult without any support features in the functionality because of the relatively long distance between the IEDs. This has been taken into consideration in the design of the line differential protection. The communication channel can be used for echoing the locally fed current phasors from the remote end. By using this mode, it is possible to verify that differential calculation is done correctly in each phase. Also, the protection communication operation is taken into account with the differential current calculation when this test mode is used.

#### Required material for testing the IED

- Calculated settings
- Terminal diagram
- Circuit diagrams
- Technical and application manuals of the IED
- Single of three-phase secondary current source
- Single phase primary current source
- Timer with start and stop interfaces
- Auxiliary voltage source for the IEDs
- PC with related software, a web browser for web HMI

The setting and configuration of the IED must be completed before testing.

The terminal diagram, available in the technical manual, is a general diagram of the IED. Note, that the same diagram is not always applicable to each specific delivery, especially for the configuration of all the binary inputs and outputs. Therefore, before testing, check that the available terminal diagram corresponds to the IED.

Also, the circuit diagrams of the application are recommended to be available. Especially these are required for checking the terminal block numbers of the current, trip, alarm and possibly other auxiliary circuits.

The technical and application manuals contain application and functionality summaries, function blocks, logic diagrams, input and output signals, setting parameters and technical data sorted per function.

The minimum requirement for a secondary current injection test device is the ability to work as a one phase current source.

Prepare the IED for the test before testing a particular function. Consider the logic diagram of the tested protection function when performing the test. All included functions in the IED are tested according to the corresponding test instructions in this chapter. The functions can be tested in any order according to user preferences. Therefore, the test instructions are presented in alphabetical order. Only the functions that are in use (*Operation* is set to "On") should be tested.

The response from the test can be viewed in different ways:

- Binary output signals
- Monitored data values in the local HMI (logical signals)
- A PC with a web browser for web HMI use (logical signals and phasors).

All used setting groups should be tested.

## Checking the external optical and electrical connections

The user must check the installation to verify that the IED is connected to the other required parts of the protection system. The IED and all the connected circuits are to be de-energized during the check-up.

### Checking CT circuits

The CTs must be connected in accordance with the terminal diagram provided with the IED, both with regards to phases and polarity. The following tests are recommended for every primary CT or CT core connected to the IED:

- Primary injection test to verify the current ratio of the CT, the correct wiring up to the protection IED and correct phase sequence connection (that is L1, L2, L3.)
- Polarity check to prove that the predicted direction of secondary current flow is correct for a given direction of primary current flow. This is an essential test for the proper operation of the directional function, protection or measurement in the IED.
- CT secondary loop resistance measurement to confirm that the current transformer secondary loop dc resistance is within specification and that there are no high resistance joints in the CT winding or wiring.
- CT excitation test to ensure that the correct core in the CT is connected to the IED. Normally only a few points along the excitation curve are checked to ensure that there are no wiring errors in the system, for example due to a mistake in connecting the CT's measurement core to the IED.

- CT excitation test to ensure that the CT is of the correct accuracy rating and that there are no short circuited turns in the CT windings. Manufacturer's design curves should be available for the CT to compare the actual results.
- Check the earthing of the individual CT secondary circuits to verify that each three-phase set of main CTs is properly connected to the station earth and only at one electrical point.
- Insulation resistance check.
- Phase identification of CT shall be made.

Both primary and secondary sides must be disconnected from the line and IED when plotting the excitation characteristics.

If the CT secondary circuit is opened or its earth connection is missing or removed without the CT primary being de-energized first, dangerous voltages may be produced. This can be lethal and damage, for example, insulation. The re-energizing of the CT primary should be inhibited as long as the CT secondary is open or unearthed.

#### Checking the power supply

Check that the auxiliary supply voltage remains within the permissible input voltage range under all operating conditions. Check that the polarity is correct.

#### Checking binary I/O circuits

### Binary input circuits

Always check the entire circuit from the equipment to the IED interface to make sure that all signals are connected correctly. If there is no need to test a particular input, the corresponding wiring can be disconnected from the terminal of the IED during testing. Check all the connected signals so that both input voltage level and polarity are in accordance with the IED specifications. However, attention must be paid to the electrical safety instructions.

### Binary output circuits

Always check the entire circuit from the IED to the equipment interface to make sure that all signals are connected correctly. If a particular output needs to be tested, the corresponding wiring can be disconnected from the terminal of the IED during testing. Check all the connected signals so that both load and polarity are in accordance with the IED specifications. However, attention must be paid to the electrical safety instructions.

#### Checking optical connections

Check that the Tx and Rx optical connections are correct.

### Applying required settings for the IED

Download all calculated settings and measurement transformer parameters in the IED.

### Connecting test equipment to the IED

Before testing, connect the test equipment according to the IED specific connection diagram.

Pay attention to the correct connection of the input and output current terminals. Check that the input and output logical signals in the logic diagram for the function under test are connected to the corresponding binary inputs and outputs of the IED. Also, pay attention to selecting the correct auxiliary voltage source according to the power supply module of the IED. Also, pay attention to selecting the correct auxiliary voltage source according to the power supply module of the IED.

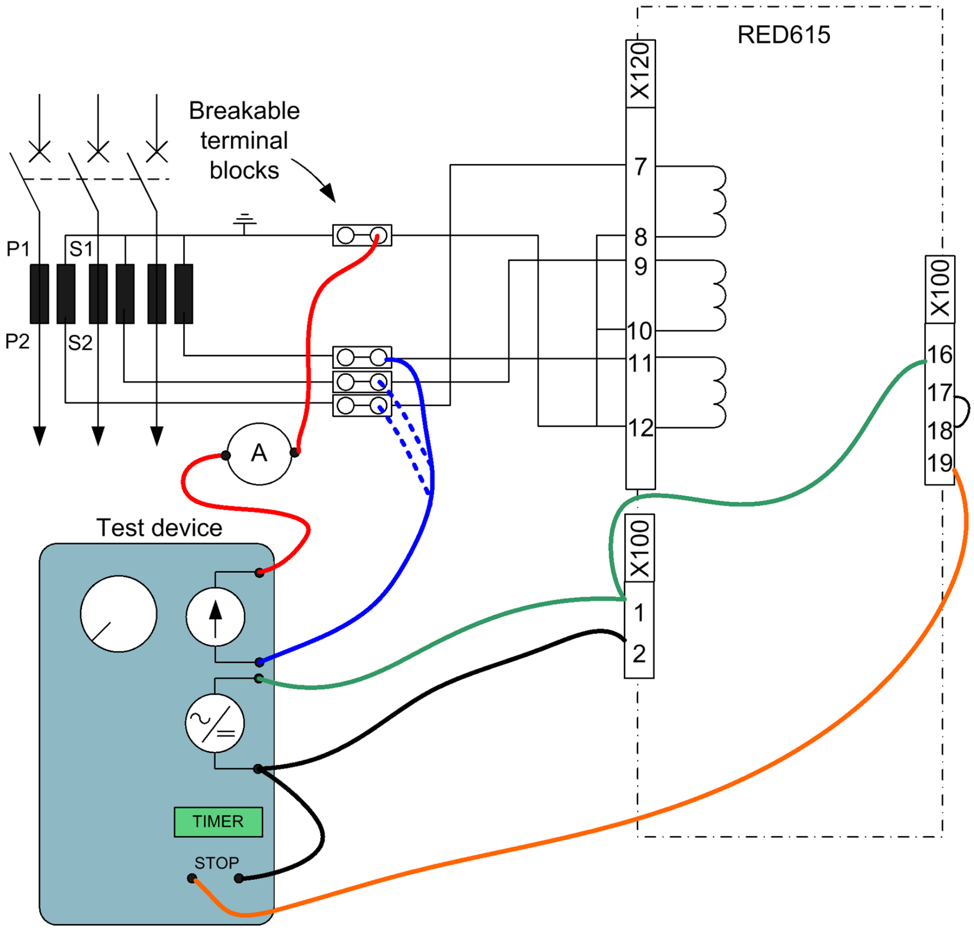



*Figure 81: Example of connections to test the line differential IED*

### Secondary current injection

There are two alternative modes to check the operation of a line differential IED. These are not exclusive methods for each other and can be used for various test on the IED.

#### Normal mode

In normal mode, that is, the mode when the function is on normal operation, the local end IED sends phasors to the remote end IED and receives phasors measured by the remote end IED. This mode can be used in testing the operating level and time of the low and high stages of the local end IED. This is due to a test situation when the remote end does not measure any current and therefore, all the current fed to the local end current circuit is seen as differential current at both ends.

Testing of the line differential protection is done with both IEDs separated geographically from each other. It is important to note that local actions in one IED cause operation also in the remotely located IED. When testing the line differential function, actions have to be done in both IEDs.

Before the test, the trip signal to the circuit breaker shall be blocked, for example by breaking the trip circuit by opening the terminal block or by using some other suitable method.

When injecting current to one phase in the local end IED, the current is seen as a differential current at both ends. If a current $I_{injected}$ is injected, L1 in phase L1, the differential and stabilizing currents for phase L1 are:

$$IDIFF\_A = 2 \times IBIAS\_A = I_{injected}$$

(Equation 16)

The operation is equal for phases L2 and L3.

#### Verifying the settings

Procedure

1. Block the unwanted trip signals from the IED units involved.
2. Inject a current in phase L1 and increase the current until the function operates for phase L1.
   The injected operate current shall correspond to the set *Low operate value*.
   The monitored values for IDIFF_A and IBIAS_A should be equal to the injected current.
3. Repeat point 2 by current injection in phases L2 and L3.
4. Measure the operating time by injecting the single-phase current in phase 1.
   The injected current should be four times the operating current. The time measurement is stopped by the trip output from the IED unit.
5. Disconnect the test equipment and reconnect the current transformers and all other circuits including the trip circuit.

### Phasor echoing method

The line differential function in one IED can be set to special test mode, that is, the *Operation* setting is set to “Test/blocked”. When this mode is in use, the remote end IED echoes locally injected current phasors back with the shifted phase and settable amplitude. The local end line differential function is also automatically blocked during this and the remote end line differential function discards the phasors it receives from the IED that is in the test mode

When the test mode is active, the *CT connection type* and *CT ratio correction* setting parameter values are still used by the line differential protection function as in the normal operation mode. These can be used for shifting the phase (0 or 180 degrees) and setting the amplitude of the echoed back phasors. For example, if three phase currents are injected to the local end IED which is also set to the test mode, the selected *CT connection type* is "Type 2" and the *CT ratio correction* setting parameter value is 0.500.

**Parameter Setting**

| Group/Parameter Name | IED Value | New Value | Unit | Min. | Max. | Step |
|---|---|---|---|---|---|---|
| Operation | test/blocked | test/blocked | | | | |
| High operate value | 2000 | 2000 | % | 200 | 4000 | |
| High Op value Mult | 1.0 | 1.0 | | 0.5 | 1.0 | |
| Low operate value | 10 | 10 | % | 10 | 200 | |
| End section 1 | 100 | 100 | % | 0 | 200 | |
| Slope section 2 | 50 | 50 | % | 10 | 50 | |
| End section 2 | 500 | 500 | % | 200 | 2000 | |
| Slope section 3 | 150 | 150 | % | 100 | 200 | |
| Operate delay time | 100 | 100 | ms | 40 | 200000 | |
| Operating curve type | IEC Def. Time | IEC Def. Time | | | | |
| Time multiplier | 1.00 | 1.00 | | 0.05 | 15.00 | |
| Start value 2.H | 20 | 20 | % | 10 | 50 | |
| Restraint mode | None | None | | | | |
| Reset delay time | 0 | 0 | ms | 0 | 60000 | |
| Minimum operate time | 40 | 40 | ms | 40 | 60000 | |
| CT ratio correction | 0.500 | 0.500 | | 0.200 | 5.000 | |
| CT connection type | Type 2 | Type 2 | | | | |

*Figure 82: An example of a test mode situation where three phase currents are injected to the local end IED*

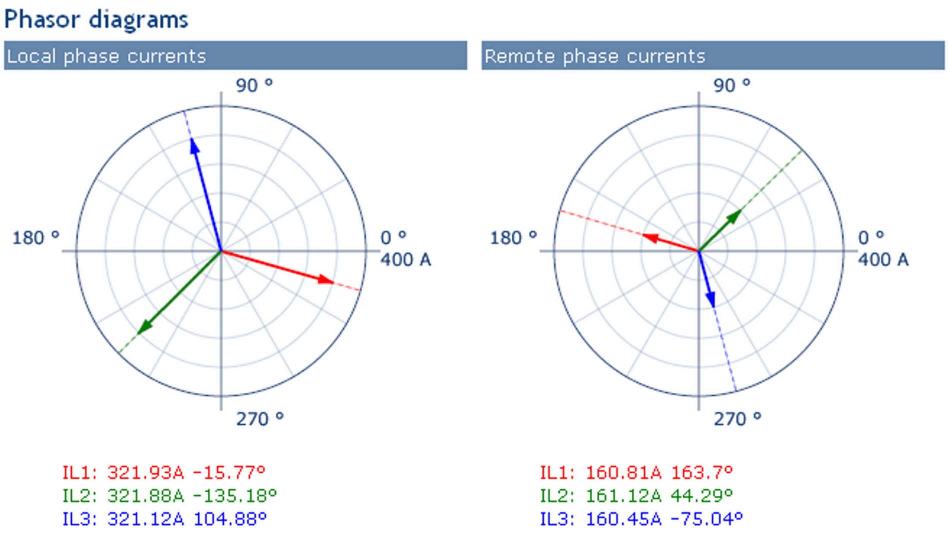



*Figure 83: Local and remote end currents presented in a web HMI of the IED*

## 4.3.1.6 Application

LNPLDF is designed for the differential protection of overhead line and cable feeders in a distribution network. LNPLDF provides absolute selectivity and fast operating times as unit protection also in short lines where distance protection cannot be applied.

LNPLDF provides selective protection for radial, looped and meshed network topologies and can be used in isolated neutral networks, resistance earthed networks, compensated (impedance earthed) networks and solidly earthed networks. In a typical network configuration where the line differential protection scheme is applied, the protected zone, that is, the line or cable, is fed from two directions.

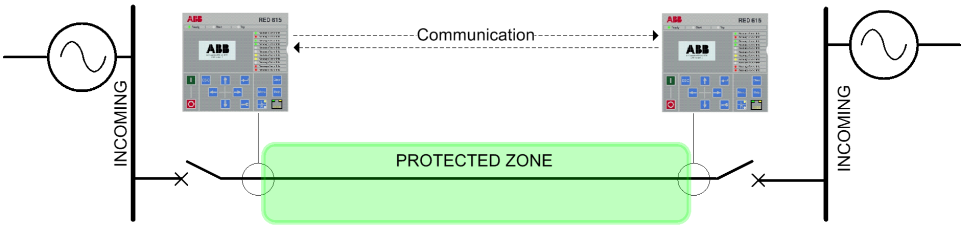



*Figure 84: Line protection with phase segregated line differential IEDs*

LNPLDF can be utilized for various types of network configurations or topologies. Case A shows the protection of a ring-type distribution network. The network is also used in the closed ring mode. LNPLDF is used as the main protection for different sections of the feeder. In case B, the interconnection of two substations is done with parallel lines and each line is protected with the line differential protection. In case C, the connection line to mid scale power generation (typical size around 10 - 50MVA) is protected with the line differential function. In case D, the connection between two substations and a small distribution transformer is located at the tapped load. The usage of LNPLDF is not limited to these applications.

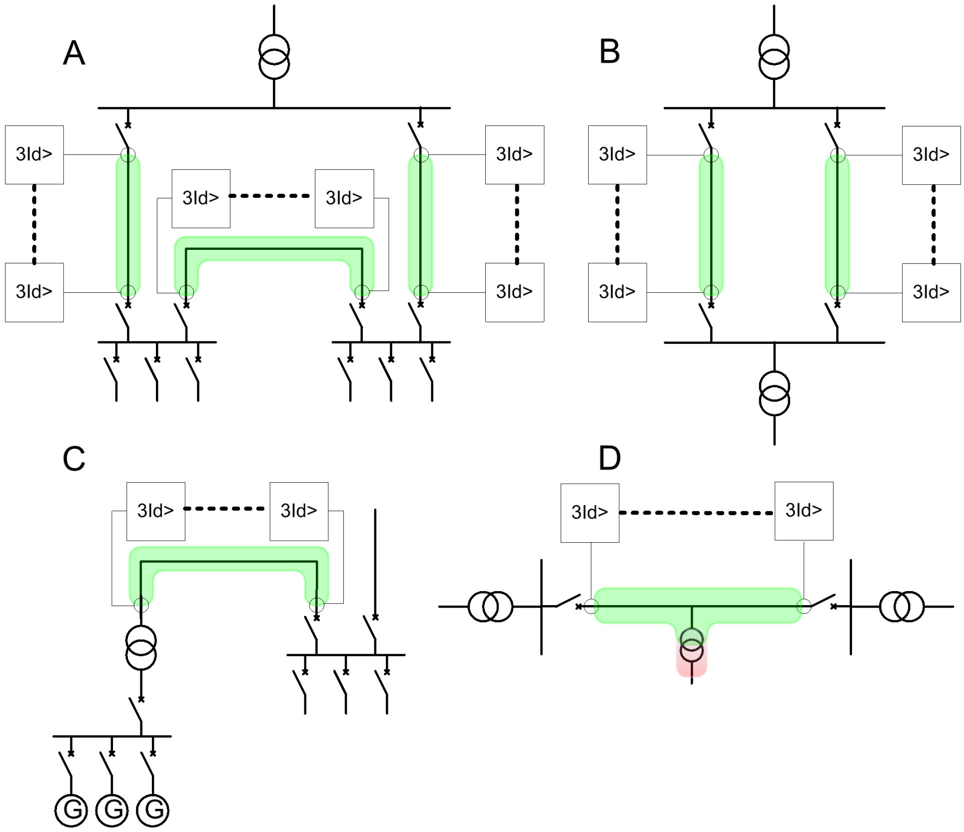



*Figure 85: Line differential applications*

## Communication supervision

A typical line differential protection application includes LNPLDF as main protection. Backup over current functions are needed in case of a protection communication failure. When the communication supervision function detects a failure in the communication between the protective units, the safe operation of the line is still guaranteed by blocking the line differential protection and unblocking the over current functions.

When a communication failure is detected, the protection communication supervision function issues block for the LNPLDF line differential protection and unblock for the instantaneous and high stages (instance 2) of the over current protection. These are used to give backup protection for the remote end feeder protection IED. Although there can be a situation where the selectivity is weaker than usually, the protection should still be available for the system.

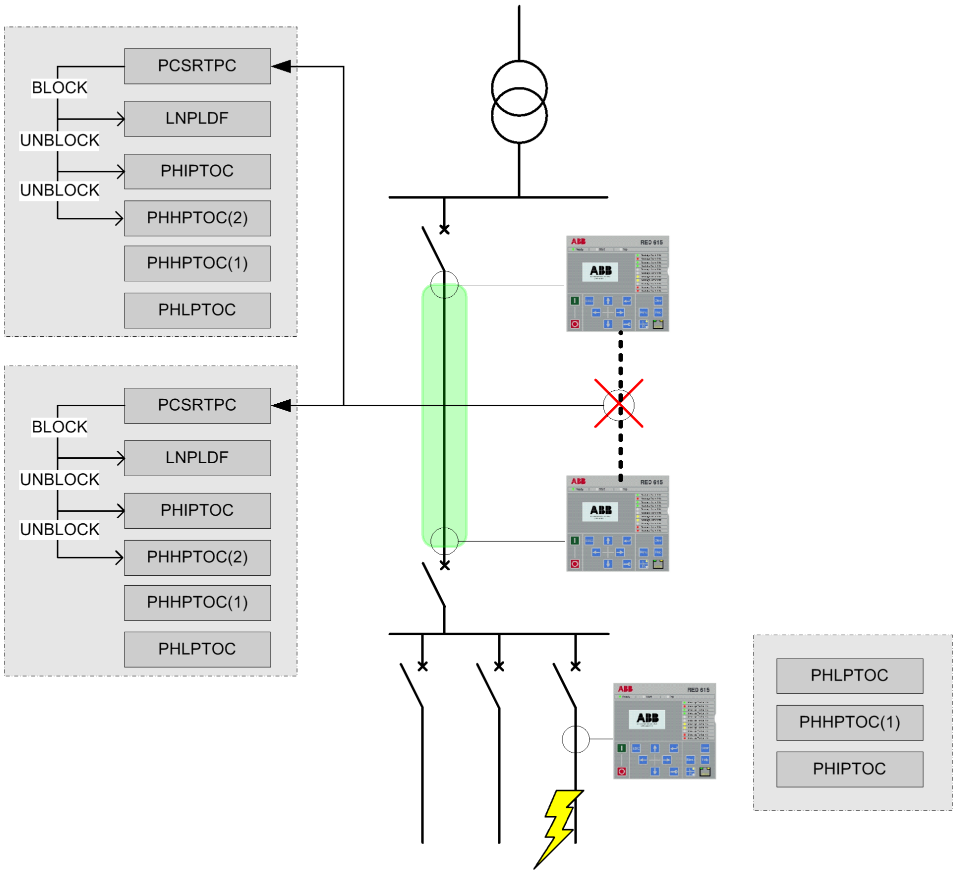
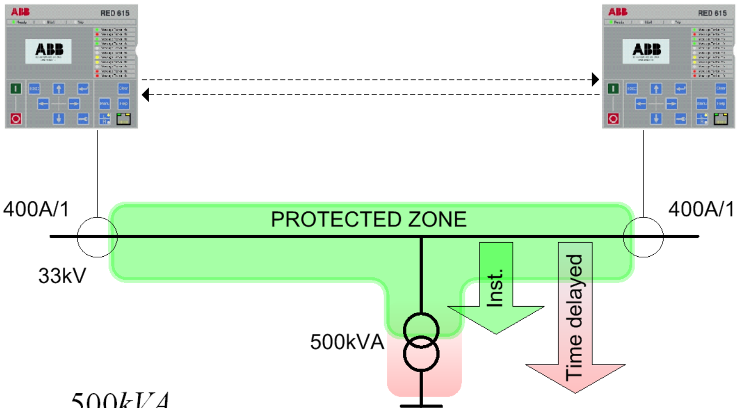



*Figure 86: Protection communication supervision detects failures on communication*

## Small power transformers in a tap

With a relatively small power transformer in a line tap, the line differential protection can be applied without the need of current measurement from the tap. In such cases, the line differential function is time delayed for low differential currents below the high set limit and LNPLDF coordinates with the downstream IEDs in the relevant tap. For differential currents above the set limit, the operation is instantaneous. As a consequence, when the load current of the tap is negligible, the low resistive line faults are cleared instantaneously at the same time as maximum sensitivity for the high resistive faults are maintained but with a time delayed operation.

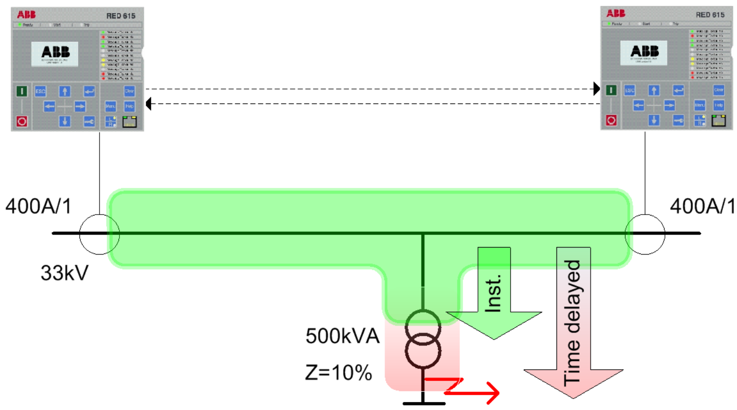



$$I_L = \frac{500kVA}{\sqrt{3} \cdot 33kV} \cong 8.75A$$

$$\mathrm{I}_\Delta > \left[\frac{8.75A}{400\ A}\right] * 1\mathrm{A} = 0.02A = 2\%$$

*Figure 87: Influence of the tapped transformer load current to the stabilized low stage setting*

The stabilized stage provides both DT and IDMT characteristics that are used to provide time selective protection against faults external to the instantaneous stage coverage. The impedance of the line is typically an order of magnitude lower than the transformer impedance providing significantly higher fault currents when the fault is located on the line.




$$I_F = \frac{1.1 \cdot 500kVA}{\sqrt{3} \cdot 33kV \cdot 0.10} \cong 96.23A$$

$$\mathrm{I}_\Delta < \left[\frac{96.23A}{400\ A}\right] * 1\mathrm{A} = 0.24A = 24\%$$

*Figure 88: Influence of the short circuit current at LV side of the tapped transformer to the differential current*

### Detection of the inrush current during transformer start-up

When the line is energized, the transformer magnetization inrush current is seen as differential current by the line differential protection and may cause malfunction of the protection if not taken into account. The inrush situation may only be detected on one end but the differential current is always seen on both ends. The inrush current includes high order harmonic components which can be detected and used as the blocking criteria for the stabilized stage. The inrush detection information is changed between two ends so that fast and safe blocking of the stabilized stage can be issued on both ends.

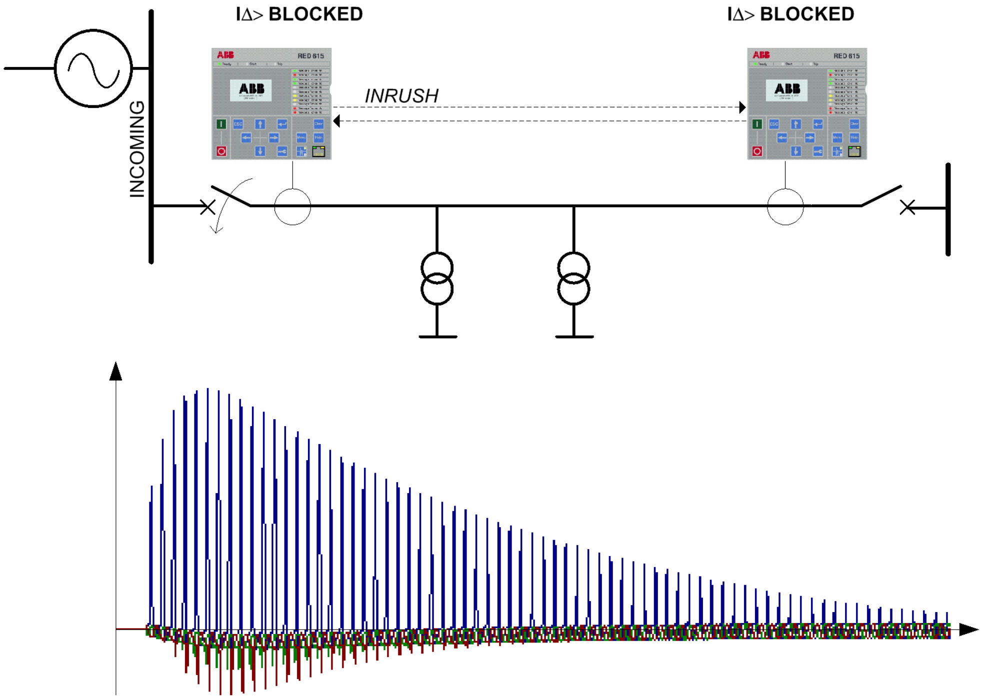



*Figure 89: Blocking of line differential functions during detected transformer startup current*

If the protection stage is allowed to start during the inrush situation, the time delay can be selected in such a way that the stabilized stage does not operate in the inrush situation.

## 4.3.1.7 Signals

*Table 170: LNPLDF Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| I_LOC_A | SIGNAL | 0 | Phase A local current |
| I_LOC_B | SIGNAL | 0 | Phase B local current |
| I_LOC_C | SIGNAL | 0 | Phase C local current |
| I_REM_A | SIGNAL | 0 | Phase A remote current |

Table continues on next page

| Name | Type | Default | Description |
|---|---|---|---|
| I_REM_B | SIGNAL | 0 | Phase B remote current |
| I_REM_C | SIGNAL | 0 | Phase C remote current |
| BLOCK | BOOLEAN | 0=False | Signal for blocking the function |
| BLOCK_LS | BOOLEAN | 0=False | Signal for blocking the stab. stage |
| ENA_MULT_HS | BOOLEAN | 0=False | Enables the high stage multiplier |

*Table 171: LNPLDF Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate, local or remote, stabilized or instantaneous stage |
| START | BOOLEAN | Start, local or remote |
| STR_LS_LOC | BOOLEAN | Start stabilized stage local |
| STR_LS_REM | BOOLEAN | Start stabilized stage remote |
| OPR_LS_LOC | BOOLEAN | Operate stabilized stage local |
| OPR_LS_REM | BOOLEAN | Operate stabilized stage remote |
| OPR_HS_LOC | BOOLEAN | Operate instantaneous stage local |
| OPR_HS_REM | BOOLEAN | Operate instantaneous stage remote |
| RSTD2H_LOC | BOOLEAN | Restraint due 2nd harmonics detected local |
| RSTD2H_REM | BOOLEAN | Restraint due 2nd harmonics detected remote |
| PROT_ACTIVE | BOOLEAN | Status of the protection, true when function is operative |

### 4.3.1.8 Settings

*Table 172: LNPLDF Group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| High operate value | 200...4000 | %In | 1 | 2000 | Instantaneous stage operate value |
| High Op value Mult | 0.5...1.0 | | 0.1 | 1.0 | Multiplier for scaling the high stage operate value |
| Low operate value | 10...200 | %In | 1 | 10 | Basic setting for the stabilized stage start |
| End section 1 | 0...200 | %In | 1 | 100 | Turn-point between the first and the second line of the operating characteristics |
| Slope section 2 | 10...50 | % | 1 | 50 | Slope of the second line of the operating characteristics |
| End section 2 | 200...2000 | %In | 1 | 500 | Turn-point between the second and the third line of the operating characteristics |
| Slope section 3 | 100...200 | % | 1 | 150 | Slope of the third line of the operating characteristics |
| Operate delay time | 45...200000 | ms | 1 | 45 | Operate delay time for stabilized stage |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operating curve type | 1=ANSI Ext. inv.<br>3=ANSI Norm. inv.<br>5=ANSI Def. Time<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>12=IEC Ext. inv.<br>15=IEC Def. Time | | | 15=IEC Def. Time | Selection of time delay curve for stabilized stage |
| Time multiplier | 0.05...15.00 | | 0.05 | 1.00 | Time multiplier in IDMT curves |
| Start value 2.H | 10...50 | % | 1 | 20 | The ratio of the 2. harmonic component to fundamental component required for blocking |

*Table 173: LNPLDF Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>4=test/blocked<br>5=off | | | 1=on | Operation mode of the function |
| Restraint mode | 1=None<br>2=Harmonic2 | | | 1=None | Selects what restraint modes are in use |
| Reset delay time | 0...60000 | ms | 1 | 0 | Reset delay time for stabilized stage |
| Minimum operate time | 45...60000 | ms | 1 | 45 | Minimum operate time for stabilized stage IDMT curves |
| CT ratio correction | 0.200...5.000 | | 0.001 | 1.000 | Remote phase current transformer ratio correction |
| CT connection type | 1=Type 1<br>2=Type 2 | | | 1=Type 1 | CT connection type. Determined by the directions of the connected current transformers. |

## 4.3.1.9 Monitored data

*Table 174: LNPLDF Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| I_INST_LOC_A | FLOAT32 | 0.00...40.00 | xIn | Local phase A Amplitude |
| I_INST_LOC_B | FLOAT32 | 0.00...40.00 | xIn | Local phase B Amplitude |
| I_INST_LOC_C | FLOAT32 | 0.00...40.00 | xIn | Local phase C Amplitude |
| I_INST_REM_A | FLOAT32 | 0.00...40.00 | xIn | Remote phase A Amplitude after correction |
| I_INST_REM_B | FLOAT32 | 0.00...40.00 | xIn | Remote phase B Amplitude after correction |
| I_INST_REM_C | FLOAT32 | 0.00...40.00 | xIn | Remote phase C Amplitude after correction |
| IDIFF_A | FLOAT32 | 0.00...80.00 | xIn | Differential current phase A |
| IDIFF_B | FLOAT32 | 0.00...80.00 | xIn | Differential current phase B |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| IDIFF_C | FLOAT32 | 0.00...80.00 | xIn | Differential current phase C |
| IBIAS_A | FLOAT32 | 0.00...80.00 | xIn | Stabilization current phase A |
| IBIAS_B | FLOAT32 | 0.00...80.00 | xIn | Stabilization current phase B |
| IBIAS_C | FLOAT32 | 0.00...80.00 | xIn | Stabilization current phase C |
| I_ANGL_DIFF_A | FLOAT32 | -180.00...180.00 | deg | Current phase angle differential between local and remote, phase A |
| I_ANGL_DIFF_B | FLOAT32 | -180.00...180.00 | deg | Current phase angle differential between local and remote, phase B |
| I_ANGL_DIFF_C | FLOAT32 | -180.00...180.00 | deg | Current phase angle differential between local and remote, phase C |
| START_DUR | FLOAT32 | 0.00...100.00 | % | Ratio of start time / operate time |
| LNPLDF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |
| IL1-diff-A | FLOAT32 | 0.00...80.00 | xIn | Measured differential current amplitude phase IL1 |
| IL2-diff-A | FLOAT32 | 0.00...80.00 | xIn | Measured differential current amplitude phase IL2 |
| IL3-diff-A | FLOAT32 | 0.00...80.00 | xIn | Measured differential current amplitude phase IL3 |
| IL1-bias-A | FLOAT32 | 0.00...80.00 | xIn | Measured bias current amplitude phase IL1 |
| IL2-bias-A | FLOAT32 | 0.00...80.00 | xIn | Measured bias current amplitude phase IL2 |
| IL3-bias-A | FLOAT32 | 0.00...80.00 | xIn | Measured bias current amplitude phase IL3 |

## 4.3.1.10 Technical data

*Table 175: LNPLDF Technical data*

| Characteristics | Value | |
|---|---|---|
| Operation accuracy [1)] | Depending on the frequency of the current measured: $f_n$ ±2 Hz | |
| | Low stage | ±2.5% of the set value |
| | High stage | ±2.5% of the set value |
| Table continues on next page | | |

| Characteristics | Value | | |
|---|---|---|---|
| | Minimum | Typical | Maximum |
| High stage, operate time 2)3) | 22 ms | 25 ms | 29 ms |
| Reset time | < 40 ms | | |
| Reset ratio | Typical 0.96 | | |
| Retardation time (Low stage) | < 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 set value or ±20 ms 4) | | |

1) With the symmetrical communication channel (as when using dedicated fiber optic).
2) Without additional delay in the communication channel (as when using dedicated fiber optic).
3) Including the delay of the output contact. When differential current = 2 x *High operate value* and $f_n$ = 50 Hz.
4) *Low operate value* multiples in range of 1.5 to 20.

## 4.3.2 Transformer differential protection for two winding transformers TR2PTDF

### 4.3.2.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Transformer differential protection for two winding transformers | TR2PTDF | 3dI>T | 87T |

### 4.3.2.2 Function block

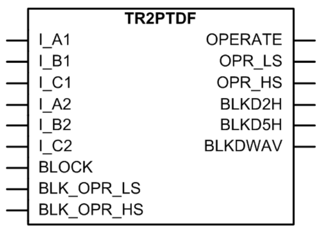



*Figure 90: Function block symbol*

### 4.3.2.3 Functionality

The transformer differential protection TR2PTDF is designed to protect two-winding transformers and generator-transformer blocks. TR2PTDF includes low biased and high instantaneous stages.

The biased low stage provides a fast clearance of faults while remaining stable with high currents passing through the protected zone increasing errors on current measuring. The second harmonic restraint, together with the waveform based algorithms, ensures that the low stage does not operate due to the transformer inrush currents. The fifth harmonic restraint ensures that the low stage does not operate on apparent differential current caused by a harmless transformer over-excitation.

The instantaneous high stage provides a very fast clearance of severe faults with a high differential current regardless of their harmonics.

The setting characteristic can be set more sensitive with the aid of tap changer position compensation. The correction of transformation ratio due to the changes in tap position is done automatically based on the tap changer status information.

### 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 transformer differential protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

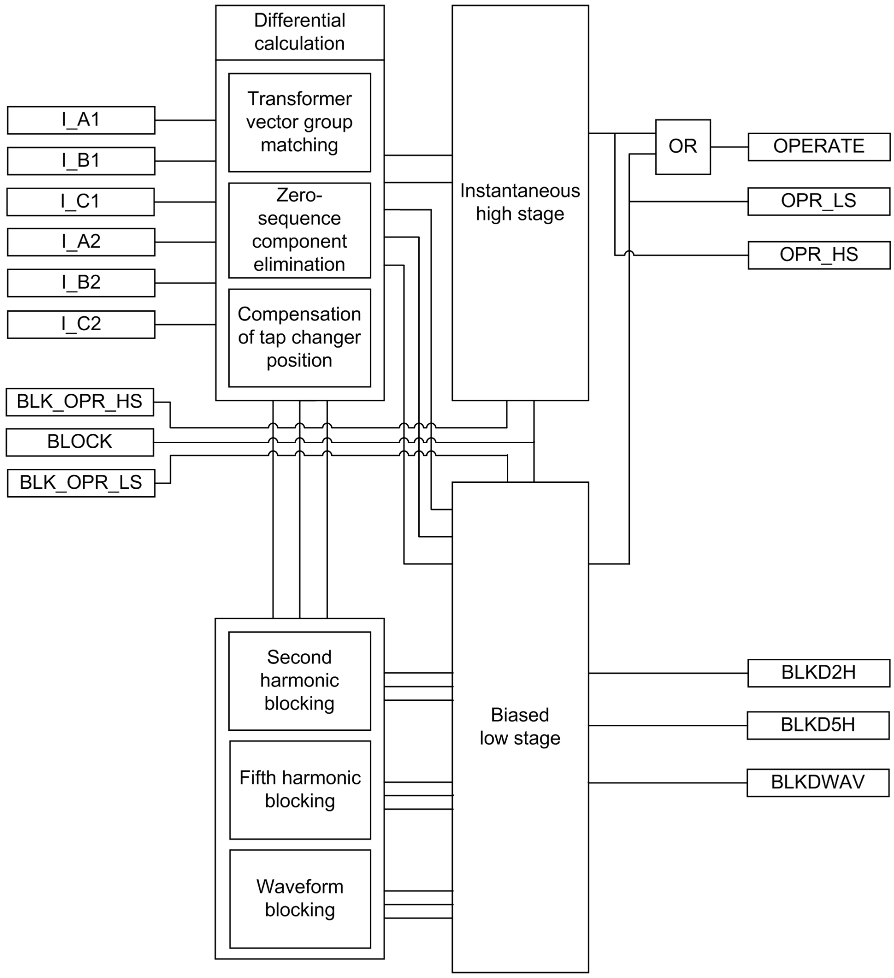



*Figure 91: Functional module diagram. I_x1 and I_x2 represent the phase currents of winding 1 and winding 2*

## Differential calculation

TR2PTDF operates phase-wisely on a difference of incoming and outgoing currents. The positive direction of the currents is towards the protected object.

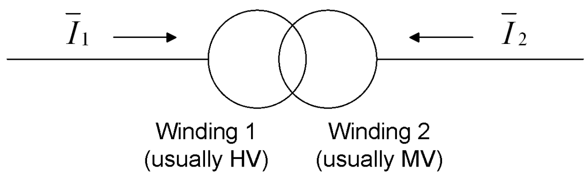



*Figure 92: Positive direction of the currents*

$$I_d = \left|\bar{I}_1 + \bar{I}_2\right|$$

(Equation 17)

In a normal situation, no fault occurs in the area protected by TR2PTDF. Then the currents $\bar{I}_1$ and $\bar{I}_2$ are equal and the differential current $I_d$ is zero. In practice, however, the differential current deviates from zero in normal situations. In the power transformer protection, the differential current is caused by CT inaccuracies, variations in tap changer position (if not compensated), transformer no-load current and instantaneous transformer inrush currents. An increase in the load current causes the differential current, caused by the CT inaccuracies and the tap changer position, to grow at the same percentage rate.

In a biased differential IED in normal operation or during external faults, the higher the load current is the higher is the differential current required for tripping. When an internal fault occurs, the currents on both sides of the protected object are flowing into it. This causes the biasing current to be considerably smaller, which makes the operation more sensitive during internal faults.

$$I_b = \frac{\left|\bar{I}_1 - \bar{I}_2\right|}{2}$$

(Equation 18)

If the biasing current drops below 30 percent of the differential current or if the phase angle between the winding 1 and winding 2 phase currents is less than 50 degrees, a fault has most certainly occurred in the area protected by the differential IED. Then the operate 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 relay. The *Winding 2 type* parameter determines the connections of the phase windings on the low voltage side (“y,”, ”yn,” ”d,” ”z,” ”zn”). Similarly, the *Winding 1 type* parameter determines the connection on winding 1 (”Y”, ”YN”, ”D”, ”Z”, ”ZN”).

The vector group matching can be implemented either on both, winding 1 and winding 2, or only on winding 1 or winding 2, at intervals of 30° with the *Clock number* setting.

When the vector group matching is Yy0 and the *CT connection type* is according to “Type 2”, the phase angle of the phase currents connected to the relay does not change. When the vector group matching is Yy6, the phase currents are turned 180° in the 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 19)

### 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 20)

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 4”, “Clk Num 6”, “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 21)

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. This is taken into account in the table where the supported transformer vector groups are listed and the need for explicit zero-sequence component elimination is stated.

## Compensation of tap changer position

The position of the tap changer used for voltage control can be compensated and the position information is provided for the protection function through the tap position indication function TPOSSLTC1.

Typically, the tap changer is located within the high voltage winding, that is, winding 1, of the power transformer. The *Tapped winding* parameter specifies whether the tap changer is connected to the high voltage side winding or the low voltage side winding. This parameter is also used to enable and disable the automatic adaptation to the tap changer position. The possible values are “Not in use”; “Winding 1”; “Winding 2.”

The *Tap nominal* parameter tells the number of the tap, which results in the nominal voltage (and current). When the current tap position deviates from this value, the input current values on the side where the tap changer resides are scaled to match the currents on the other side.

A correct scaling is determined by the number of steps and the direction of the deviation from the nominal tap and the percentage change in voltage resulting from a deviation of one tap step. The percentage value is set using the *Step of tap* parameter.

The operating range of the tap changer is defined by the *Min winding tap* and *Max winding tap* parameters. The *Min winding tap* parameter tells the tap position number resulting in the minimum effective number of winding turns on the side of the transformer where the tap changer is connected. Correspondingly, the *Max winding tap* parameter tells the tap position number resulting in the maximum effective number of winding turns.

The *Min winding tap* and *Max winding tap* parameters help the tap position compensation algorithm know in which direction the compensation is being made. This ensures also that if the current tap position information is corrupted for some reason, the automatic tap changer position adaptation does not try to adapt to any unrealistic position values.

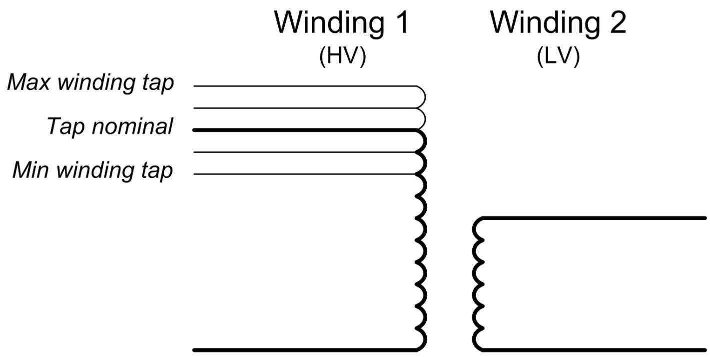



*Figure 93: Simplified presentation of the high voltage and medium voltage windings with demonstration of the Max winding tap, Min winding tap and Tap nominal parameters*

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 22)

### 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 relay, the inrush current represents a differential current, which would cause the relay 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 relay's biased low stage at a magnetizing inrush current is based on the ratio of the amplitudes of the second harmonic digitally filtered from the differential current and the fundamental frequency (Id2f /Id1f).

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of another transformer running in parallel with the protected transformer already connected to the network.

The ratio of the second harmonic to a fundamental component can vary considerably between the phases. Especially when the delta compensation is done for a Ynd1 connected transformer and the two phases of the inrush currents are otherwise equal but opposite in phase angle, the subtraction of the phases in a delta compensation results in a very small second harmonic component.

Some measures have to be taken in order to avoid the false tripping of a phase having too low a ratio of the second harmonic to the fundamental component. One way could be to always block all the phases when the second harmonic blocking conditions are fulfilled in at least one phase. The other way is to calculate the weighted ratios of the second harmonic to the fundamental component for each phase using the original ratios of the phases. The latter option is used here. The second harmonic ratios I_2H_RAT_x are given in monitored data.

The ratio to be used for second harmonic blocking is therefore calculated as a weighted average on the basis of the ratios calculated from the differential currents of the three phases. The ratio of the concerned phase is of most weight compared to the ratios of the other two phases. In this IED, if the weighting factors are four, one and one, four is the factor of the phase concerned. The operation of the biased stage on the concerned phase is blocked if the weighted ratio of that phase is above the set blocking limit *Start value 2.H* and if blocking is enabled through the *Restraint mode* parameter.

Using separate blocking for the individual phases and weighted averages calculated for the separate phases provides a blocking scheme that is stable at the connection inrush currents.

If the peak value of the differential current is very high, that is $I_r$> 12 p.u., 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.

Normally, there are low current periods in the differential current during inrush. Also the rate of change of the differential current is very low during these periods. If these features are not present in the differential current, it can be suspected that there is a fault in the transformer. This second harmonic deblocking method is used, for example, in the case of switch on to a fault. This feature can also be enabled and disabled using the *Harmonic deblock 2.H* parameter.

### Fifth harmonic blocking

The inhibition of relay 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 the relay 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.

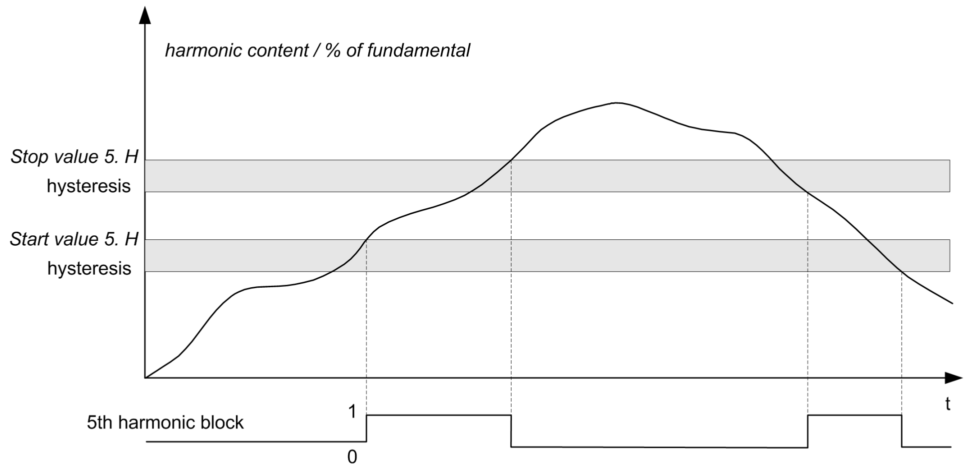



*Figure 94: The limits and operation of the fifth harmonic blocking when both blocking and deblocking features are enabled using the Harmonic deblock 5.H control parameter.*

The fifth harmonic blocking has a hysteresis to avoid rapid fluctuation between "TRUE" and "FALSE". The blocking also has a counter, which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

Also the fifth harmonic deblocking has a hysteresis and a counter which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

### Waveform blocking

The biased low stage can always be blocked with waveform blocking. The stage can not be disabled with the *Restraint mode* parameter. This algorithm has two parts. The first part is intended for external faults while the second is intended for inrush situations. The algorithm has criteria for a low current period during inrush where also the differential current (not derivative) is checked.

### Biased low stage

The current differential protection needs to be biased because the possible appearance of a differential current can be due to something else than an actual fault in the transformer (or generator).

In the case of transformer protection, a false differential current can be caused by:

- CT errors
- Varying tap changer positions (if not automatically compensated)
- Transformer no-load current
- Transformer inrush currents
- Transformer overexcitation in overvoltage
- Underfrequency situations
- CT saturation at high currents passing through the transformer.

The differential current caused by CT errors or tap changer positions increases at the same percent ratio as the load current.

In the protection of generators, the false differential current can be caused by:

- CT errors
- CT saturation at high currents passing through the generator.

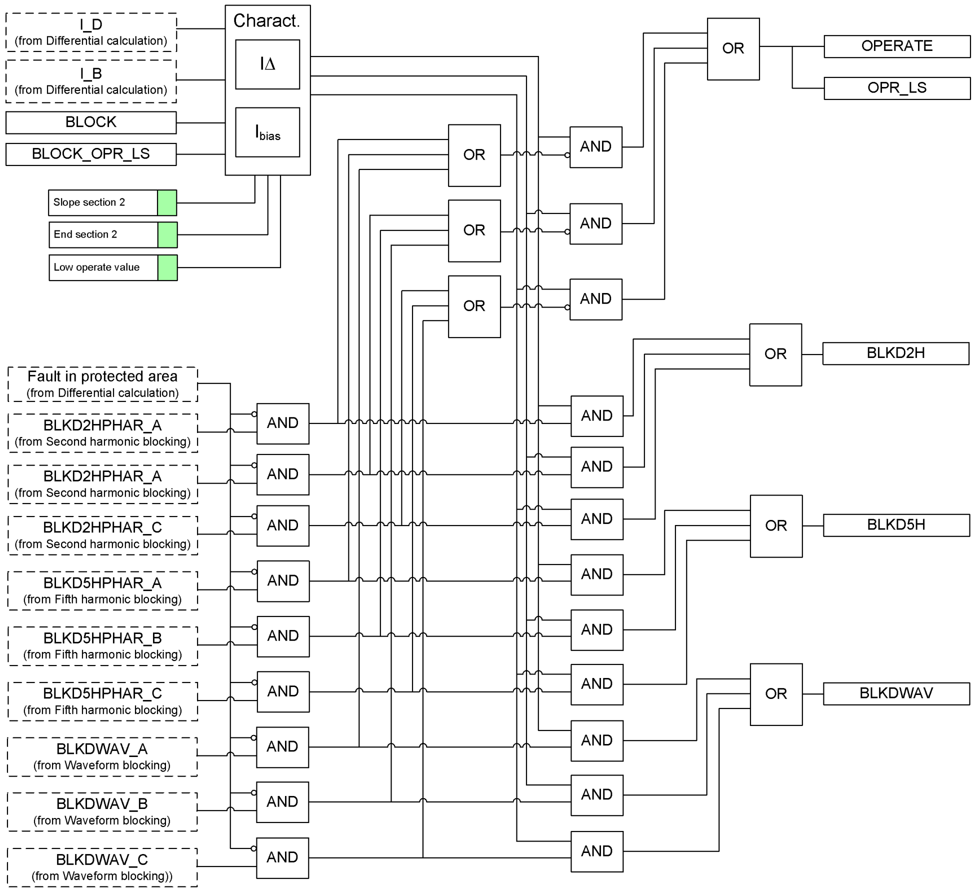



*Figure 95: Operation logic of the biased low stage*

The high currents passing through a protected object can be caused by the short circuits outside the protected area, the large currents fed by the transformer in motor startup or the transformer inrush situations. Therefore, the operation of the differential relay is biased in respect to the load current. In a biased differential relay, the higher the differential current required for the relay to operate, the higher the load current.

The operating characteristic of the biased low stage is determined by *Low operate value*, *Slope section 2* and the setting of the second turning point of the operating characteristic curve, *End section 2* (the first turning point and the slope of the last part of the characteristic are fixed). The settings are the same for all the phases. When the differential current exceeds the operating value determined by the operating characteristic, the differential function awakes. If the differential current stays above the operating value continuously for a 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.

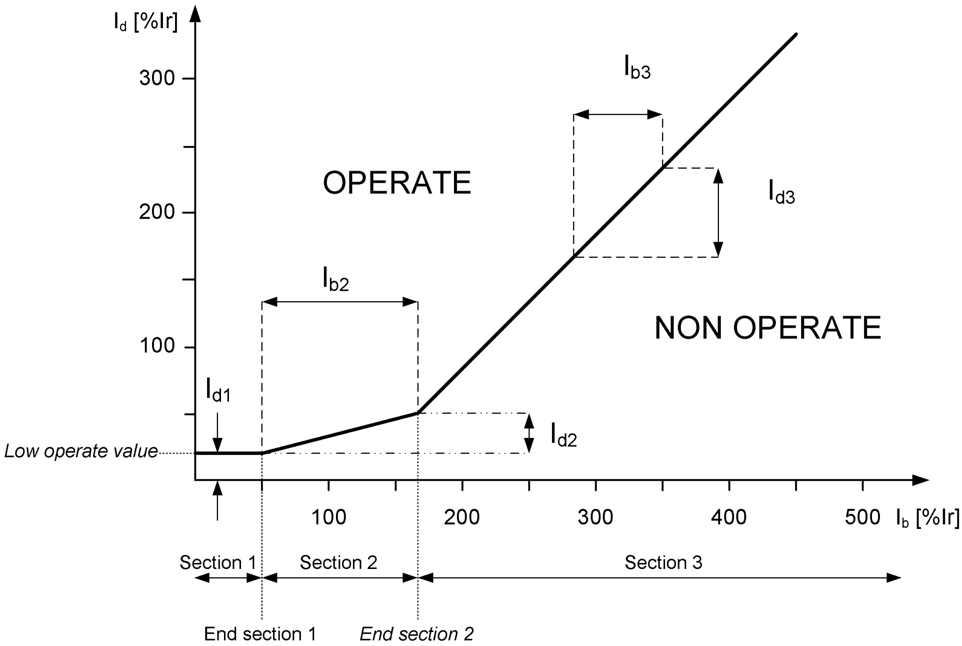



*Figure 96: Operation characteristic for biased operation of the transformer differential protection function TR2PTDF*

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* is determined correspondingly:

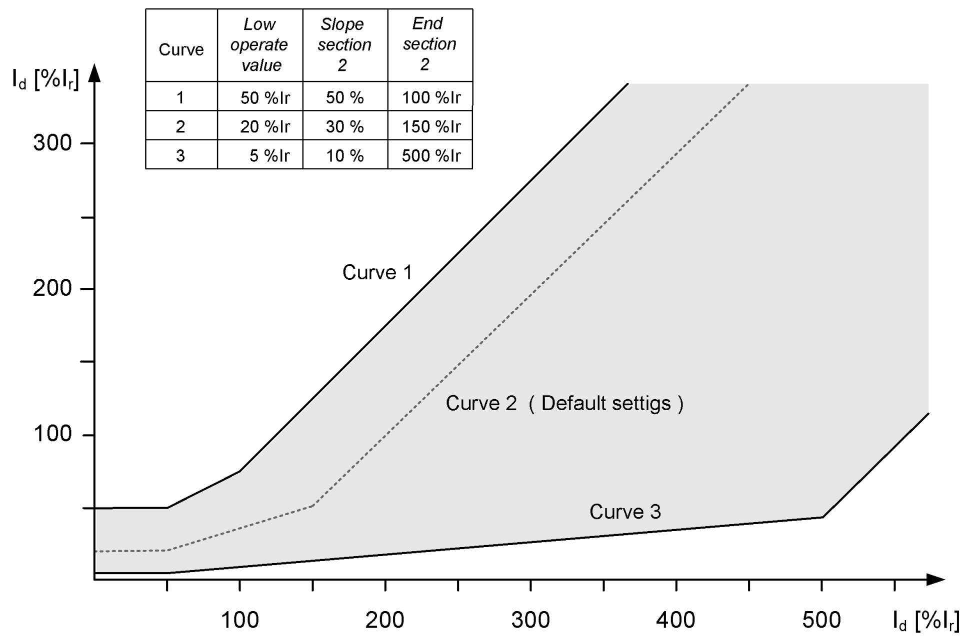
$$Slope\,section\,2 = Id2\,/\,Ib2 \times 100\%$$

(Equation 23)

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*.
- Section 2, where End section 1 < Ib/In < *End section 2*, is called the influence area of *Slope section 2*. In this section, variations in the starting ratio affect the slope of the characteristic, that is, how big a change in the differential current is required for tripping in comparison with the change in the load current. The starting ratio should consider CT errors and variations in the transformer tap changer position (if not compensated). Too high a starting ratio should be avoided, because the sensitivity of the protection for detecting inter-turn faults depends basically on the starting ratio.
- In section 3, where Ib/In > *End section 2*, the slope of the characteristic is constant. The slope is 100%, which means that the increase in the differential current is equal to the corresponding increase in the biasing current.




| Curve | *Low operate value* | *Slope section 2* | *End section 2* |
|---|---|---|---|
| 1 | 50 %Ir | 50 % | 100 %Ir |
| 2 | 20 %Ir | 30 % | 150 %Ir |
| 3 | 5 %Ir | 10 % | 500 %Ir |

*Figure 97: Setting range for biased low stage*

If the biasing current drops below 30 percent of the differential current or the phase angle between the winding 1 and winding 2 phase currents is less than 50 degrees, a fault has most likely occurred in the area protected by the differential relay. Then the internal blocking signals of the biased stage are inhibited.

### Instantaneous high stage

The instantaneous high stage operation can be enabled and disabled using the *Enable high set* setting. The corresponding parameter values are "TRUE" and "FALSE."

The operation of the instantaneous high stage is not biased. The instantaneous stage operates and the output OPR_HS is activated when the amplitude of the fundamental frequency component of the differential current exceeds the set *High operate value* or when the instantaneous value of the differential current exceeds 2.5 times the value of *High operate value*. The factor 2.5 (=1.8 x √2) is due to the maximum asymmetric short-circuit current.

If the biasing current drops below 30 percent of the differential current or the phase angle between the winding 1 and winding 2 phase currents is less than 50 degrees, a fault has occurred in the area protected by the differential relay. Then the operate value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

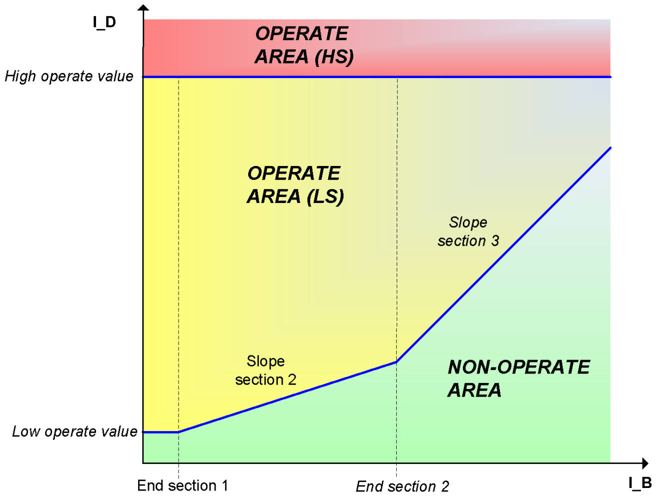



*Figure 98: Operating characteristics of the protection. (LS) stands for the biased low stage and (HS) for the instantaneous high stage*

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.

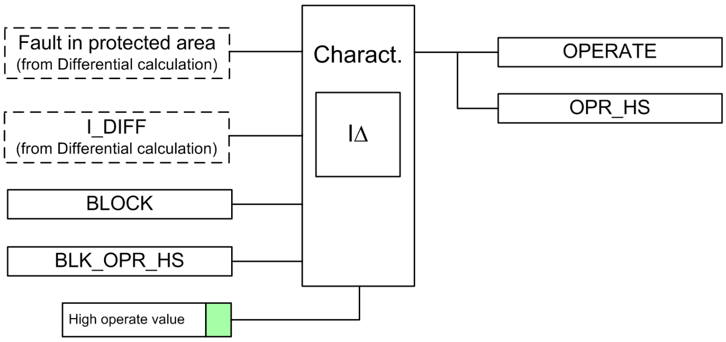



*Figure 99: Operation logic of instantaneous high stage*

### 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 over 130 degrees after the automatic vector group matching has been made. 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 IED, the protective zone does not include the bus work or cables between the circuit breaker and the power transformer.

In some substations, there is a current differential protection for the busbar. The busbar protection includes bus work or cables between the circuit breaker and the power transformer. Internal electrical faults are very serious and cause immediate damage. Short circuits and earth faults in windings and terminals are normally detected by the differential protection. If enough turns are short-circuited, the interturn faults, which are flashovers between the conductors within the same physical winding, are also detected. The interturn faults are the most difficult transformer-winding faults to detect with electrical protections. A small interturn fault including a few turns results in an undetectable amount of current until the fault develops into an earth fault. Therefore, it is important that the differential protection has a high level of sensitivity and that it is possible to use a sensitive setting without causing unwanted operations for external faults.

It is important that the faulty transformer is disconnected as fast as possible. As TR2PTDF is a unit protection function, it can be designed for fast tripping, thus providing a selective disconnection of the faulty transformer. TR2PTDF should never operate to faults outside the protective zone.

TR2PTDF compares the current flowing into the transformer to the current leaving the transformer. A correct analysis of fault conditions by TR2PTDF must consider the changes to voltages, currents and phase angles. The traditional transformer differential protection functions required auxiliary transformers for the correction of the phase shift and turns ratio. The numerical microprocessor based differential algorithm implemented in TR2PTDF compensates for both the turns ratio and the phase shift internally in the software.

The differential current should theoretically be zero during normal load or external faults if the turns ratio and the phase shift are correctly compensated. 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.

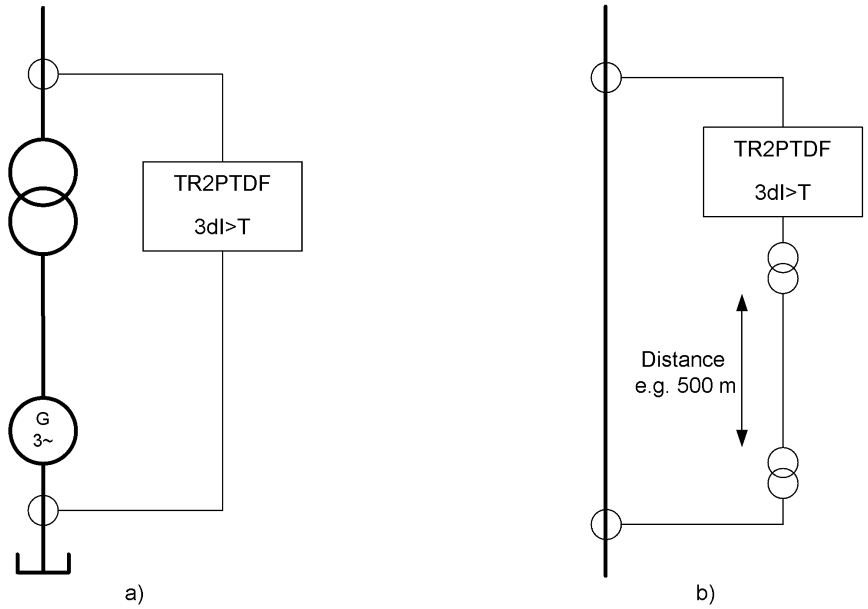



*Figure 100: Differential protection of a generator-transformer block and short cable/line*

TR2PTDF can also be used in three-winding transformer applications or two-winding transformer applications with two output feeders.

On the double-feeder side of the power transformer, the current of the two CTs per phase must be summed by connecting the two CTs of each phase in parallel. Generally this requires the interposing CTs to handle the vector group and/or ratio mismatch between the two windings/feeders.

The accuracy limit factor for the interposing CT must fulfill the same requirements as the main CTs. Please note that the interposing CT imposes an additional burden to the main CTs.

The most important rule in these applications is that at least 75 percent of the short-circuit power has to be fed on the side of the power transformer with only one connection to the IED.

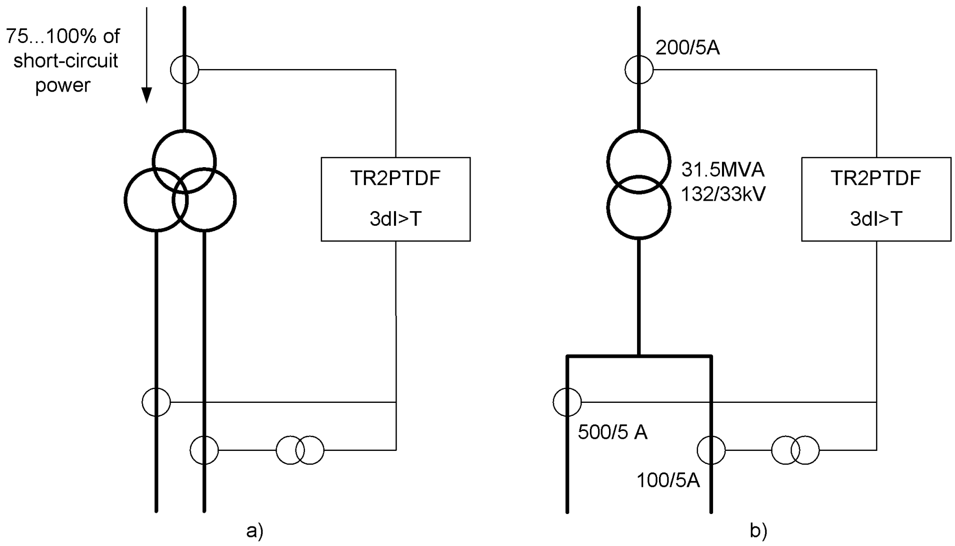



*Figure 101: Differential protection of a three-winding transformer and a transformer with two output feeders*

## 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 24)

$I_{nT}$ 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 25)

$I_{1n}$ 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 $I_r$ ($\%I_r$).

### 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

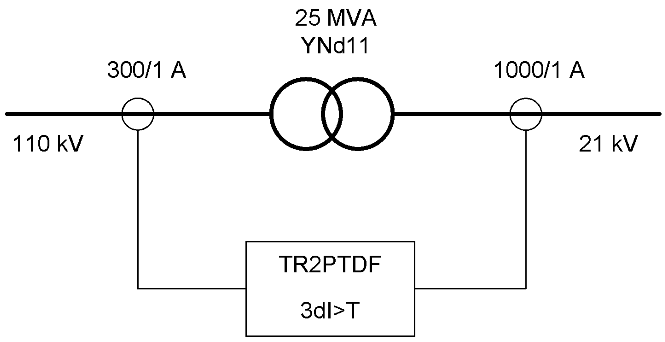



*Figure 102: Example of two-winding power transformer differential protection*

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 IED. If the neutral of a star-connected power transformer is earthed, any earth fault in the network is perceived by the IED as a differential current. The elimination of the zero-sequence component can be selected for that winding by setting the *Zro A elimination* parameter.

*Table 176: TR2PTDF settings corresponding to the power transformer vector groups and zero-sequence elimination*

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---|---|---|---|---|
| Yy0 | Y | y | Clk Num 0 | Not needed |
| YNy0 | YN | y | Clk Num 0 | HV side |
| YNyn0 | YN | yn | Clk Num 0 | HV & LV side |
| Yyn0 | Y | yn | Clk Num 0 | LV side |
| Yy2 | Y | y | Clk Num 2 | Not needed |
| YNy2 | YN | y | Clk Num 2 | Not needed |
| YNyn2 | YN | yn | Clk Num 2 | Not needed |
| Yyn2 | Y | yn | Clk Num 2 | Not needed |
| Yy4 | Y | y | Clk Num 4 | Not needed |
| YNy4 | YN | y | Clk Num 4 | Not needed |
| YNyn4 | YN | yn | Clk Num 4 | Not needed |
| Yyn4 | Y | yn | Clk Num 4 | Not needed |
| Yy6 | Y | y | Clk Num 6 | Not needed |
| YNy6 | YN | y | Clk Num 6 | HV side |
| YNyn6 | YN | yn | Clk Num 6 | HV & LV side |
| Yyn6 | Y | yn | Clk Num 6 | LV side |
| Yy8 | Y | y | Clk Num 8 | Not needed |
| YNy8 | YN | y | Clk Num 8 | Not needed |
| YNyn8 | YN | yn | Clk Num 8 | Not needed |
| Yyn8 | Y | yn | Clk Num 8 | Not needed |
| Yy10 | Y | y | Clk Num 10 | Not needed |
| YNy10 | YN | y | Clk Num 10 | Not needed |
| YNyn10 | YN | yn | Clk Num 10 | Not needed |
| Yyn10 | Y | yn | Clk Num 10 | Not needed |
| Yd1 | Y | d | Clk Num 1 | Not needed |
| YNd1 | YN | d | Clk Num 1 | Not needed |
| Yd5 | Y | d | Clk Num 5 | Not needed |
| YNd5 | YN | d | Clk Num 5 | Not needed |
| Yd7 | Y | d | Clk Num 7 | Not needed |
| YNd7 | YN | d | Clk Num 7 | Not needed |
| Yd11 | Y | d | Clk Num 11 | Not needed |
| YNd11 | YN | d | Clk Num 11 | Not needed |
| Dd0 | D | d | Clk Num 0 | Not needed |
| Dd2 | D | d | Clk Num 2 | Not needed |
| Dd4 | D | d | Clk Num 4 | Not needed |
| Dd6 | D | d | Clk Num 6 | Not needed |
| Dd8 | D | d | Clk Num 8 | Not needed |

Table continues on next page

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---|---|---|---|---|
| Dd10 | D | d | Clk Num 10 | Not needed |
| Dy1 | D | y | Clk Num 1 | Not needed |
| Dyn1 | D | yn | Clk Num 1 | Not needed |
| Dy5 | D | y | Clk Num 5 | Not needed |
| Dyn5 | D | yn | Clk Num 5 | Not needed |
| Dy7 | D | y | Clk Num 7 | Not needed |
| Dyn7 | D | yn | Clk Num 7 | Not needed |
| Dy11 | D | y | Clk Num 11 | Not needed |
| Dyn11 | D | yn | Clk Num 11 | Not needed |
| Yz1 | Y | z | Clk Num 1 | Not needed |
| YNz1 | YN | z | Clk Num 1 | Not needed |
| YNzn1 | YN | zn | Clk Num 1 | LV side |
| Yzn1 | Y | zn | Clk Num 1 | Not needed |
| Yz5 | Y | z | Clk Num 5 | Not needed |
| YNz5 | YN | z | Clk Num 5 | Not needed |
| YNzn5 | YN | zn | Clk Num 5 | LV side |
| Yzn5 | Y | zn | Clk Num 5 | Not needed |
| Yz7 | Y | z | Clk Num 7 | Not needed |
| YNz7 | YN | z | Clk Num 7 | Not needed |
| YNzn7 | YN | zn | Clk Num 7 | LV side |
| Yzn7 | Y | zn | Clk Num 7 | Not needed |
| Yz11 | Y | z | Clk Num 11 | Not needed |
| YNz11 | YN | z | Clk Num 11 | Not needed |
| YNzn11 | YN | zn | Clk Num 11 | LV side |
| Yzn11 | Y | zn | Clk Num 11 | Not needed |
| Zy1 | Z | y | Clk Num 1 | Not needed |
| Zyn1 | Z | yn | Clk Num 1 | Not needed |
| ZNyn1 | ZN | yn | Clk Num 1 | HV side |
| ZNy1 | ZN | y | Clk Num 1 | Not needed |
| Zy5 | Z | y | Clk Num 5 | Not needed |
| Zyn5 | Z | yn | Clk Num 5 | Not needed |
| ZNyn5 | ZN | yn | Clk Num 5 | HV side |
| ZNy5 | ZN | y | Clk Num 5 | Not needed |
| Zy7 | Z | y | Clk Num 7 | Not needed |
| Zyn7 | Z | yn | Clk Num 7 | Not needed |
| ZNyn7 | ZN | yn | Clk Num 7 | HV side |
| ZNy7 | ZN | y | Clk Num 7 | Not needed |
| Zy11 | Z | y | Clk Num 11 | Not needed |
| Zyn11 | Z | yn | Clk Num 11 | Not needed |

Table continues on next page

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---|---|---|---|---|
| ZNyn11 | ZN | yn | Clk Num 11 | HV side |
| ZNy11 | ZN | y | Clk Num 11 | Not needed |
| Dz0 | D | z | Clk Num 0 | Not needed |
| Dzn0 | D | zn | Clk Num 0 | LV side |
| Dz2 | D | z | Clk Num 2 | Not needed |
| Dzn2 | D | zn | Clk Num 2 | Not needed |
| Dz4 | D | z | Clk Num 4 | Not needed |
| Dzn4 | D | zn | Clk Num 4 | Not needed |
| Dz6 | D | z | Clk Num 6 | Not needed |
| Dzn6 | D | zn | Clk Num 6 | LV side |
| Dz8 | D | z | Clk Num 8 | Not needed |
| Dzn8 | D | zn | Clk Num 8 | Not needed |
| Dz10 | D | z | Clk Num 10 | Not needed |
| Dzn10 | D | zn | Clk Num 10 | Not needed |
| Zd0 | Z | d | Clk Num 0 | Not needed |
| ZNd0 | ZN | d | Clk Num 0 | HV side |
| Zd2 | Z | d | Clk Num 2 | Not needed |
| ZNd2 | ZN | d | Clk Num 2 | Not needed |
| Zd4 | Z | d | Clk Num 4 | Not needed |
| ZNd4 | ZN | d | Clk Num 4 | Not needed |
| Zd6 | Z | d | Clk Num 6 | Not needed |
| ZNd6 | ZN | d | Clk Num 6 | HV side |
| Zd8 | Z | d | Clk Num 8 | Not needed |
| ZNd8 | ZN | d | Clk Num 8 | Not needed |
| Zd10 | Z | d | Clk Num 10 | Not needed |
| ZNd10 | ZN | d | Clk Num 10 | Not needed |
| Zz0 | Z | z | Clk Num 0 | Not needed |
| ZNz0 | ZN | z | Clk Num 0 | HV side |
| ZNzn0 | ZN | zn | Clk Num 0 | HV & LV side |
| Zzn0 | Z | zn | Clk Num 0 | LV side |
| Zz2 | Z | z | Clk Num 2 | Not needed |
| ZNz2 | ZN | z | Clk Num 2 | Not needed |
| ZNzn2 | ZN | zn | Clk Num 2 | Not needed |
| Zzn2 | Z | zn | Clk Num 2 | Not needed |
| Zz4 | Z | z | Clk Num 4 | Not needed |
| ZNz4 | ZN | z | Clk Num 4 | Not needed |
| ZNzn4 | ZN | zn | Clk Num 4 | Not needed |
| Zzn4 | Z | zn | Clk Num 4 | Not needed |
| Zz6 | Z | z | Clk Num 6 | Not needed |

Table continues on next page

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---|---|---|---|---|
| ZNz6 | ZN | z | Clk Num 6 | HV side |
| ZNzn6 | ZN | zn | Clk Num 6 | HV & LV side |
| Zzn6 | Z | zn | Clk Num 6 | LV side |
| Zz8 | Z | z | Clk Num 8 | Not needed |
| ZNz8 | ZN | z | Clk Num 8 | Not needed |
| ZNzn8 | ZN | zn | Clk Num 8 | Not needed |
| Zzn8 | Z | zn | Clk Num 8 | Not needed |
| Zz10 | Z | z | Clk Num 10 | Not needed |
| ZNz10 | ZN | z | Clk Num 10 | Not needed |
| ZNzn10 | ZN | zn | Clk Num 10 | Not needed |
| Zzn10 | Z | zn | Clk Num 10 | Not needed |
| 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 |

Table continues on next page

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---|---|---|---|---|
| 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 |
| 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 |

Table continues on next page

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---|---|---|---|---|
| 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 $I_r$.

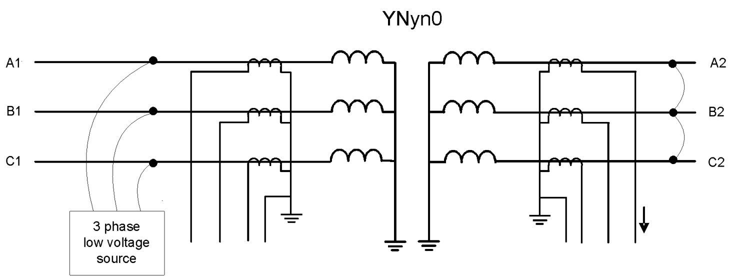



*Figure 103: Low voltage test arrangement. The three-phase low voltage source can be the station service transformer.*

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 0 deg. There can be several reasons if the angle values are not 0 deg. If the values are ±180 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 26)

$F_a$ 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 IED at a rated current of 5A is < 20 mΩ. If the measurement conductors have a resistance of 0.113 Ω, the actual burden of the current transformer is $S_a$=$(5A)^2$ * (0.113 + 0.020) Ω = 3.33 VA. Thus the accuracy limit factor $F_a$ corresponding to the actual burden is approximately 46.

The CT burden can grow considerably at the rated current 5A. The actual burden of the current transformer decreases at the rated current of 1A while the repeatability simultaneously improves.

At faults occurring in the protected area, the currents may be very high compared to the rated currents of the current transformers. Due to the instantaneous stage of the differential function block, it is sufficient that the current transformers are capable of repeating the current required for instantaneous tripping during the first cycle.

Thus the current transformers usually are able to reproduce the asymmetric fault current without saturating within the next 10 ms after the occurrence of the fault to secure that the operate times of the IED comply with the retardation time.

The accuracy limit factors corresponding to the actual burden of the phase current transformer to be used in differential protection fulfill the requirement.

$$F_a > K_r \times Ik_{\max} \times (T_{dc} \times \omega \times (1 - e^{-T_m / T_{dc}}) + 1)$$

(Equation 27)

$Ik_{max}$ 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 27, 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 26 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:

$$F_a = \frac{IrCT}{IrTR} * F_n$$

(Equation 28)

| | |
|---|---|
| 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 IED currents are opposite, the *CT connection type* setting parameter is “Type 1”. If the positive directions of the winding 1 and winding 2 IED currents equate, the *CT connection type* setting parameter is “Type 2”. The default is “Type 1”.

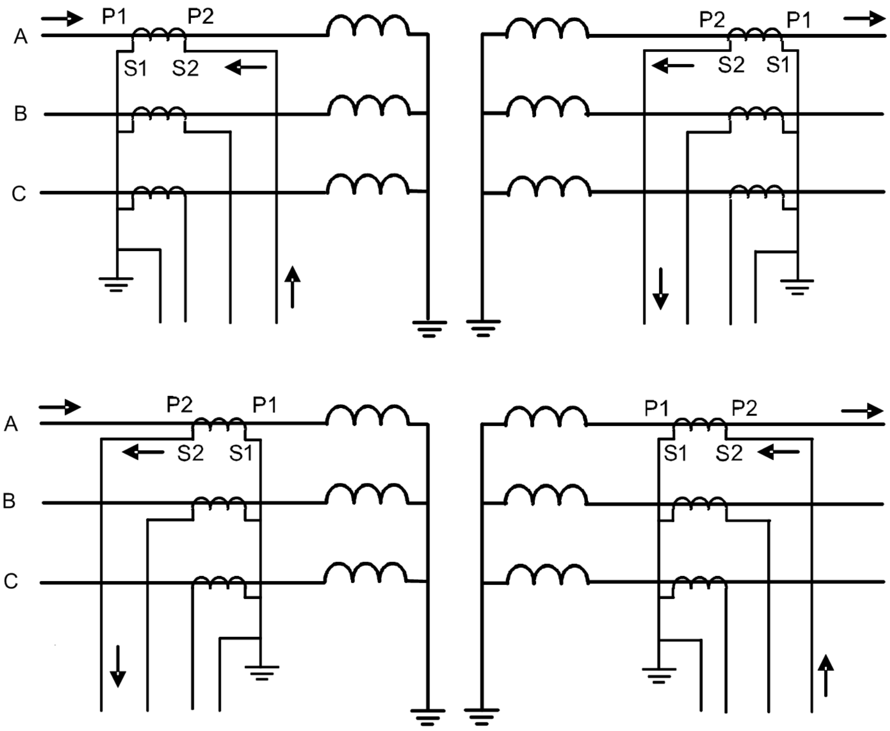



*Figure 104: Connection of current transformers of Type 1 and example of the currents during an external fault*

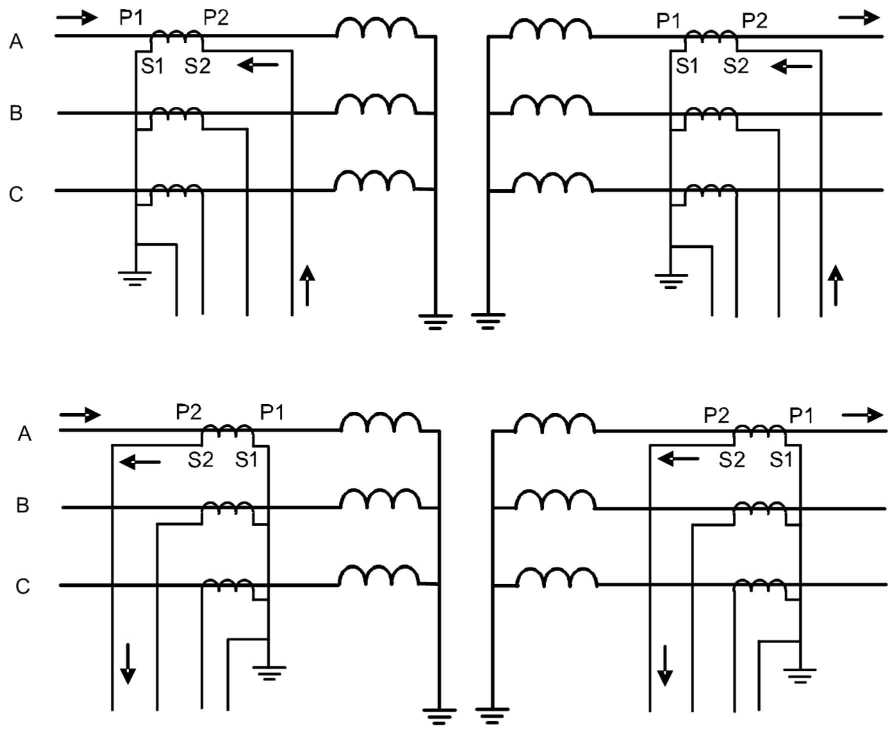



*Figure 105: Connection of current transformers of Type 2 and example of the currents during an external fault*

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 177: 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 |
| 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 |

Table 178: 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 179: TR2PTDF Group settings

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| High operate value | 500...3000 | %Ir | 10 | 1000 | Instantaneous stage setting |
| Enable high set | 0=False<br>1=True | | | 1=True | Enable high set stage |
| 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 | -1=2.h + 5.h + wav<br>5=Waveform<br>6=2.h + waveform<br>7=5.h + waveform | | | -1=2.h + 5.h + wav | Restraint mode |
| Harmonic deblock 2. | 0=False<br>1=True | | | 1=True | 2. harmonic deblocking in case of switch on to fault |
| Start value 2.H | 7...20 | % | 1 | 15 | 2. harmonic blocking ratio |
| Start value 5.H | 10...50 | % | 1 | 35 | 5. harmonic blocking ratio |
| Stop value 5.H | 10...50 | % | 1 | 35 | 5. harmonic deblocking ratio |
| Harmonic deblock 5. | 0=False<br>1=True | | | 0=False | 5. harmonic deblocking in case of severe overvoltage |

Table 180: TR2PTDF Non group settings

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off/On |
| CT connection type | 1=Type 1<br>2=Type 2 | | | 1=Type 1 | CT connection type. Determined by the directions of the connected current transformers |
| Winding 1 type | 1=Y<br>2=YN<br>3=D<br>4=Z<br>5=ZN | | | 1=Y | Connection of the HV side windings |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Winding 2 type | 1=y<br>2=yn<br>3=d<br>4=z<br>5=zn | | | 1=y | Connection of the LV side windings |
| Clock number | 0=Clk Num 0<br>1=Clk Num 1<br>2=Clk Num 2<br>4=Clk Num 4<br>5=Clk Num 5<br>6=Clk Num 6<br>7=Clk Num 7<br>8=Clk Num 8<br>10=Clk Num 10<br>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) |
| Zro A elimination | 1=Not eliminated<br>2=Winding 1<br>3=Winding 2<br>4=Winding 1 and 2 | | | 1=Not eliminated | Elimination of the zero-sequence current |
| 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<br>2=Winding 1<br>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 |
| 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 |

## 4.3.2.9 Monitored data

*Table 181: TR2PTDF Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| OPR_A | BOOLEAN | 0=False<br>1=True | | Operate phase A |
| OPR_B | BOOLEAN | 0=False<br>1=True | | Operate phase B |
| OPR_C | BOOLEAN | 0=False<br>1=True | | Operate phase C |
| BLKD2H_A | BOOLEAN | 0=False<br>1=True | | 2nd harmonic restraint block phase A status |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| BLKD2H_B | BOOLEAN | 0=False<br>1=True | | 2nd harmonic restraint block phase B status |
| BLKD2H_C | BOOLEAN | 0=False<br>1=True | | 2nd harmonic restraint block phase C status |
| BLKD5H_A | BOOLEAN | 0=False<br>1=True | | 5th harmonic restraint block phase A status |
| BLKD5H_B | BOOLEAN | 0=False<br>1=True | | 5th harmonic restraint block phase B status |
| BLKD5H_C | BOOLEAN | 0=False<br>1=True | | 5th harmonic restraint block phase C status |
| BLKDWAV_A | BOOLEAN | 0=False<br>1=True | | Waveform blocking phase A status |
| BLKDWAV_B | BOOLEAN | 0=False<br>1=True | | Waveform blocking phase B status |
| BLKDWAV_C | BOOLEAN | 0=False<br>1=True | | Waveform blocking phase C status |
| BLKD2HPHAR | BOOLEAN | 0=False<br>1=True | | 2nd harmonic restraint blocking for PHAR LN, combined |
| BLKD2HPHAR_A | BOOLEAN | 0=False<br>1=True | | 2nd harmonic restraint blocking for PHAR LN, phase A |
| BLKD2HPHAR_B | BOOLEAN | 0=False<br>1=True | | 2nd harmonic restraint blocking for PHAR LN, phase B |
| BLKD2HPHAR_C | BOOLEAN | 0=False<br>1=True | | 2nd harmonic restraint blocking for PHAR LN, phase C |
| BLKD5HPHAR | BOOLEAN | 0=False<br>1=True | | 5th harmonic restraint blocking for PHAR LN, combined |
| BLKD5HPHAR_A | BOOLEAN | 0=False<br>1=True | | 5th harmonic restraint blocking for PHAR LN, phase A |
| BLKD5HPHAR_B | BOOLEAN | 0=False<br>1=True | | 5th harmonic restraint blocking for PHAR LN, phase B |
| BLKD5HPHAR_C | BOOLEAN | 0=False<br>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 |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| 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 |
| 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 |
| 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 |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| I_5H_RAT_C | FLOAT32 | 0.00...1.00 | | Differential current fifth harmonic ratio, phase C |
| TR2PTDF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>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 182: TR2PTDF Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the current measured: $f_n$ ±2Hz | | |
| | | ±3.0% of the set value or ±0.002 x $I_n$ | | |
| Operate time[1)2)] | | Minimum | Typical | Maximum |
| | Low stage<br>High stage | 34 ms<br>21 ms | 40 ms<br>22 ms | 44 ms<br>24 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 0.96 | | |
| Suppression of harmonics | | DFT: -50dB at f = n x $f_n$, 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 output contact. When differential current = 2 x set operate value and $f_n$ = 50 Hz.

## 4.3.3 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 |
|---|---|---|---|
| Low impedance restricted earth-fault protection | LREFPNDF | dIoLo> | 87NL |

### 4.3.3.2 Function block

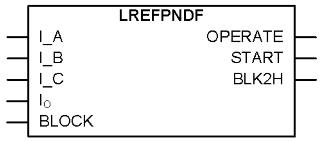



*Figure 106: Function block symbol*

### 4.3.3.3 Functionality

The stabilized restricted low-impendence earth-fault protection LREFPNDF for a two winding transformer is based on the numerically stabilized differential current principle. No external stabilizing resistor or non-linear resistor are required.

The fundamental components of the currents are used for calculating the residual current of the phase currents, the neutral current, differential currents and stabilizing currents. The operating characteristics are according to the definite time.

LREFPNDF contains a blocking functionality. The neutral-current second harmonic is used for blocking during the transformer inrush situation. 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 the stabilized restricted low impedance earth-fault protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

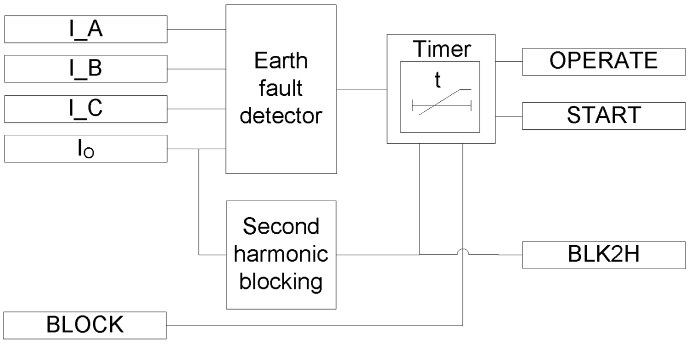



*Figure 107: Functional module diagram*

## 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 ($I_0$) 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 through the Monitored data view.

$$ID\_COSPHI = (|\Sigma I - I_0|)\cos\varphi$$

(Equation 29)

| | |
|---|---|
| ΣI | Residual current |
| φ | Phase difference between the residual and neutral currents |
| $I_0$ | 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 $I_0$ 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 through the Monitored data view.

$$IB = \frac{|I\_A| + |I\_B| + |I\_C|}{3}$$

(Equation 30)

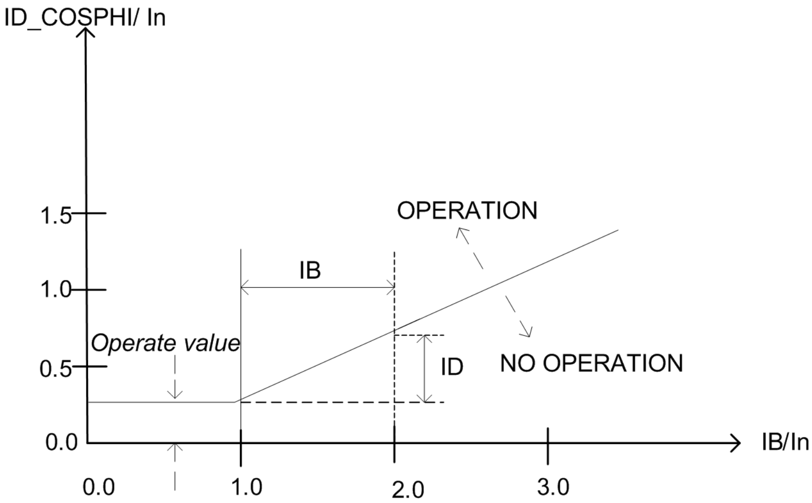



*Figure 108: Operating characteristics of the stabilized earth-fault protection function*

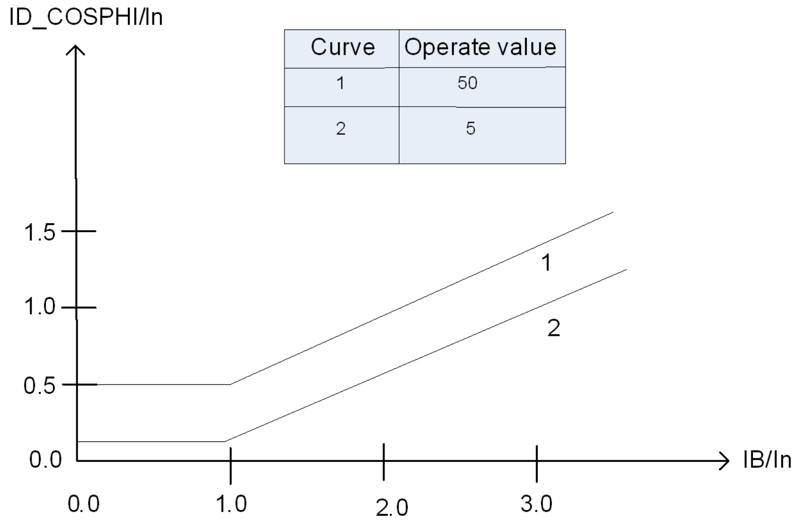



*Figure 109: Setting range of the operating characteristics for the stabilized differential current principle of the earth-fault protection function*

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.

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 “2nd harmonic”.

### 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 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 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 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.

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.

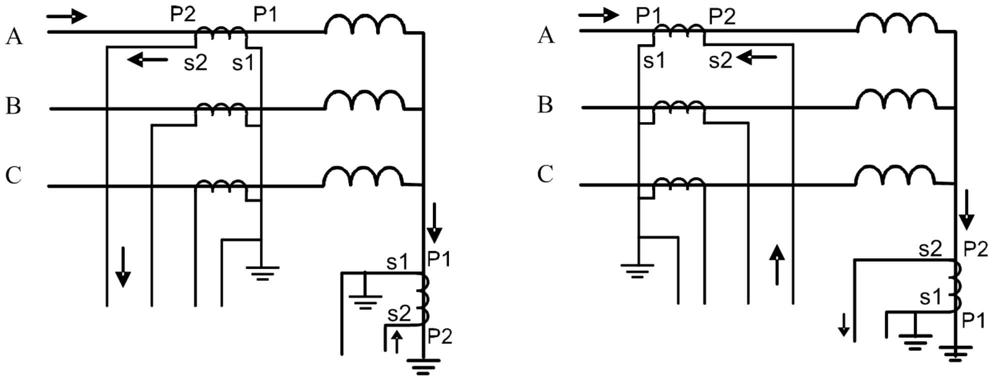
The restricted earth-fault protection is mainly used as a unit protection for the transformer windings. LREFPNDF is a sensitive protection applied to protect the star-connected winding of a transformer. This protection system remains stable for all the faults outside the protected zone.

LREFPNDF provides higher sensitivity for the detection of ground faults than the overall transformer differential protection. This is a high speed unit protection scheme applied to the star-connected winding of the transformer. In LREFPNDF, the difference of the fundamental component of all three phase currents and the neutral current is provided to the differential element to detect the earth fault in the transformer winding based on the numerical stabilized differential current principle.

### Connection of current transformers

The connections of the main CTs are designated as "Type 1" and "Type 2". In case the earthings of the current transformers on the phase side and the neutral side are both either inside or outside the area to be protected, the setting parameter *CT connection type* is "Type 1".

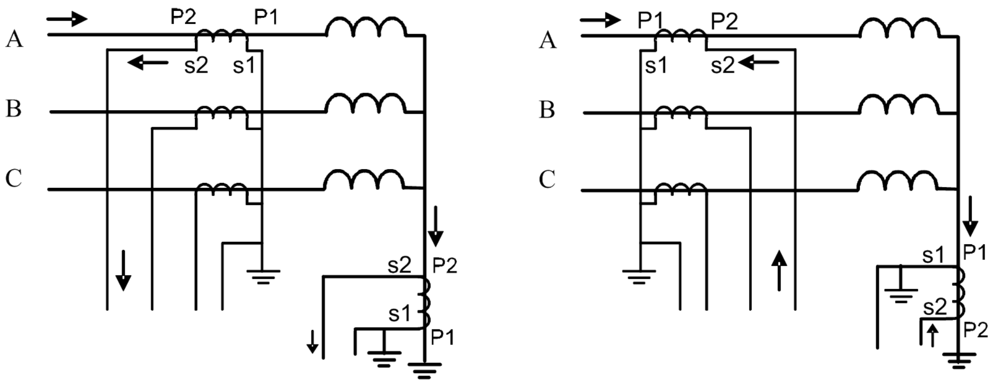
If the earthing of the current transformers on the phase side is inside the area to be protected and the neutral side is outside the area to be protected or vice versa, the setting parameter CT connection type is "Type 2".




a. Both earthings are inside area to be protected

b. Both earthings are outside area to be protected

*Figure 110: 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.*




a. Phase earthing is inside and neutral earthing is outside area to be protected

b. Phase earthing is outside and neutral earthing is inside area to be protected

*Figure 111: Connection of the current transformers of Type 2. The phase currents and the neutral current have equal directions at an external earth-fault situation.*

## Internal and external faults

LREFPNDF does not respond to any faults outside the protected zone. An external fault is detected by checking the phase angle difference of the neutral current and the sum of the phase currents. When the difference is less than 90 degrees, the operation is internally restrained or blocked. Hence the protection is not sensitive to an external fault.

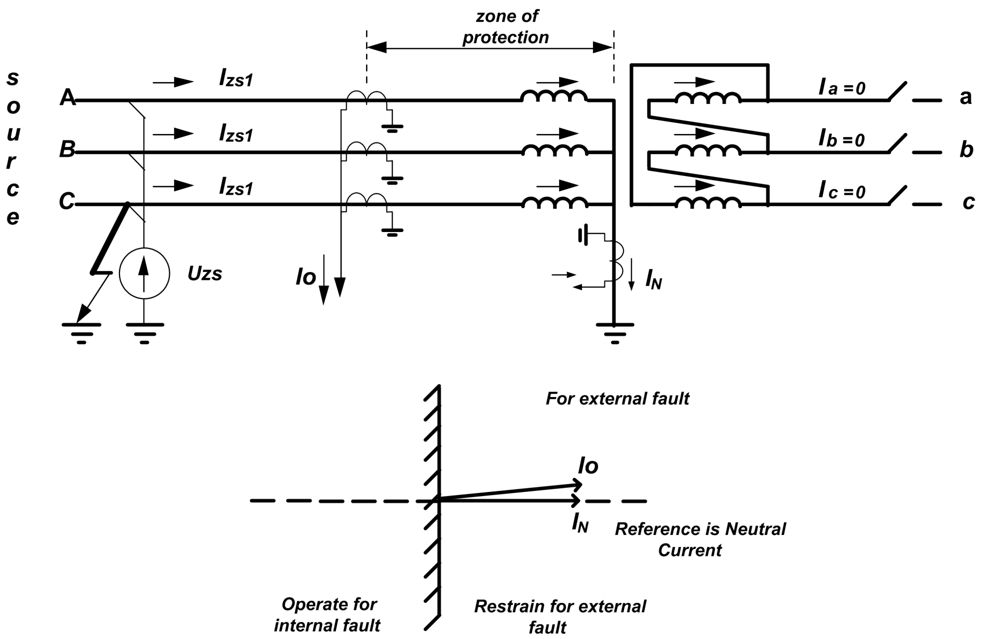



*Figure 112: Current flow in all the CTs for an external fault*

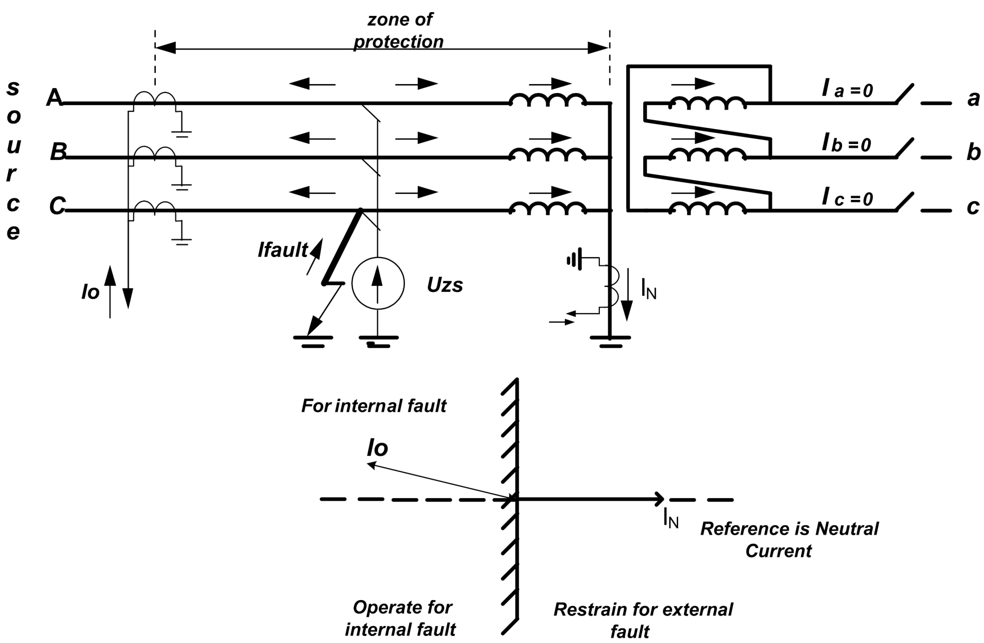



*Figure 113: Current flow in all the CTs for an internal fault*

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.

LREFPNDF is normally applied when the transformer is solidly grounded because in this case the fault current is high enough and the earth fault can be detected easily.

#### Blocking based on the second harmonic of the neutral current

The transformer magnetizing inrush currents occur when the transformer is energized after a period of de-energization. The inrush current can be many times the rated current, and the halving time can be up to several seconds. For the differential IED, the inrush current represents the differential current, which causes the 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 $I_0$_2H / $I_0$. 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 183: 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 |
| $I_0$ | SIGNAL | 0 | Zero-sequence current |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

*Table 184: LREFPNDF Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |
| BLK2H | BOOLEAN | 2nd harmonic block |

### 4.3.3.7 Settings

*Table 185: LREFPNDF Group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operate value | 5...50 | %In | 1 | 5 | Operate value |
| Minimum operate time | 40...300000 | ms | 1 | 40 | Minimum operate time |
| Restraint mode | 1=None<br>2=Harmonic2 | | | 1=None | Restraint mode |
| Start value 2.H | 10...50 | %In | 1 | 50 | The ratio of the 2. harmonic to fundamental component required for blocking |

*Table 186: LREFPNDF Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |
| CT connection type | 1=Type 1<br>2=Type 2 | | | 2=Type 2 | CT connection type |

### 4.3.3.8 Monitored data

*Table 187: 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<br>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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.3.3.9 Technical data

*Table 188: LREFPNDF Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the current measured: $f_n$ ±2Hz | | |
| | | ±2.5% of the set value or ±0.002 x $I_n$ | | |
| Start time[1)2)] | | Minimum | Typical | Maximum |
| | $I_{Fault}$ = 2.0 x set *Operate value* | 38 ms | 40 ms | 43 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 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: -50dB at f = n x $f_n$, 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

## 4.3.4 High impedance restricted earth-fault protection HREFPDIF

### 4.3.4.1 Identification

| Functional description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| High impedance restricted earth-fault protection | HREFPDIF | dIoHi> | 87NH |

### 4.3.4.2 Function block

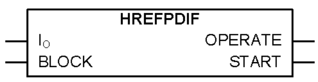



*Figure 114: Function block symbol*

### 4.3.4.3 Functionality

The high impedance restricted earth-fault protection HREFPDIF is used for the restricted earth-fault protection of generators and power transformers based on the high-impedance principle.

HREFPDIF starts and operates when the $I_0$, the differential neutral current, exceeds the set limit. HREFPDIF operates with the DT characteristic.

HREFPDIF contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

## 4.3.4.4 Operation principle

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

The operation of the high impedance restricted earth-fault protection function can be described using a module diagram. All the blocks in the diagram are explained in the next sections.

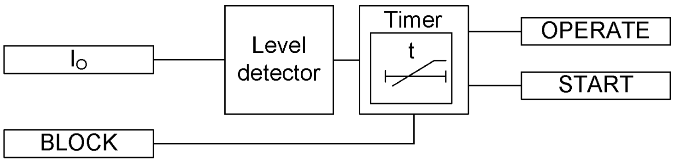



*Figure 115: Functional module diagram*

### Level detector

The level detector compares the differential neutral current $I_0$ to the set value of the *Operate value* setting. The timer module is activated if the $I_0$ value exceeds the set value of the *Operate value* setting.

### Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *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 operate 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 operate time. The value is available through the Monitored data view.

The binary input `BLOCK` is used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets the internal timers. The binary input `BLK_ST` is used to block the start signals. The binary input `BLK_OPR` is used to block the `OPERATE` signal. The binary input `BLK_ST` is used to block the `START` output. The operation timer counting is frozen to the prevailing value by activating the `RF_TIMER` input.

### 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 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 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.

### 4.3.4.5 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 of 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.

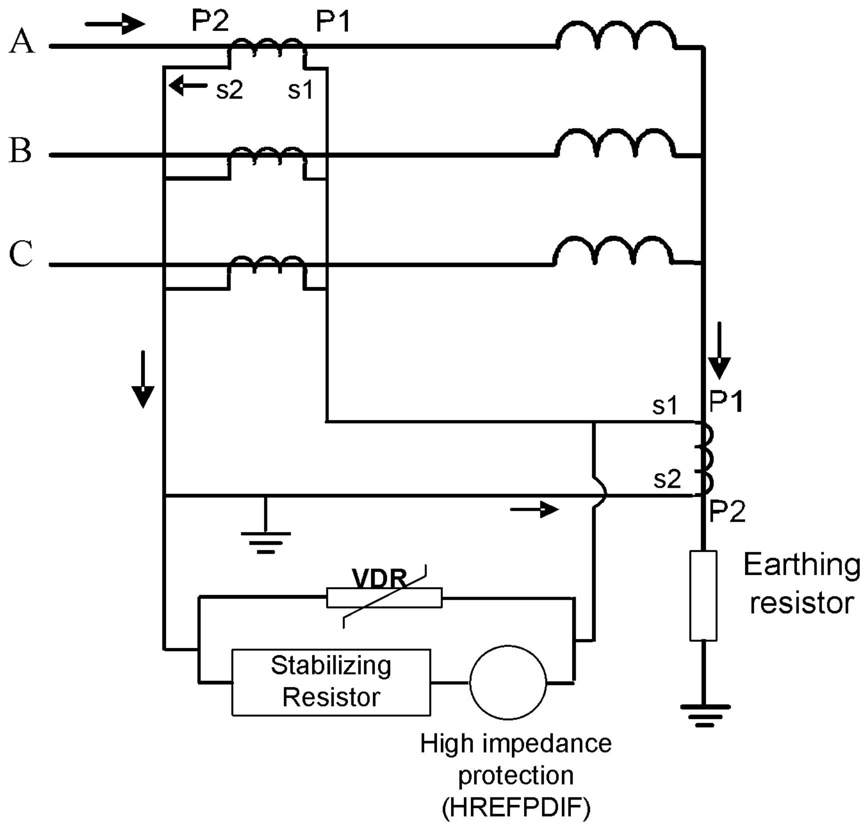



*Figure 116: Connection scheme for the restricted earth-fault protection according to the high-impedance principle*

## 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 variable resistor 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 31)

$R_s$ the resistance of the stabilizing resistor

$U_s$ the stabilizing voltage of the relay

$I_{rs}$ the value of the *Low operate value* relay setting

The stabilizing voltage is calculated with the formula:

$$U_s = \frac{I_{k\max}}{n}(R_{in} + R_m)$$

(Equation 32)

| | |
|---|---|
| $I_{kmax}$ | 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 differential current protection stabilized through a resistor are related to the current transformers used. The number of turns of the current transformers that are part of the same differential current circuit should be the same. Moreover, the current transformers should have the same transformation ratio.

For a fast and reliable response to in-zone faults during the operation of the IED, the knee-point voltage has to be twice the stabilizing voltage. The stabilizing voltage $U_S$ of the function block is given by the stabilizing voltage equation:

$$U_s = \frac{I_{k\max}}{n}(R_{in} + R_m)$$

(Equation 33)

| | |
|---|---|
| $I_{kmax}$ | 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 |

The required knee-point voltage $U_k$ of the current transformer is calculated using the formula:

$$U_k = 2 \times U_s$$

(Equation 34)

The factor 2 is used when no operate delay is permitted for the protection. The sensitivity requirements for the protection are risked if the value of the magnetizing current of the current transformers at the knee-point voltage is too high. The $I_{prim}$ value of the primary current at which the function block operates at certain settings is calculated using the formula:

$$I_{prim} = n \times (I_{rs} + I_u + m \times I_m)$$

(Equation 35)

n the transformation ratio of the current transformer

$I_{rs}$ the current value representing the function block setting

$I_u$ the current flowing through the protection varistor

m the number of current transformers included in the protection

$I_m$ the magnetizing current of one current transformer

The $I_e$ value given in many catalogues is the excitation current at the knee-point voltage. $I_m$ = 0.5 x $I_e$ gives a realistic value for $I_{prim}$.

The selection of current transformers can be divided into procedures:

1. The nominal current $I_n$ of the protected winding has to be known. The value of $I_n$ also affects how high $I_{kmax}$ is. Normally, the $I_{kmax}$ values are:
   - for small transformers $I_{kmax}$ = 16 x $I_n$
   - for big transformers $I_{kmax}$ = 12 x $I_n$
   - for generators $I_{kmax}$ = 6 x $I_n$
2. The nominal primary current I1n of the CT has to be higher than the nominal current of the protected winding. The choice of the CT also specifies Rin.
3. The required $U_k$ is calculated using Equation 34. If the $U_k$ of the CT is not high enough, another CT has to be chosen. The value of the $U_k$ is given by the manufacturer in the case of class X current transformer or it can be estimated using Equation 36.
4. The sensitivity $I_{prim}$ is calculated using Equation 35. 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 current transformers are used, an estimate for $U_k$ is calculated:

$$U_k = 0.8 \times F_a \times I_{2n} \times (R_{in} + R_m)$$

(Equation 36)

$F_a$ the actual accuracy limit factor

$I_{2n}$ the rated secondary current of the current transformer

$R_{in}$ the secondary internal resistance of the CT

$R_m$ the resistance of the longest loop of secondary circuit

If the rated accuracy limit factor $F_n$ is used here instead of $F_a$, $R_m$ is replaced with the rated burden of the current transformer.

For a transformer, the value 12 x $I_n$ is given to $I_{kmax}$ where $I_n$ is the nominal current of the protected winding of the power transformer. For a generator, the value 6 x $I_n$ is used as $I_{kmax}$. When calculating the $I_{prim}$ value, $I_{rs}$ = m x $I_m$ is given for the setting of the IED and the value $I_u$ = 0 A for the varistor current. The $I_{rs}$ value depends on the application. However, it is recommended that $I_{rs} \geq m \times I_m$. The number of CTs connected in parallel is here m = 4.

The formulae are based on a worst-case analysis, that is, choosing the CTs according to Equation 34 results in an absolute stable scheme. In some cases, it is possible to achieve stability with knee-point voltages lower than stated in the formulae. The conditions in the network, however, have to be known well enough to ensure the stability:

1. If $U_k$ is higher than required by the criterion, stability is ensured.
2. If $U_k$ is higher than 50 percent of the value recommended by the criterion, the stability of the scheme is highly case-dependent.
3. If $U_k$ is below 50 percent of the value recommended by the criterion, stability is not achieved. Another CT has to be chosen.

The analysis of stability is based on the assumption that the ampere turns are the same for each CT. If this is not the case, the selectivity is endangered. Therefore, it is recommended that all the CTs used in the scheme are similar and preferably from the same manufacturing batch.

## 4.3.4.8 Signals

*Table 189: HREFPDIF Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $I_0$ | SIGNAL | 0 | Zero-sequence current |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

*Table 190: HREFPDIF Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.3.4.9 Settings

*Table 191: HREFPDIF Group settings*

| 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 192: HREFPDIF Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |

### 4.3.4.10 Monitored data

*Table 193: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.3.4.11 Technical data

*Table 194: HREFPDIF Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the current measured: $f_n$ ±2Hz | | |
| | | ±1.5% of the set value or ±0.002 x $I_n$ | | |
| Start time[1)2)] | | Minimum | Typical | Maximum |
| | $I_{Fault}$ = 2.0 x set *Operate value*<br>$I_{Fault}$ = 10.0 x set *Operate value* | 16 ms<br>11 ms | 21 ms<br>13 ms | 23 ms<br>14 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 0.96 | | |
| Retardation time | | < 35 ms | | |
| Operate time accuracy in definite time mode | | ±1.0% of the set value or ±20 ms | | |

1) Current before fault = 0.0, $f_n$ = 50 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

# 4.4 Unbalance protection

## 4.4.1 Negative phase-sequence current protection NSPTOC

### 4.4.1.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Negative phase-sequence current protection | NSPTOC | I2> | 46 |

### 4.4.1.2 Function block

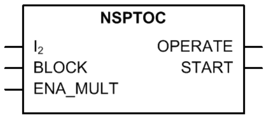



*Figure 117: Function block symbol*

### 4.4.1.3 Functionality

The negative phase-sequence current protection NSPTOC is used for increasing sensitivity to detect single phase and phase-to-phase faults, unbalanced loads due to, for example, broken conductors or to unsymmetrical feeder voltages.

NSPTOC can also be used for detecting broken conductors.

The function is based on the measurement of the negative phase-sequence current. In a fault situation, the function starts when the negative phase sequence current exceeds the set limit. The operate time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers, or the function itself, if desired.

### 4.4.1.4 Operation principle

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

The operation of negative phase-sequence current protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

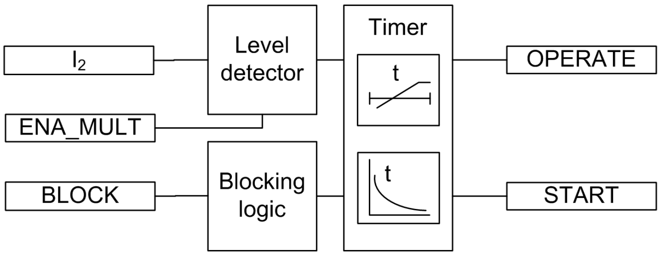



*Figure 118: Functional module diagram. $I_2$ represents negative phase sequence current.*

### Level detector

The measured negative phase-sequence current is compared with 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*.

Care needs to be taken when selecting *Start value* and *Start value Mult* even if the product of these settings exceeds the *Start value* setting range.

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.

### 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 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 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. 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 user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the General function block features section in this manual.

The timer calculates the start duration value START_DUR which indicates the percentual 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 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 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 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.

### 4.4.1.5 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.

Multiple time curves and time multiplier settings are also available for coordinating with other devices in the system.

### 4.4.1.6 Signals

*Table 195: 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 196: NSPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.4.1.7 Settings

*Table 197: NSPTOC Group settings*

| 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 | | 0.05 | 1.00 | Time multiplier in IEC/ANSI IDMT curves |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operate delay time | 40...200000 | ms | 10 | 40 | Operate delay time |
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Programmable<br>18=RI type<br>19=RD type | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset | | | 1=Immediate | Selection of reset curve type |

*Table 198: NSPTOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| 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 |
| Curve parameter A | 0.0086...120.0000 | | | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120 | | | 0.1217 | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00 | | | 2.00 | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00 | | | 29.10 | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0 | | | 1.0 | Parameter E for customer programmable curve |

### 4.4.1.8 Monitored data

*Table 199: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.4.1.9 Technical data

*Table 200: NSPTOC Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the current measured: $f_n$ ±2Hz | | |
| | | ±1.5% of the set value or ±0.002 x $I_n$ | | |
| Start time 1)2) | | Minimum | Typical | Maximum |
| | $I_{Fault}$ = 2 x set *Start value*<br>$I_{Fault}$ = 10 x set *Start value* | 22 ms<br>14 ms | 24 ms<br>16 ms | 25 ms<br>17 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 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: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5,… | | |

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
3) Maximum *Start value* = 2.5 x $I_n$, *Start value* multiples in range of 1.5 to 20

### 4.4.1.10 Technical revision history

*Table 201: NSPTOC Technical revision history*

| Technical revision | Change |
|---|---|
| B | Minimum and default values changed to 40 ms for the *Operate delay time* setting |

## 4.4.2 Phase discontinuity protection PDNSPTOC

### 4.4.2.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Phase discontinuity protection | PDNSPTOC | I2/I1> | 46PD |

### 4.4.2.2 Function block

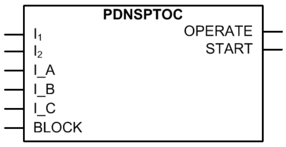



*Figure 119: Function block symbol*

### 4.4.2.3 Functionality

The phase discontinuity protection PDNSPTOC is used for detecting unbalance situations caused by broken conductors.

The function starts and operates when the unbalance current $I_2/I_1$ exceeds the set limit. To prevent faulty operation at least one phase current needs to be above the minimum level. PDNSPTOC operates with DT characteristic.

The function contains a blocking functionality. It is possible to block the function output, timer or the function itself, if desired.

### 4.4.2.4 Operation principle

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

The operation of phase discontinuity protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

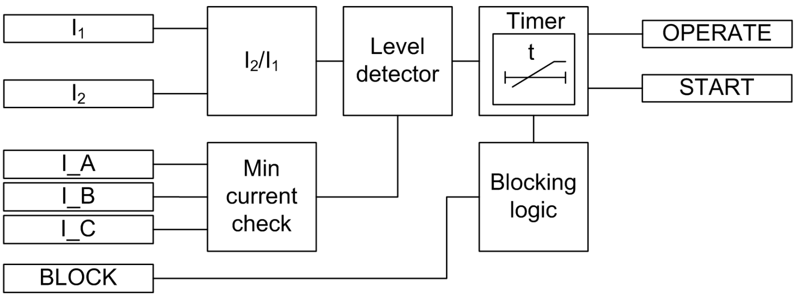



*Figure 120: Functional module diagram. $I_1$ and $I_2$ represent positive and negative phase sequence currents. I_A, I_B and I_C represent phase currents.*

#### $I_2/I_1$

The $I_2/I_1$ module calculates the ratio of the negative and positive phase sequence current. It reports the calculated value to the level detector.

### Level detector

The level detector compares the calculated ratio of negative and positive phase sequence currents with the set *Start value*. If the calculated value exceeds the set *Start value* and the min current check module has exceeded the minimum phase current limit, 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 operate time. The value is available through 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 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 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.

## 4.4.2.5 Application

In three-phase distribution and subtransmission network applications the phase discontinuity in one phase can cause increase of zero sequence voltage and short overvoltage peaks and also oscillation in the corresponding phase.

PDNSPTOC is a three-phase protection with DT characteristic, designed for detecting broken conductors in distribution and subtransmission networks. The function is applicable for both overhead lines and underground cables.

The operation of PDNSPTOC is based on the ratio of positive and negative sequence currents. This gives better sensitivity and stability compared to plain negative sequence current protection since the calculated ratio of positive and negative sequence currents is relatively constant during load variations.

When the three phase currents are measured, the positive-sequence current is calculated:

$$I_1 = \frac{1}{3}\left(Ia + aIb + a^2 Ic\right)$$

(Equation 37)

The negative sequence current is calculated:

$$I_2 = \frac{1}{3}\left(Ia + a^2 Ib + aIc\right)$$

(Equation 38)

| | |
|---|---|
| $I_a$, $I_b$, $I_c$ | phase current vectors |
| α | phase rotation operator (defined to rotate a phasor component forward by 120 degrees) |

The unbalance of the network is detected by monitoring the negative and positive sequence current ratio, where the negative-phase sequence current value is $I_2$ and $I_1$ is the positive-phase sequence current value. The unbalance is calculated:

$$Iratio = \frac{I_2}{I_1}$$

(Equation 39)

Broken conductor fault situation can occur in phase A in a feeder.

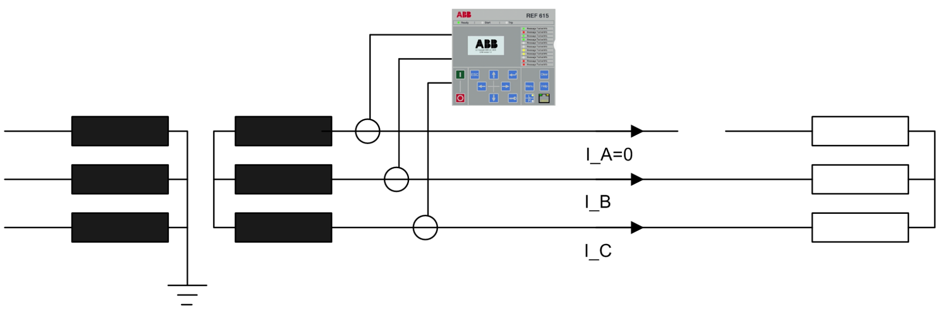



*Figure 121: Broken conductor fault situation in phase A in a distribution or subtransmission feeder*

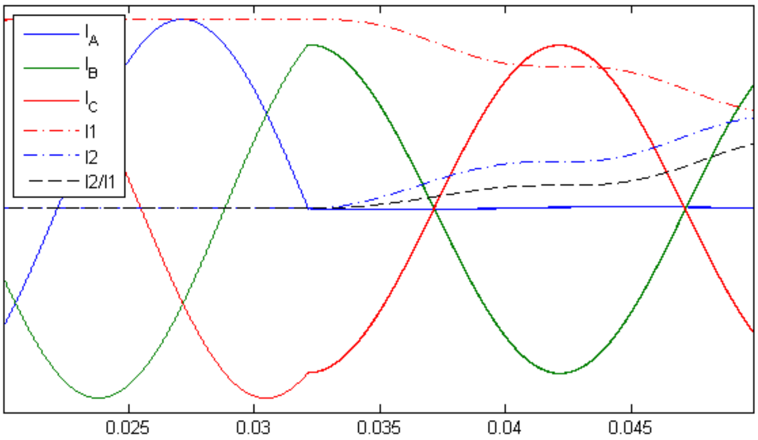



*Figure 122: Three-phase current quantities during the broken conductor fault in phase A with the ratio of negative and positive sequence currents*

## 4.4.2.6 Signals

*Table 202: PDNSPTOC Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $I_1$ | SIGNAL | 0 | Positive phase sequence current |
| $I_2$ | SIGNAL | 0 | Negative phase 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 203: PDNSPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

## 4.4.2.7 Settings

*Table 204: PDNSPTOC Group settings*

| 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 205: PDNSPTOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| 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 206: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.4.2.9 Technical data

*Table 207: PDNSPTOC Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | ±2% of the set value |
| Start time | < 70 ms |
| Reset time | < 40 ms |
| Reset ratio | Typical 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: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5,… |

## 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>> | 46 R |

### 4.4.3.2 Function block

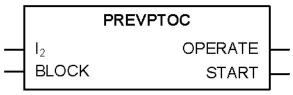



*Figure 123: Function block symbol*

### 4.4.3.3 Functionality

The phase-reversal protection PREVPTOC is used to detect the reversed connection of the phases to a three-phase motor by monitoring the negative phase-sequence current $I_2$ of the motor.

PREVPTOC starts and operates when $I_2$ exceeds the set limit. PREVPTOC operates on definite time (DT) characteristics. PREVPTOC is based on the calculated $I_2$, and the function detects too high $I_2$ values during the motor startup. The excessive $I_2$ values are caused by incorrectly connected phases, which in turn makes the motor rotate in the opposite direction.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

### 4.4.3.4 Operation principle

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

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

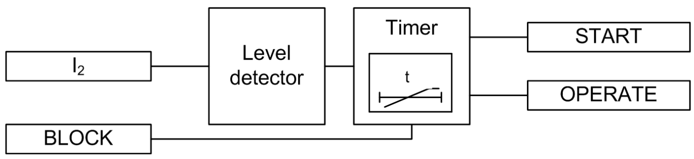



*Figure 124: Functional module diagram*

#### Level detector

The level detector compares the negative phase-sequence current to the set *Start value*. If the $I_2$ value exceeds the set *Start value*, the level detector sends an enable 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 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 operate time. The value is available through 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 phase-sequence component of the phase currents is very negligible when compared to the positive-sequence component of the current during a healthy operating condition of the motor. But when the motor is started with the phase connections in the reverse order, the magnitude of $I_2$ is very high. So whenever the value of $I_2$ exceeds the start value, the function detects the reverse rotation direction and provides an operate signal that disconnects the motor from the supply.

### 4.4.3.6 Signals

*Table 208: 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 209: PREVPTOC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.4.3.7 Settings

*Table 210: PREVPTOC Group settings*

| 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 211: PREVPTOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |

## 4.4.3.8 Monitored data

*Table 212: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 4.4.3.9 Technical data

*Table 213: PREVTOC Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the current measured: fn ±2Hz | | |
| | | ±1.5% of the set value or ±0.002 x $I_n$ | | |
| Start time[1)2)] | | Minimum | Typical | Maximum |
| | $I_{Fault}$ = 2.0 x set *Start value* | 22 ms | 24 ms | 25 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 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 x $f_n$, where n = 2, 3, 4, 5,… | | |

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 Negative phase-sequence time overcurrent protection MNSPTOC

## 4.4.4.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Negative phase-sequence time overcurrent protection | MNSPTOC | I2>M | 46M |

## 4.4.4.2 Function block

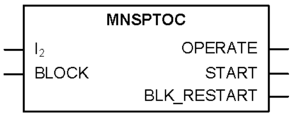



*Figure 125: Function block symbol*

## 4.4.4.3 Functionality

The unbalance protection based on negative-phase-sequence current 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, if desired.

## 4.4.4.4 Operation principle

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

The operation of unbalance protection based on negative phase-sequence current can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

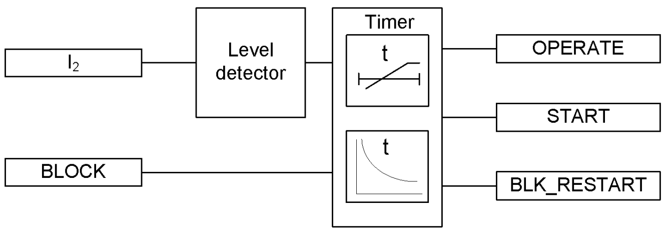



*Figure 126: Functional module diagram*

### Level detector

The 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 *Rated current* 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 operation timer counting can be frozen to the prevailing value by activating the FR_TIMER input.

The T_ENARESTART output indicates the duration for which the BLK_RESTART output remains active, that is, it indicates the remaining time of the cooling timer. The value is available through 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 operate time. The value is available through the Monitored data view.

### 4.4.4.5 Timer characteristics

MNSPTOC supports both DT and IDMT characteristics. The user can select the DT timer characteristics by selecting the “ANSI Def. Time” or “IEC Def. Time” in the *Operating curve type* setting. The functionality is identical in both cases. When the DT characteristics are selected, the functionality is only affected by the *Operate delay time* and *Reset delay time* settings.

The IED provides two user-programmable IDMT characteristics curves, the “Inverse Curve Type A” and “Inverse Curve Type B.”

#### Current-based inverse definite minimum type curve (IDMT)

In inverse-time modes, the operate time depends on the momentary value of the current: the higher the current, the faster 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.

### Inverse Curve Type A

The inverse time equation for curve type A is:

$$t[s] = \frac{k}{\left(\frac{I_2}{I_r}\right)^2}$$

(Equation 40)

| | |
|---|---|
| t[s] | Operate time in seconds |
| k | Set *Machine time Mult* |
| $I_2$ | Negative-sequence current |
| $I_r$ | Rated current |

If the negative-sequence current drops below the *Start value* setting, the reset time is defined as:

$$t[s] = a \times \left(\frac{b}{100}\right)$$

(Equation 41)

| | |
|---|---|
| t[s] | Reset time in seconds |
| a | set *Cooling time* |
| b | percentage of start time elapse (START_DUR) |

When the reset period is initiated, the time for which START has been active is saved. Now, if the fault reoccurs, that is, the negative-sequence current rises above the set value during the reset period, the operate calculations are continued using the saved values. However, if the reset period elapses without a fault being detected, the operate timer is reset and the saved values of start time and integration are cleared.

### Inverse Curve Type 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 42)

| | |
|---|---|
| t[s] | Operate time in seconds |
| k | *Machine time Mult* |
| $I_2$ | Negative-sequence current |
| $I_S$ | Set *Start value* |
| $I_r$ | Rated current |

If the fault disappears, the negative-sequence current drops below the *Start value* setting and the `START` output is deactivated. However, the function does not reset instantaneously, but instead it depends on the equation or the *Cooling time* setting.

The timer can be reset in two ways:

- With a drop in the negative-sequence current below start value, the subtraction in the denominator becomes negative and the cumulative sum starts to decrease. The decrease in the sum indicates the cooling of the machine and the cooling speed depends on the value of the negative-sequence current. If the sum reaches zero without a fault being detected, the accumulation stops and the timer is reset.
- If the reset time set through the *Cooling time* setting elapses without a fault being detected, the timer is reset.

The reset period thus continues for a time equal to the *Cooling time* setting or until the operate time decreases to zero, whichever is less.

## 4.4.4.6 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 214: 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 215: 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 216: MNSPTOC Group settings*

| 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<br>15=IEC Def. Time<br>17=Inv. Curve A<br>18=Inv. Curve B | | | 15=IEC Def. Time | Selection of time delay curve type |
| 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 217: MNSPTOC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Rated current | 0.30...2.00 | xIn | 0.01 | 1.00 | Rated current (Ir) of the machine (used only in the IDMT) |
| Maximum operate time | 500000...7200000 | ms | 1000 | 1000000 | Max operate time regardless of the inverse characteristic |
| 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 |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |

## 4.4.4.9 Monitored data

*Table 218: MNSPTOC Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| START_DUR | FLOAT32 | 0.00...100.00 | % | Ratio of start time / operate time |
| T_ENARESTART | FLOAT32 | 0.00...7200.00 | s | Estimated time to reset of block restart |
| MNSPTOC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 4.4.4.10 Technical data

*Table 219: MNSPTOC Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the current measured: fn ±2Hz | | |
| | | ±1.5% of the set value or ±0.002 x $I_n$ | | |
| Start time 1)2) | | Minimum | Typical | Maximum |
| | $I_{Fault}$ = 2.0 x set *Start value* | 22 ms | 24 ms | 25 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 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 x $f_n$, where n = 2, 3, 4, 5,… | | |

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
3) *Start value* multiples in range of 1.10 to 5.00

# 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

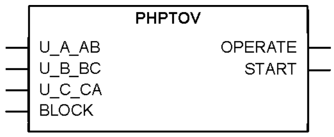



*Figure 127: Function block symbol*

### 4.5.1.3 Functionality

The three-phase overvoltage protection PHPTOV is applied on power system elements, such as generators, transformers, motors and power lines, to protect the system from excessive voltages that could damage the insulation and cause insulation breakdown. The three-phase overvoltage function includes a settable value for the detection of overvoltage either in a single phase, two phases or three phases.

PHPTOV includes both definite time (DT) and inverse definite minimum time (IDMT) characteristics for the delay of the trip.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

### 4.5.1.4 Operation principle

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

The operation of three-phase overvoltage protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

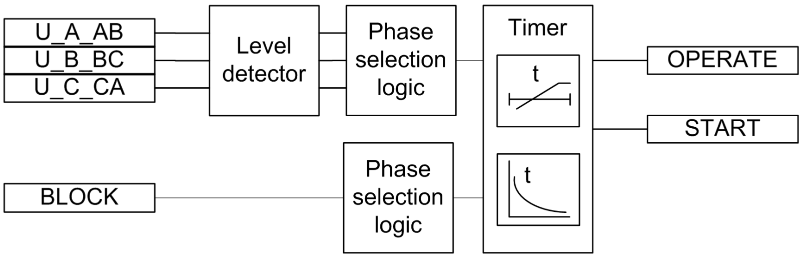



*Figure 128: Functional module diagram*

### Level detector

The fundamental frequency component of the measured three phase voltages are compared phase wise with 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 back 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 more detailed description of the IDMT curves and the usage of the *Curve Sat Relative* setting, see the General function block features section 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 the General function block features section in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value 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* and *Reset delay time* settings.

*Table 220: The reset time functionality when IDMT operate time curve selected*

| Type of reset curve | Desctiption of operation |
|---|---|
| “Immediate” | The operate timer is reset instantaneously when drop-off occurs |
| “Def time reset” | The operate timer is frozen during drop-off. Operate timer is reset after the set *Reset delay time* is exceeded |
| “DT Lin decr rst” | The operate timer value linearly decreases during the drop-off situation. The operate timer is reset after the set *Reset delay time* is exceeded |

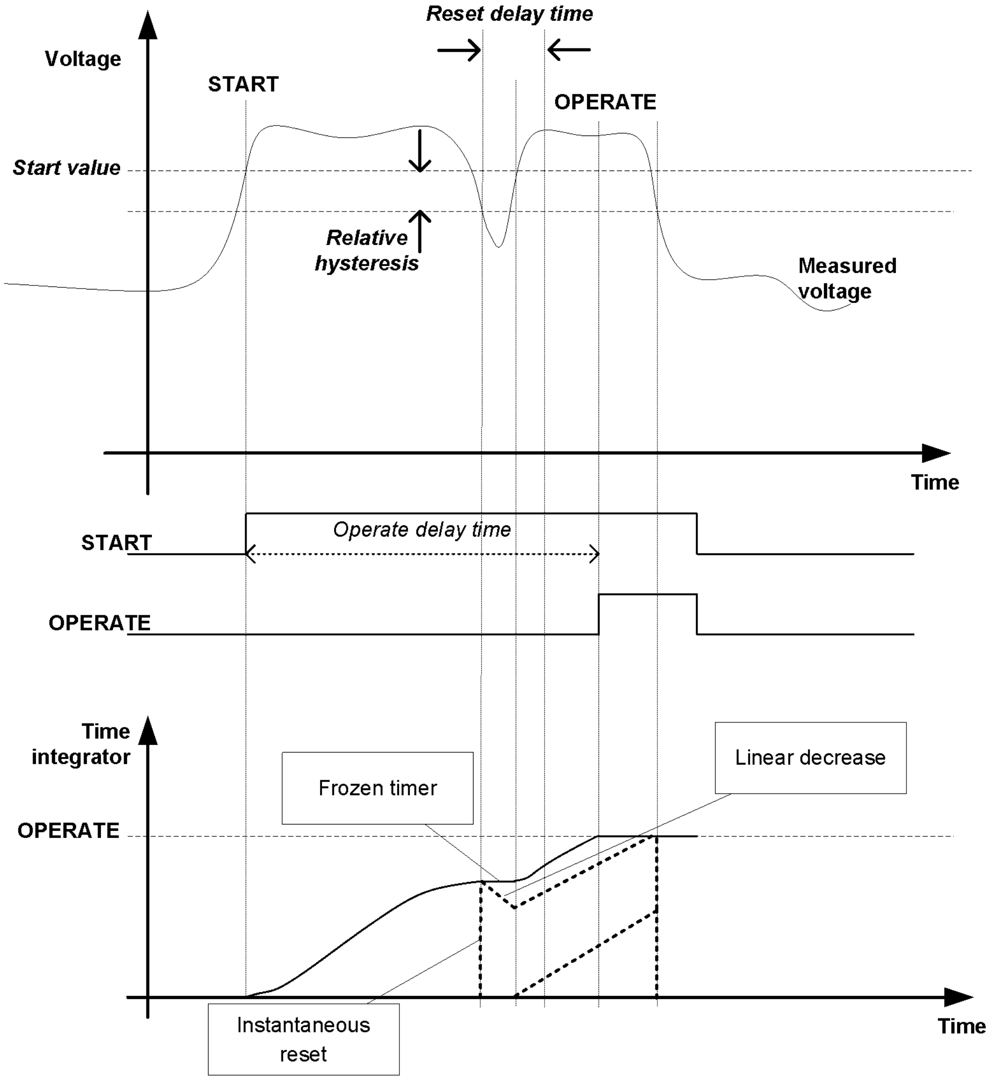



*Figure 129: Behaviour of different IDMT reset modes. The value for Type of reset curve is "Def time reset". Also other reset modes are presented for the time integrator.*

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 value of the *Minimum operate time* setting. For more information. see the General function block features section in this manual.

The timer calculates the start duration value START_DUR which indicates the percentual 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 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 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 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.

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 221: 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 IED protection function is used to protect against power frequency overvoltages.

The power frequency overvoltage may occur in the network due to the 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 222: 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 223: PHPTOV Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.5.1.8 Settings

*Table 224: PHPTOV Group settings*

| 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 | | 0.05 | 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<br>15=IEC Def. Time<br>17=Inv. Curve A<br>18=Inv. Curve B<br>19=Inv. Curve C<br>20=Programmable | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>-1=DT Lin decr rst | | | 1=Immediate | Selection of reset curve type |

*Table 225: PHPTOV Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 | | | 1=1 out of 3 | Number of phases required for operate activation |
| 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 parameter A | 0.005...200.000 | | | 1.000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.50...100.00 | | | 1.00 | Parameter B for customer programmable curve |
| Curve parameter C | 0.0...1.0 | | | 0.0 | Parameter C for customer programmable curve |
| Curve parameter D | 0.000...60.000 | | | 0.000 | Parameter D for customer programmable curve |
| Curve parameter E | 0.000...3.000 | | | 1.000 | Parameter E for customer programmable curve |
| Curve Sat Relative | 0.0...3.0 | | 0.1 | 2.0 | Tuning parameter to avoid curve discontinuities |
| Voltage selection | 1=phase-to-earth<br>2=phase-to-phase | | | 2=phase-to-phase | Parameter to select phase or phase-to-phase voltages |
| Relative hysteresis | 1.0...5.0 | % | 0.1 | 4.0 | Relative hysteresis for operation |

### 4.5.1.9 Monitored data

*Table 226: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.5.1.10 Technical data

*Table 227: PHPTOV Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the voltage measured: $f_n$ ±2Hz | | |
| | | ±1.5% of the set value or ±0.002 x $U_n$ | | |
| Start time1)2) | | Minimum | Typical | Maximum |
| | $U_{Fault}$ = 1.1 x set *Start value* | 22 ms | 24 ms | 26 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Depends of the set *Relative hysteresis* | | |
| Retardation time | | < 35 ms | | |
| Operate time accuracy in definite time mode | | ±1.0% of the set value or ±20 ms | | |
| Operate time accuracy in inverse time mode | | ±5.0% of the theoretical value or ±20 ms3) | | |
| Suppression of harmonics | | DFT: -50 dB at f = n x $f_n$, where n = 2, 3, 4, 5,… | | |

1) *Start value* = 1.0 x $U_n$, Voltage before fault = 0.9 x $U_n$, $f_n$ = 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 x $U_n$, *Start value* multiples in range of 1.10 to 2.00

## 4.5.2 Three-phase undervoltage protection PHPTUV

### 4.5.2.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Three-phase undervoltage protection | PHPTUV | 3U< | 27 |

### 4.5.2.2 Function block

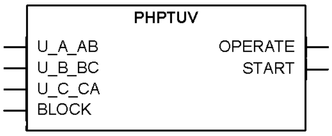



*Figure 130: Function block symbol*

### 4.5.2.3 Functionality

The three-phase undervoltage protection PHPTUV is used to disconnect from the network devices, for example electric motors, which are damaged when subjected to service under low voltage conditions. PHPTUV includes a settable value for the detection of undervoltage either in a single phase, two phases or three phases.

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 three-phase undervoltage protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

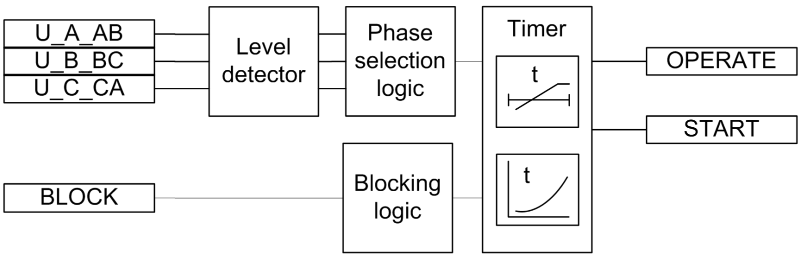



*Figure 131: Functional module diagram*

#### Level detector

The fundamental frequency component of the measured three phase voltages are compared phase wise with 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 the General function block features 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 is useful when it is wanted to avoid unnecessary starts and operates during, for example, an auto-reclose 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 matches 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 the General function block features section in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value 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* and *Reset delay time* settings.

*Table 228: The reset time functionality when IDMT operate time curve selected*

| Type of reset curve | Desctiption of operation |
|---|---|
| "Immediate" | The operate timer is reset instantaneously when drop-off occurs |
| "Def time reset" | The operate timer is frozen during drop-off. Operate timer is reset after the set *Reset delay time* is exceeded |
| "DT Lin decr rst" | The operate timer value linearly decreases during the drop-off situation. The operate timer is reset after the set *Reset delay time* is exceeded |

### Example

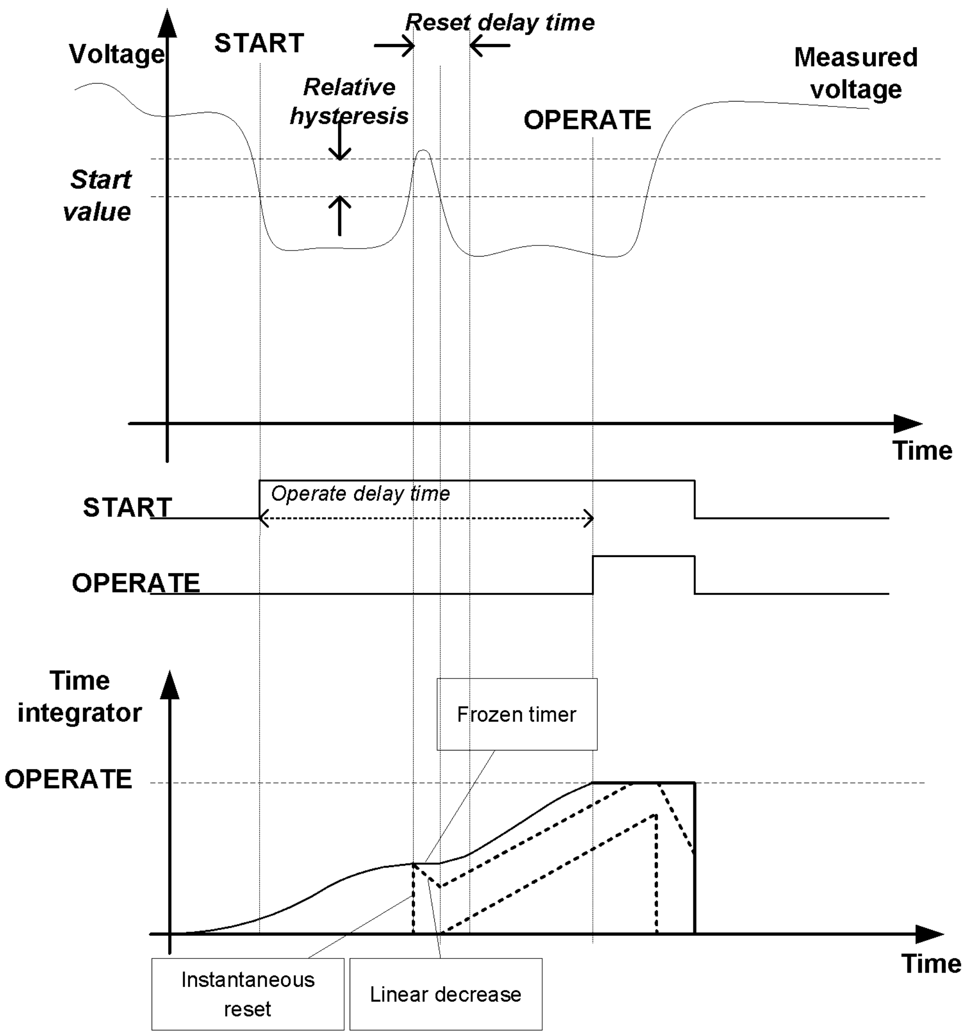



*Figure 132: Behaviour of different IDMT reset modes. The value for Type of reset curve is "Def time reset". Also other reset modes are presented for the time integrator.*

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 value of the *Minimum operate time* setting. For more information. see the General function block features section in this manual.

The timer calculates the start duration value START_DUR which indicates the percentual 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 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 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 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.

The “Freeze timers” mode of blocking has no effect during the “Inverse reset” mode.

## 4.5.2.5 Timer characteristics

The operating curve types supported by PHPTUV are:

*Table 229: 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 |

## 4.5.2.6 Application

PHPTUV is applied to power system elements, such as generators, transformers, motors and power lines, to detect low voltage conditions. Low voltage conditions are caused by abnormal operation or a fault in the power system. PHPTUV can be used in combination with overcurrent protections. Other applications are the detection of a no-voltage condition, for example before the energization of a high voltage line, or an automatic breaker trip in case of a blackout. PHPTUV is also used to initiate voltage correction measures, such as insertion of shunt capacitor banks, to compensate for a reactive load and thereby to increase the voltage.

PHPTUV can be used to disconnect from the network devices, such as electric motors, which are damaged when subjected to service under low voltage conditions. PHPTUV deals with low voltage conditions at power system frequency. Low voltage conditions can be caused by:

- 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.

### 4.5.2.7 Signals

*Table 230: 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 231: PHPTUV Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.5.2.8 Settings

*Table 232: PHPTUV Group settings*

| 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 | | 0.05 | 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<br>15=IEC Def. Time<br>21=Inv. Curve A<br>22=Inv. Curve B<br>23=Programmable | | | 15=IEC Def. Time | Selection of time delay curve type |
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>-1=DT Lin decr rst | | | 1=Immediate | Selection of reset curve type |

*Table 233: PHPTUV Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 | | | 1=1 out of 3 | Number of phases required for operate activation |
| 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 parameter A | 0.005...200.000 | | | 1.000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.50...100.00 | | | 1.00 | Parameter B for customer programmable curve |
| Curve parameter C | 0.0...1.0 | | | 0.0 | Parameter C for customer programmable curve |
| Curve parameter D | 0.000...60.000 | | | 0.000 | Parameter D for customer programmable curve |
| Curve parameter E | 0.000...3.000 | | | 1.000 | Parameter E for customer programmable curve |
| 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<br>1=True | | | 1=True | Enable internal blocking |
| Voltage selection | 1=phase-to-earth<br>2=phase-to-phase | | | 2=phase-to-phase | Parameter to select phase or phase-to-phase voltages |
| Relative hysteresis | 1.0...5.0 | % | 0.1 | 4.0 | Relative hysteresis for operation |

## 4.5.2.9 Monitored data

*Table 234: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

### 4.5.2.10 Technical data

*Table 235: PHPTUV Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the voltage measured: fn ±2Hz | | |
| | | ±1.5% of the set value or ±0.002 x $U_n$ | | |
| Start time[1)2)] | | Minimum | Typical | Maximum |
| | $U_{Fault}$ = 0.9 x set *Start value* | 62 ms | 64 ms | 66 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Depends of the set *Relative hysteresis* | | |
| Retardation time | | < 35 ms | | |
| Operate time accuracy in definite time mode | | ±1.0% of the set value or ±20 ms | | |
| Operate time accuracy in inverse time mode | | ±5.0% of the theoretical value or ±20 ms[3)] | | |
| Suppression of harmonics | | DFT: -50 dB at f = n x $f_n$, where n = 2, 3, 4, 5,… | | |

1) *Start value* = 1.0 x $U_n$, Voltage before fault = 1.1 x $U_n$, $f_n$ = 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 to 0.20

## 4.5.3 Residual overvoltage protection ROVPTOV

### 4.5.3.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Residual overvoltage protection | ROVPTOV | U0> | 59G |

### 4.5.3.2 Function block


*Figure 133: Function block symbol*

### 4.5.3.3 Functionality

The residual overvoltage protection ROVPTOV is used in distribution networks where the residual overvoltage can reach non-acceptable levels, for example, in high impedance earthing.

The function starts when the residual voltage exceeds the set limit. ROVPTOV operates with the definite time (DT) characteristic.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

### 4.5.3.4 Operation principle

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

The operation of residual overvoltage protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

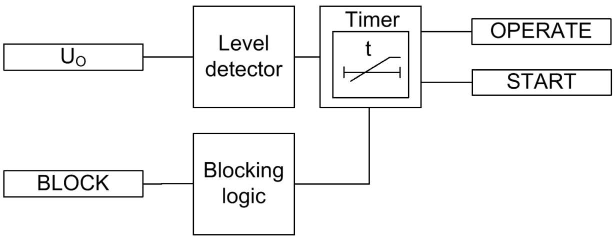



*Figure 134: Functional module diagram. $U_0$ represents the residual voltage.*

#### Level detector

The measured or calculated residual voltage is compared with the set *Start value*. If the value exceeds the set *Start value*, the level detector sends an enable-signal to the timer.

#### Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR which indicates the percentage ratio of the start situation and the set operate time. The value is available through 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 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 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.

### 4.5.3.5 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 back-up protection of feeders for busbar protection when 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-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 earth-fault protection of generators and motors and for the unbalance protection of capacitor banks.

The residual voltage can be calculated internally based on the measurement of the three-phase voltage. This voltage can also be measured by a single-phase voltage transformer, located between a transformer star point and earth, or by using an open-delta connection of three single-phase voltage transformers.

### 4.5.3.6 Signals

*Table 236: ROVPTOV Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $U_0$ | SIGNAL | 0 | Residual voltage |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

*Table 237: ROVPTOV Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.5.3.7 Settings

*Table 238: ROVPTOV Group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Start value | 0.010...1.000 | xUn | 0.001 | 0.030 | Residual overvoltage start value |
| Operate delay time | 40...300000 | ms | 1 | 40 | Operate delay time |

*Table 239: ROVPTOV Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |

### 4.5.3.8 Monitored data

*Table 240: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

*Table 241: ROVPTOV Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the voltage measured: $f_n$ ±2Hz | | |
| | | ±1.5% of the set value or ±0.002 x $U_n$ | | |
| Start time[1)2)] | | Minimum | Typical | Maximum |
| | $U_{Fault}$ = 1.1 x set *Start value* | 29 ms | 31 ms | 32 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 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 x $f_n$, where n = 2, 3, 4, 5,… | | |

1) Residual voltage before fault = 0.0 x $U_n$, $f_n$ = 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

## 4.5.4 Negative sequence overvoltage protection NSPTOV

### 4.5.4.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Negative sequence overvoltage protection | NSPTOV | U2> | 47O- |

### 4.5.4.2 Function block

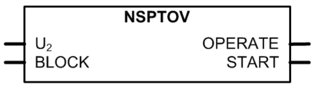



*Figure 135: Function block symbol*

### 4.5.4.3 Functionality

The negative sequence overvoltage protection NSPTOV is used to detect negative phase sequence overvoltage conditions. NSPTOV is used for protection of machines.

The function starts when the negative phase sequence voltage exceeds the set limit. NSPTOV operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

### 4.5.4.4 Operation principle

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

The operation of negative sequence overvoltage protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

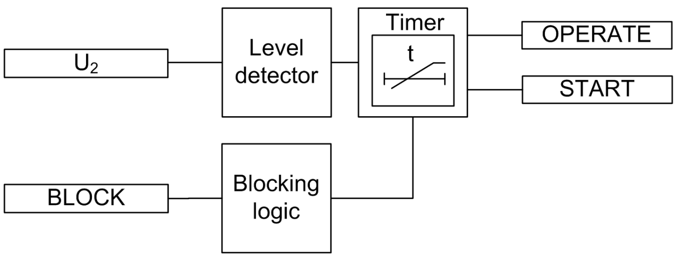



*Figure 136: Functional module diagram. $U_2$ is used for representing negative phase sequence voltage.*

### Level detector

The calculated negative sequence voltage is compared with 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 operate time. The value is available through 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 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 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.

## 4.5.4.5 Application

A continuous or temporary voltage unbalance may appear in the network for various reasons. Mainly, the voltage unbalance 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 continuous negative phase 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 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 bus bar.

If the machines have 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.

### 4.5.4.6 Signals

*Table 242: 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 243: NSPTOV Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.5.4.7 Settings

*Table 244: NSPTOV Group settings*

| 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 245: NSPTOV Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |

## 4.5.4.8 Monitored data

*Table 246: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 4.5.4.9 Technical data

*Table 247: NSPTOV Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the voltage measured: fn ±2Hz | | |
| | | ±1.5% of the set value or ±0.002 x $U_n$ | | |
| Start time[1)2)] | | Minimum | Typical | Maximum |
| | $U_{Fault}$ = 1.1 x set *Start value*<br>$U_{Fault}$ = 2.0 x set *Start value* | 33 ms<br>24 ms | 35 ms<br>26 ms | 37 ms<br>28 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 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 x $f_n$, where n = 2, 3, 4, 5,… | | |

1) Negative-sequence voltage before fault = 0.0 x $U_n$, $f_n$ = 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

## 4.5.5 Positive sequence undervoltage protection PSPTUV

### 4.5.5.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Positive-sequence undervoltage protection function | PSPTUV | U1 | 47U+ |

### 4.5.5.2 Function block

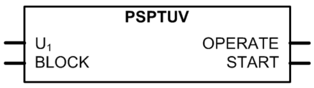



*Figure 137: Function block symbol*

### 4.5.5.3 Functionality

The positive-sequence undervoltage protection PSPTUV is used to detect positive phase sequence undervoltage conditions. PSPTUV is used for 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 phase sequence voltage goes below the set limit. PSPTUV operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

### 4.5.5.4 Operation principle

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

The operation of positive sequence undervoltage protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

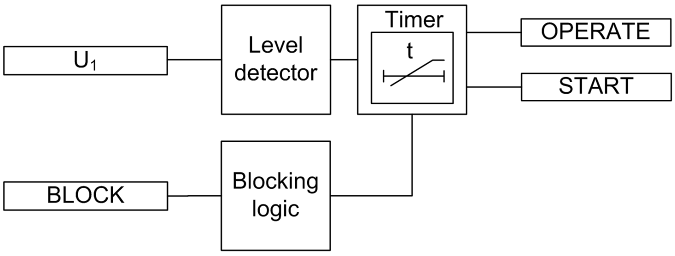



*Figure 138: Functional module diagram. $U_1$ is used for representing positive phase sequence voltage.*

## Level detector

The calculated positive sequence voltage is compared to the set *Start value* setting. If the value goes below the set *Start value*, the level detector enables the timer. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies from the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

The level detector contains a low level blocking functionality for cases where the positive sequence voltage is below the desired level. This feature is useful when it is wanted to avoid unnecessary starts and operates during, for example, an auto-reclose 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. 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 operate time. The value is available through 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 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 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.

## 4.5.5.5 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 may be dangerous for the power station for various reasons. The operation of the protection may 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 may 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 an 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 may 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 may be different from the corresponding voltage in the rest of the network. The island may get 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 frequency and voltage operation.

### 4.5.5.6 Signals

*Table 248: 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 249: PSPTUV Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| START | BOOLEAN | Start |

### 4.5.5.7 Settings

*Table 250: PSPTUV Group settings*

| 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 |
| Voltage block value | 0.01...1.00 | xUn | 0.01 | 0.20 | Internal blocking level |
| Enable block value | 0=False<br>1=True | | | 1=True | Enable Internal Blocking |

*Table 251: PSPTUV Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| 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 |

### 4.5.5.8 Monitored data

*Table 252: 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

#### 4.5.5.9 Technical data

*Table 253: PSPTUV Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | Depending on the frequency of the voltage measured: $f_n$ ±2Hz | | |
| | | ±1.5% of the set value or ±0.002 x $U_n$ | | |
| Start time[1)2)] | | Minimum | Typical | Maximum |
| | $U_{Fault}$ = 0.99 x set *Start value* | 51 ms | 53 ms | 54 ms |
| | $U_{Fault}$ = 0.9 x set *Start value* | 43 ms | 45 ms | 46 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Depends of the set *Relative hysteresis* | | |
| Retardation time | | < 35 ms | | |
| Operate time accuracy in definite time mode | | ±1.0% of the set value or ±20 ms | | |
| Suppression of harmonics | | DFT: -50 dB at f = n x $f_n$, where n = 2, 3, 4, 5,… | | |

1) *Start value* = 1.0 x $U_n$, Positive sequence voltage before fault = 1.1 x $U_n$, $f_n$ = 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

## 4.6 Arc protection ARCSARC

### 4.6.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Arc protection | ARCSARC | ARC | 50L/50NL |

### 4.6.2 Function block

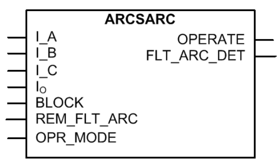



*Figure 139: Function block symbol*

## 4.6.3 Functionality

The arc protection (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.

## 4.6.4 Operation principle

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

The operation of arc protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

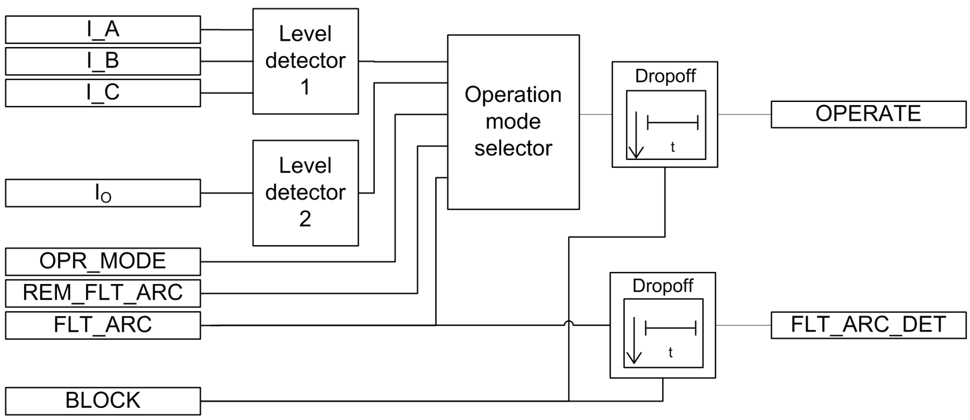



*Figure 140: Functional module diagram. I_A, I_B and I_C represent phase currents.*

### Level detector 1

The measured phase currents are compared phase-wise with 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 with 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 FLT_ARC_DET.

## 4.6.5 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 FLT_ARC_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 `FLT_ARC_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 IED

In installations, with limited possibilities to realize signalling between IEDs protecting incoming and outgoing feeders, or if only the IED 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 IED only is realized by installing two arc lens sensors connected to the IED 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.

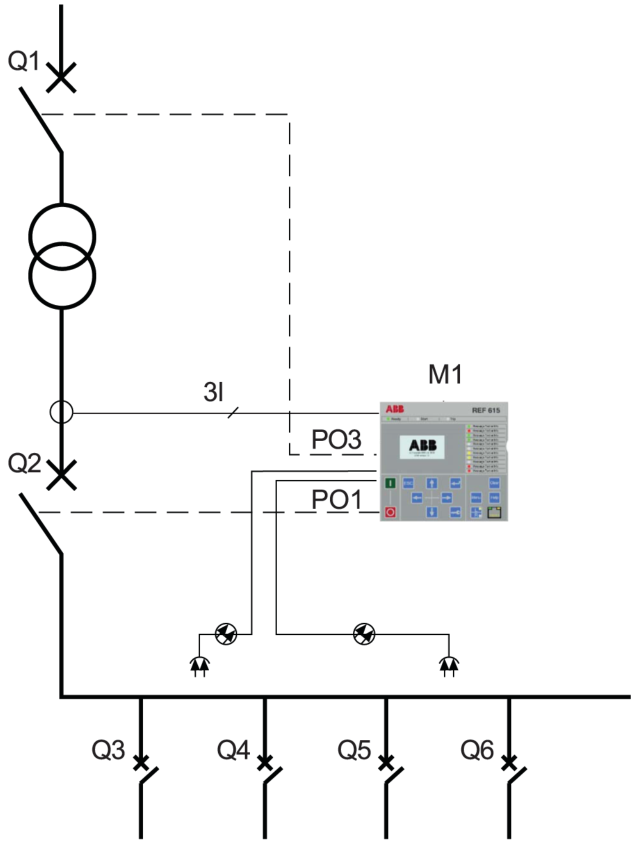



*Figure 141: Arc protection with one IED*

## Arc protection with several IEDs

When using several IEDs, the IED protecting the outgoing feeder trips the circuit breaker of the outgoing feeder when detecting an arc at the cable terminations. If the IED 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 IED protecting the incoming feeder. When detecting the signal, the IED protecting the incoming feeder trips the circuit breaker of the incoming feeder and generates an external trip signal to all IEDs protecting the outgoing feeders, which in turn results in tripping of all circuit breakers of the outgoing feeders. For maximum safety, the IEDs can be configured to trip all the circuit breakers regardless of where the arc is detected.

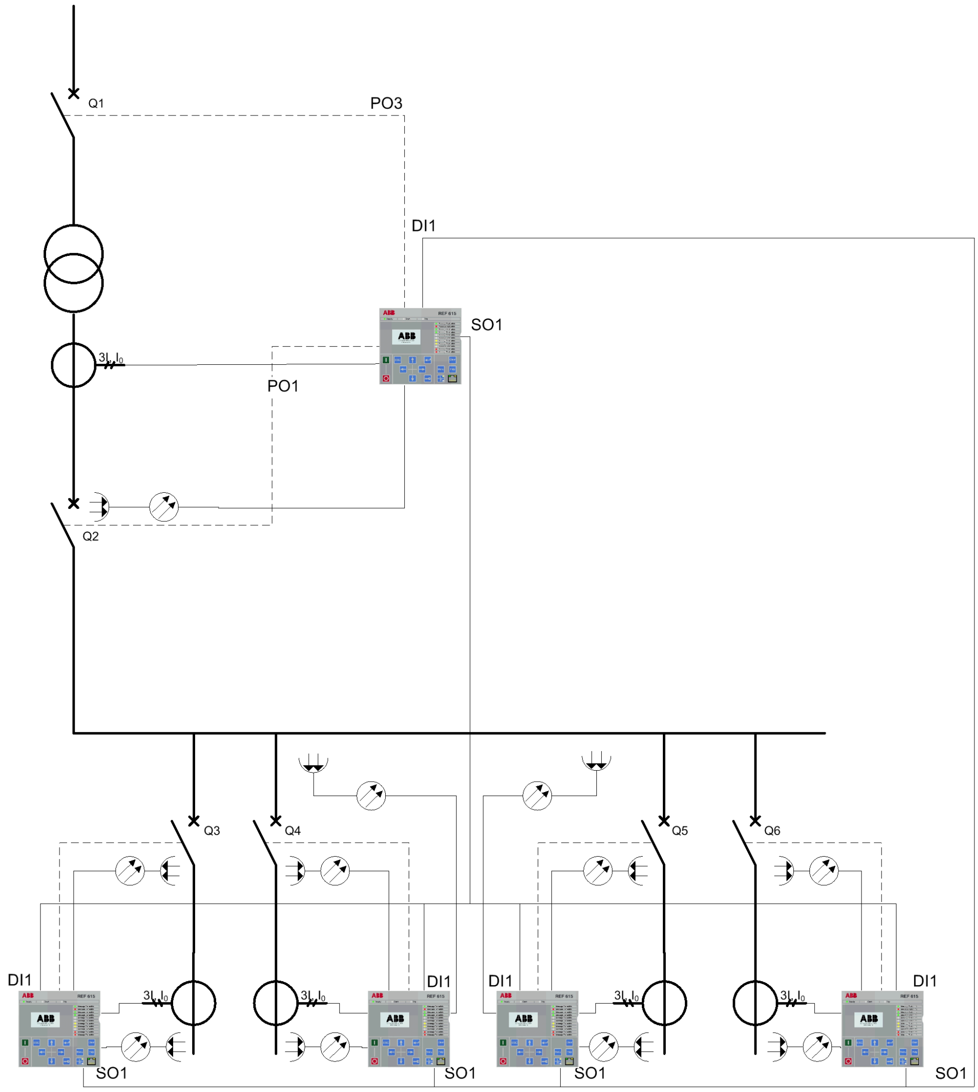



*Figure 142: Arc protection with several IEDs*

## Arc protection with several IEDs and a separate arc protection system

When realizing an arc protection with both IEDs and a separate arc protection system, the cable terminations of the outgoing feeders are protected by IEDs using one lens sensor for each IED. 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 IED 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 IEDs protecting the outgoing feeders, which in turn results in tripping of all circuit breakers of the outgoing feeders.

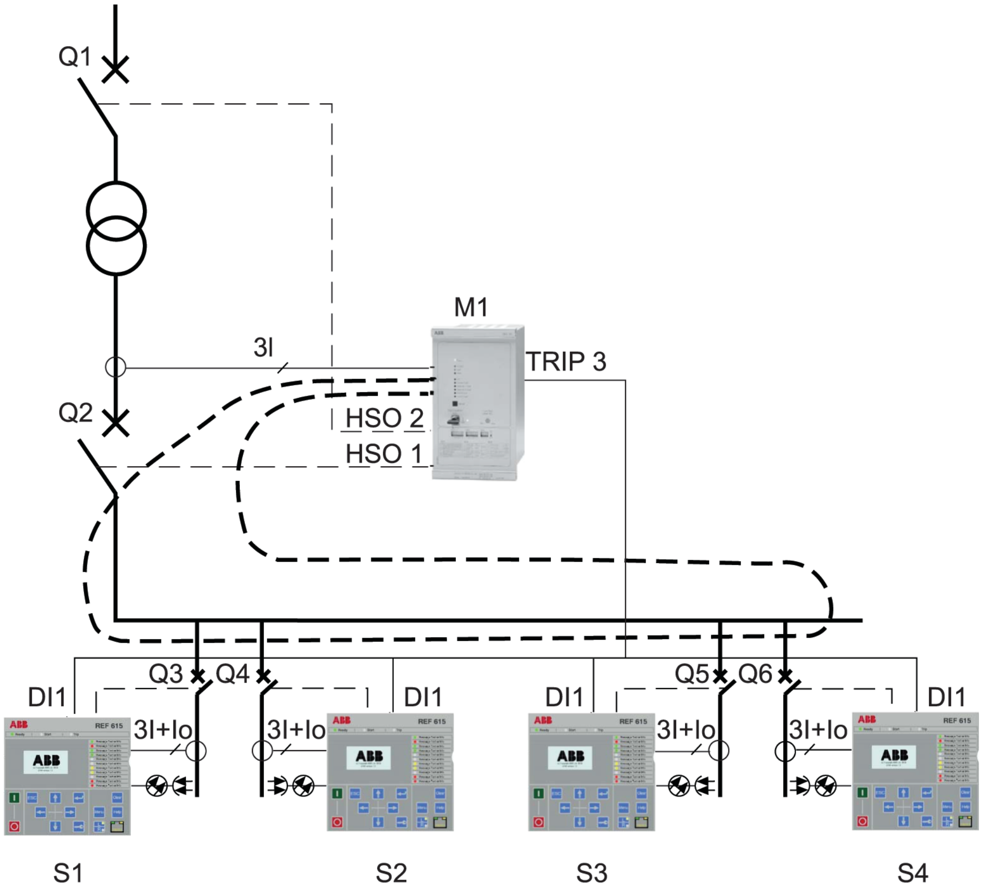



Figure 143: *Arc protection with several IEDs and a separate arc protection system*

## 4.6.6 Signals

*Table 254: 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 |
| $I_0$ | 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 255: ARCSARC Output signals*

| Name | Type | Description |
|---|---|---|
| OPERATE | BOOLEAN | Operate |
| ARC_FLT_DET | BOOLEAN | Fault arc detected=light signal output |

## 4.6.7 Settings

*Table 256: ARCSARC Group settings*

| 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<br>2=Light only<br>3=BI controlled | | | 1=Light+current | Operation mode |

*Table 257: ARCSARC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |

## 4.6.8 Monitored data

*Table 258: ARCSARC Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| ARCSARC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 4.6.9 Technical data

*Table 259: ARCSARC Technical data*

| Characteristic | | Value | | |
|---|---|---|---|---|
| Operation accuracy | | ±3% of the set value or ±0.01 x $I_n$ | | |
| Operate time | | Minimum | Typical | Maximum |
| | *Operation mode* = "Light+current"1)2) | 9 ms | 12 ms | 15 ms |
| | *Operation mode* = "Light only"2) | 9 ms | 10 ms | 12 ms |
| Reset time | | < 40 ms | | |
| Reset ratio | | Typical 0.96 | | |

1) *Phase start value* = 1.0 x $I_n$, current before fault = 2.0 x 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

# 4.7 Motor startup supervision STTPMSU

## 4.7.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Motor startup supervision | STTPMSU | Is2tn< | 49,66,48,51LR |

## 4.7.2 Function block

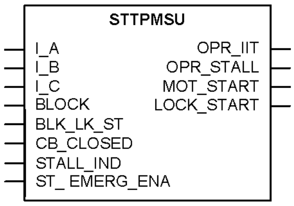



*Figure 144: Function block symbol*

## 4.7.3 Functionality

The motor startup supervision function STTPMSU is designed for protection against excessive starting time and locked rotor conditions of the motor during starting. For good and reliable operation of motor, the thermal stress during the motor starting is maintained within the allowed limits.

The starting of motor is supervised by monitoring the TRMS magnitude of all the phase currents or by monitoring the status of the circuit breaker connected to the motor.

During the startup period of the motor, STTPMSU calculates the integral of $I^2t$ value. If the calculated value exceeds the set value, the operate signal is activated.

STTPMSU has the provision to check the locked rotor condition of the motor using the speed switch, which means checking if the rotor is able to rotate or not. This feature operates after a predefined operating time.

STTPMSU also protects the motor from an excessive number of startups. Upon exceeding the specified number of startups within certain duration, STTPMSU blocks further starts. The restart of the motor is also inhibited after each start and continues to be inhibited for a set duration. When the lock of start of motor is enabled, STTPMSU gives the time remaining until the restart of the motor.

STTPMSU contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

## 4.7.4 Operation principle

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

The operation of the motor startup supervision function can be described using a module diagram. All the blocks in the diagram are explained in the next sections.

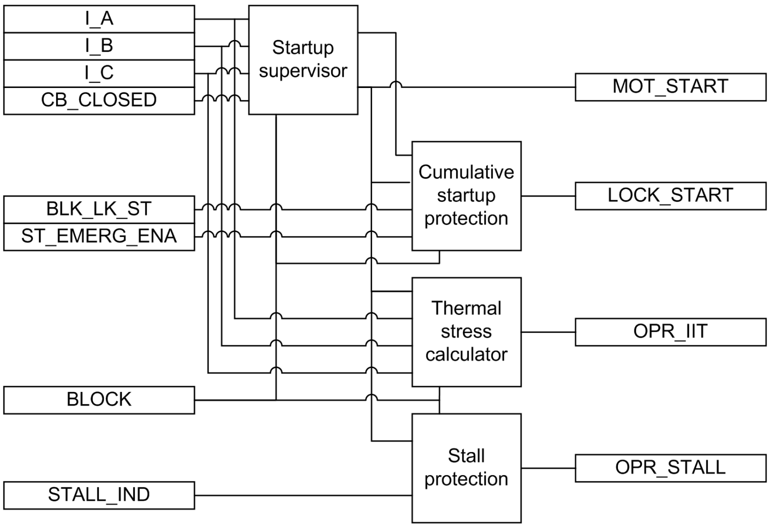



*Figure 145: Functional module diagram*

### 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 startup condition. In this mode, the startup condition is detected by monitoring the TRMS currents.

The *Operation mode* setting in the “IIt, CB” mode enables the function to calculate the value of the thermal stress when a startup is monitored in addition to the `CB_CLOSED` input.

In the “IIt & stall” mode, the function calculates the thermal stress of the motor during the startup condition. In this mode, the startup condition is detected by monitoring the TRMS currents. In the “IIt & stall” mode, the function also checks for motor stalling by monitoring the speed switch.

In the “IIt & stall, CB” mode, the function calculates the thermal stresses of the motor during the startup condition. The startup condition is monitored in addition to the circuit breaker status. In the “IIt & stall, CB” mode, the function also checks for motor stalling by monitoring the speed switch.

When the measured current value is used for startup supervision in the “IIt” and “IIt & stall” modes, the module initially recognizes the de-energized condition of the motor when the values of all three phase currents are less than *Motor standstill A* for longer than 100 milliseconds. If any of the phase currents of the de-energized condition rises to a value equal or greater than the *Motor standstill A*, the MOT_START output signal is activated indicating that the motor startup is in progress. The MOT_START output remains active until the values of all three phase currents drop below 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 startup situation is over.

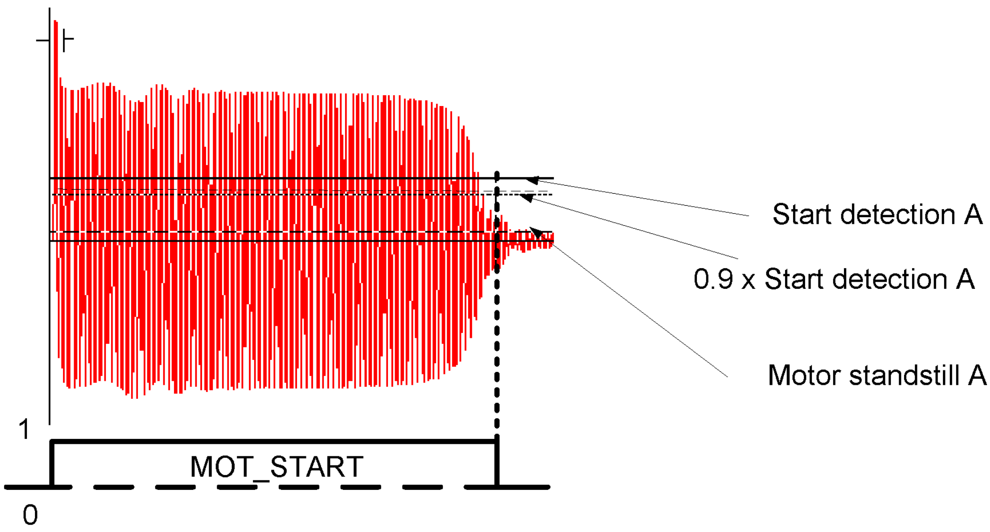



*Figure 146: Functionality of startup supervision in "IIt and IIt&stall" mode*

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 startup is recognized when CB is closed, that is, when the CB_CLOSED input is activated and at least one phase current value exceeds the *Motor standstill A* setting.

But in normal practice, 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 startup is recognized.

The motor startup ends either within the value of the *Str over delay time* setting from the beginning of the startup or the opening of CB or when the CB_CLOSED input is de-activated. The operation of the MOT_START output signal in this operation mode is as illustrated

This CB mode can be used in soft-started or slip ring motors for protection against too high a starting current, that is, a problem in starting and so on.

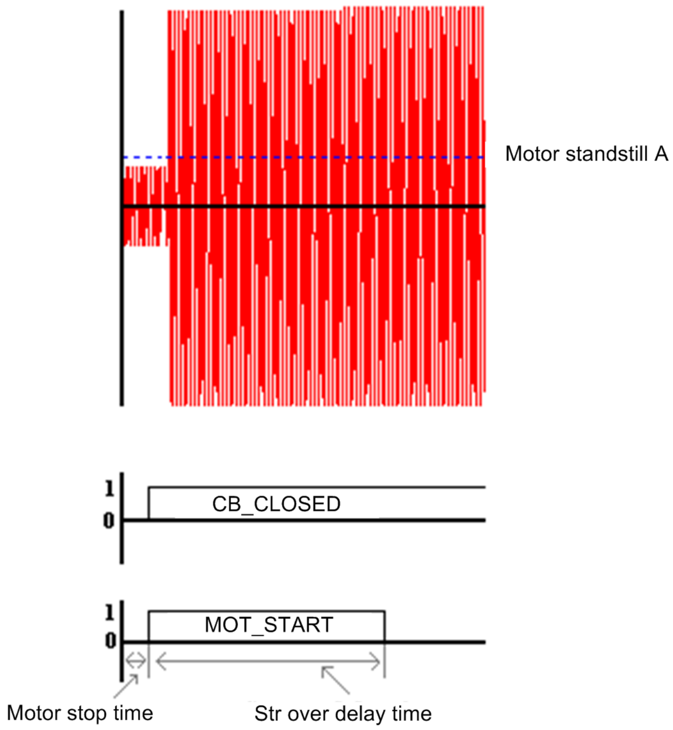



*Figure 147: Functionality of startup supervision in "IIt, CB" mode and "IIt and stall, CB" mode*

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 startup period. The purpose of this time delay setting is to allow for short interruptions in the current without changing the state of the MOT_START output. In this mode of operation, the value of the setting is in the range of around 100 milliseconds.
- In the “IIt, CB” or “IIt & stall, CB” modes, the purpose of this setting is to check for the life of the protection scheme after the CB_CLOSED input has been activated. Based on the values of the phase currents, the completion of the startup period cannot be judged. 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 BLOCK input signal is used to block the operation of the MOT_START output. The activation of the BLOCK input signal deactivates the MOT_START output.

### Thermal stress calculator

Because of the high current surges during the startup period, 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 startup causes a rapid heating of the rotor.

This module calculates the thermal stress developed in the motor during startup. The heat developed during the starting can be calculated using the formula,

$$W = R_s \int_0^t i_s^2(t)\, dt$$

(Equation 43)

$R_s$ combined rotor and stator resistance

$i_s$ starting current of the motor

t starting time of the motor

This equation is normally represented as the integral of $I^2t$. It is a commonly used method in protective relays to protect the motor from thermal stress during starting. The advantage of this method over the traditional definite time overcurrent protection is that when the motor is started with a reduced voltage as in the star-delta starting method, the starting current is lower. This allows more starting time for the motor since the module is monitoring the integral of $I^2t$.

The module calculates the accumulated heat continuously and compares it to the limiting value obtained from the product of the square of the values of the *Motor start-up A* and *Motor start-up time* settings. When the calculated value of the thermal stress exceeds this limit, the OPR_IIT output is activated.

The module also measures the time START_TIME required by the motor to attain the rated speed and the relative thermal stress IIT_RL. The values are available through the monitored data view.

The BLOCK input is used to reset the operation of thermal stress calculator. The activation of the BLOCK input signal blocks the operation of the OPR_IIT output.

### Stall protection

This module is activated only when the selected *Operation mode* setting value is “IIt & stall” or “IIt & stall, CB”.

The startup current is specific to each motor and depends on the startup method used, like direct on-line, autotransformer and rotor resistance insertion, and so on. The startup time is dependent of the load connected to the motor.

Based on the motor characteristics supplied by the manufacturer, this module is required if the stalling time is shorter than or too close to the starting time. In such cases, a speed switch must be used to indicate whether a motor is accelerating during startup or not.

At motor standstill, the STALL_IND input is active. It indicates that the motor is not running. When the motor is started, at certain revolution the activation of the STALL_IND input by the speed switch indicates the motor is running. If the input is activated 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 through the monitored data view.

The BLOCK input signal is used to block the operation of the OPR_STALL output. The activation of the BLOCK input resets the operate timer.

### Cumulative startup protection

This module protects the motor from an excessive number of startups.

Whenever the motor is started, the latest value of START_TIME is added to the existing value of T_ST_CNT and the updated cumulative startup time is available at T_ST_CNT. If the value of T_ST_CNT is greater than the value of *Cumulative time Lim*, the LOCK_START output, that is, the lockout condition for the restart of motor, is enabled. 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*.

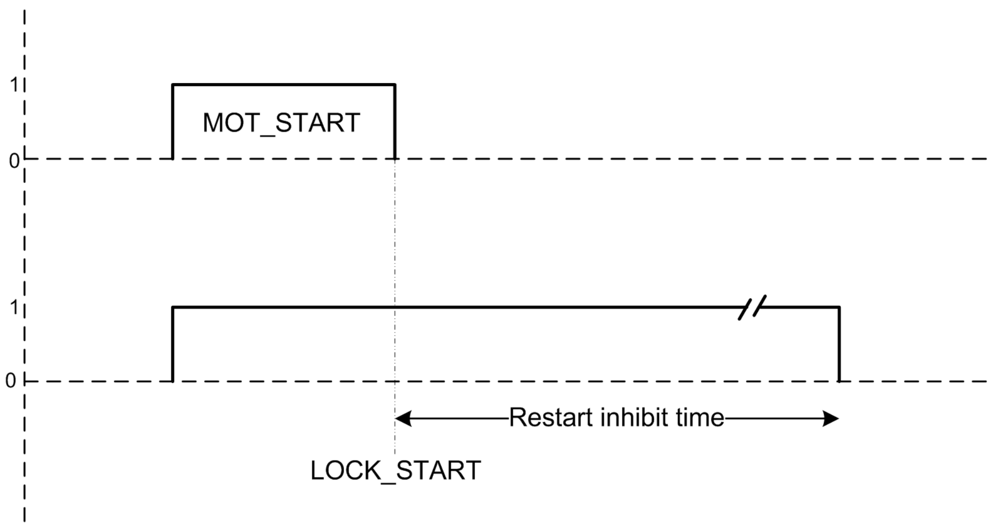



*Figure 148: Time delay for cumulative start*

This module also protects the motor from consecutive startups. When the LOCK_START output is active, T_RST_ENA shows the possible time for next restart. The value of T_RST_ENA is calculated by the difference of *Restart inhibit time* and the elapsed time from the instant LOCK_START is enabled.

When the ST_EMERG_ENA emergency start is set high, the value of the cumulative startup time counter is set 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 startups occurred, START_CNT. The value can be reset from the clear menu.

The calculated values of T_RST_ENA, T_ST_CNT and START_CNT are available through the monitored data view.

The BLK_LK_ST input signal is used to block the operation of the LOCK_START output. The activation of the BLOCK input resets the complete operation of the cumulative startup counter module.

## 4.7.5 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.

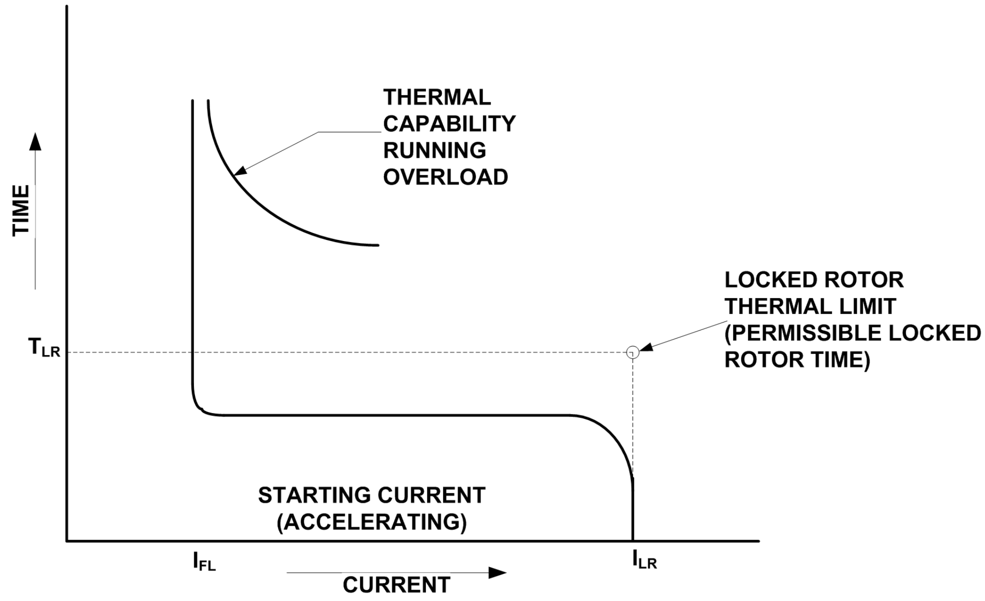



*Figure 149: Typical motor starting and capability curves*

The startup supervision of a motor is an important function because of the higher thermal stress developed during starting. During the startup, the current surge imposes a thermal strain on the rotor. This is exaggerated as the air flow for cooling is less because the fans do not rotate in their full speed. Moreover, the difference of speed between the rotating magnetic field and the rotor during the startup time induces a high magnitude of slip current in the rotor at frequencies higher than when the motor is at full speed. The skin effect is stronger at higher frequencies and all these factors increase the losses and the generated heat. This is worse when the rotor is locked.

The starting current for slip-ring motors is less than the full load current and therefore it is advisable to use the circuit breaker in the closed position to indicate the starting for such type of motors.

The starting times vary depending on motor design and load-torque characteristics. The time taken may vary from less than two seconds to more than 60 seconds. The starting time is determined for each application.

When the permissible stall time is less than the starting time of the motor, the stalling protection is used and the value of the time delay setting should be set slightly less than the permissible stall time. The speed switch on the motor shaft must be used for detecting whether the motor begins to accelerate or not. However, if the safe stall time is longer than the startup time of the motor, the speed switch is not required.

The failure of a motor to accelerate or to reach its full nominal speed in an acceptable time when the stator is energized is caused by several types of abnormal conditions, including a mechanical failure of the motor or load bearings, low supply voltage, open circuit in one phase of a three-phase voltage supply or too high starting voltage. All these abnormal conditions result in overheating.

Repeated starts increase the temperature to a high value in the stator or rotor windings, or both, unless enough time is allowed for the heat to dissipate. To ensure a safe operation it is necessary to provide a fixed-time interval between starts or limit the number of starts within a period of time. This is why the motor manufacturers have restrictions on how many starts are allowed in a defined time interval. This function does not allow starting of the motor if the number of starts exceeds the set level in the register that calculates them. This insures that the thermal effects on the motor for consecutive starts stay within permissible levels.

For example, the motor manufacturer may state that three starts at the maximum are allowed within 4 hours and the startup situation time is 60 seconds. By initiating three successive starts we reach the situation as illustrated. As a result, the value of the register adds up to a total of 180 seconds. Right after the third start has been initiated, the output lock of start of motor is activated and the fourth start will not be allowed, provided the time limit has been set to 121 seconds.

Furthermore, a maximum of three starts in 4 hours means that the value of the register should reach the set start time counter limit within 4 hours to allow a new start. Accordingly, the start time counter reduction should be 60 seconds in 4 hours and should thus be set to 60 s / 4 h = 15 s / h.

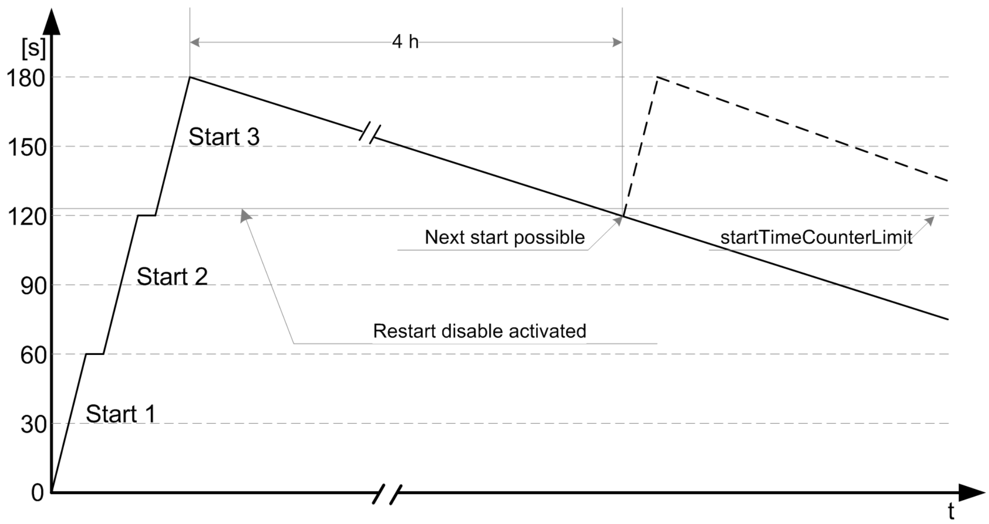



*Figure 150: Typical motor-starting and capability curves*

Setting of *Cumulative time Lim*

*Cumulative time Lim* is calculated by

$$\sum t_{si} = (n-1) \times t + margin$$

(Equation 44)

n specified maximum allowed number of motor startups

t startup time of the motor (in seconds)

margin safety margin (~10...20 percent)

Setting of *Counter Red rate*

*Counter Red rate* is calculated by

$$\Delta\sum t_s = \frac{t}{t_{reset}}$$

(Equation 45)

t specified start time of the motor in seconds

$t_{reset}$ duration during which the maximum number of motor startups stated by the manufacturer can be made; time in hours

## 4.7.6 Signals

*Table 260: 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 261: 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. |

## 4.7.7 Settings

*Table 262: STTPMSU Group settings*

| 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. |
| 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 263: STTPMSU Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Operation mode | 1=IIt<br>2=IIt, CB<br>3=IIt + stall<br>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 |
| Motor standstill A | 0.05...0.20 | xIn | 0.01 | 0.12 | Current limit to check for motor standstill condition |

## 4.7.8 Monitored data

*Table 264: 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 |
| Table continues on next page | | | | |

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| 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<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 4.7.9 Technical data

*Table 265: STTPMSU Technical data*

<table>
<tr><th colspan="2">Characteristic</th><th colspan="3">Value</th></tr>
<tr><td colspan="2" rowspan="2">Operation accuracy</td><td colspan="3">Depending on the frequency of the current measured: $f_n$ ±2Hz</td></tr>
<tr><td colspan="3">±1.5% of the set value or ±0.002 x $I_n$</td></tr>
<tr><td rowspan="2">Start time[1)2)]</td><td rowspan="2">$I_{Fault}$ = 1.1 x set Start detection A</td><td>Minimum</td><td>Typical</td><td>Maximum</td></tr>
<tr><td>27 ms</td><td>30 ms</td><td>34 ms</td></tr>
<tr><td colspan="2">Operate time accuracy</td><td colspan="3">±1.0% of the set value or ±20 ms</td></tr>
<tr><td colspan="2">Reset ratio</td><td colspan="3">Typical 0.90</td></tr>
</table>

1) Current before = 0.0 x $I_n$, $f_n$ = 50 Hz, overcurrent in one phase, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

# Section 5 Protection related functions

## 5.1 Three-phase inrush detector INRPHAR

### 5.1.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Three-phase inrush detector | INRPHAR | 3I2f> | 68 |

### 5.1.2 Function block

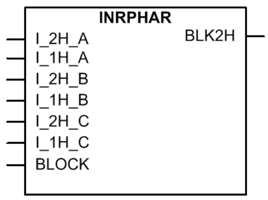



*Figure 151: Function block symbol*

### 5.1.3 Functionality

The transformer inrush detection INRPHAR is used to coordinate transformer inrush situations in distribution networks.

Transformer inrush detection is based on the following principle: the output signal BLK2H is activated once the numerically derived ratio of second harmonic current I_2H and the fundamental frequency current I_1H exceeds the set value.

The operate time characteristic for the function is of definite time (DT) type.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

### 5.1.4 Operation principle

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

The operation of an inrush current detection function can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

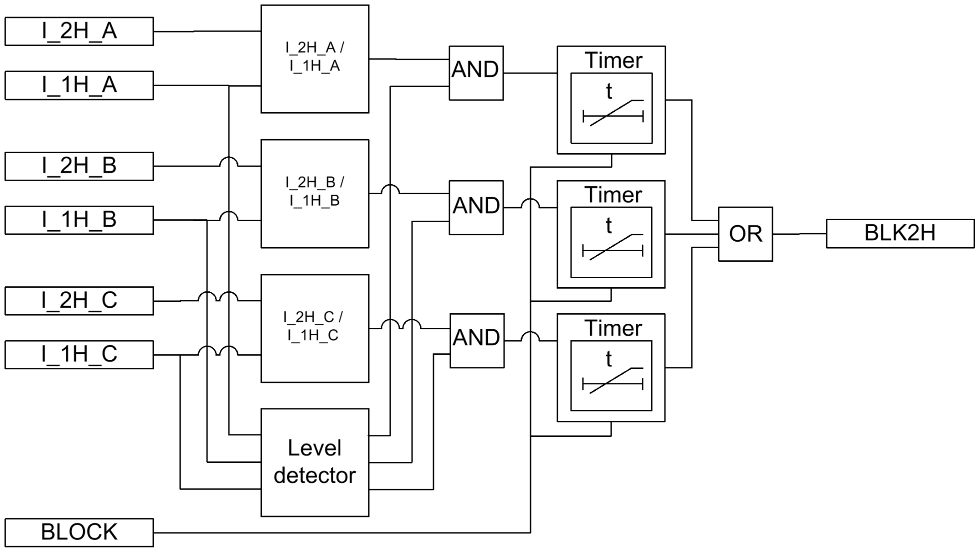



*Figure 152: Functional module diagram. I_1H and I_2H represent fundamental and second harmonic values of phase currents.*

### 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 with 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 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.

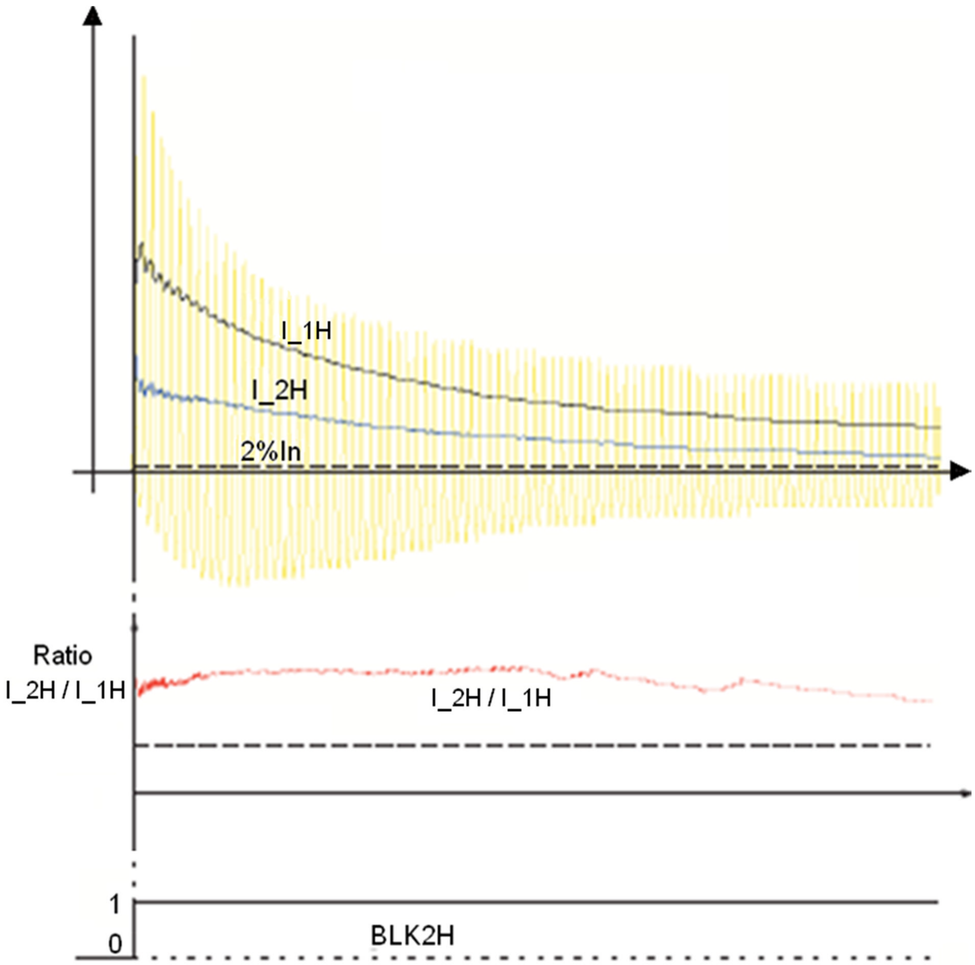



*Figure 153: Inrush current in transformer*

## 5.1.6 Signals

*Table 266: 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 267: INRPHAR Output signals*

| Name | Type | Description |
|---|---|---|
| BLK2H | BOOLEAN | Second harmonic based block |

## 5.1.7 Settings

*Table 268: INRPHAR Group settings*

| 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 269: INRPHAR Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Reset delay time | 0...60000 | ms | 1 | 20 | Reset delay time |

## 5.1.8 Monitored data

*Table 270: INRPHAR Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| INRPHAR | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 5.1.9 Technical data

*Table 271: INRPHAR Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | At the frequency $f=f_n$ |
| | Current measurement:<br>±1.5% of the set value or ±0.002 x $I_n$<br>Ratio I2f/I1f measurement:<br>±5.0% of the set value |
| Reset time | +35 ms / -0 ms |
| Reset ratio | Typical 0.96 |
| Operate time accuracy | +35 ms / -0 ms |

# 5.2 Circuit breaker failure protection CCBRBRF

## 5.2.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Circuit breaker failure protection | CCBRBRF | 3I>/Io>BF | 51BF/51NBF |

## 5.2.2 Function block

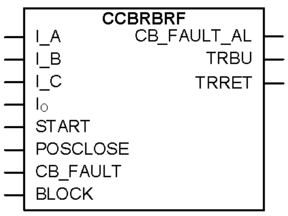



*Figure 154: Function block symbol*

## 5.2.3 Functionality

The breaker failure function CCBRBRF is activated by trip commands from the protection functions. The commands are either internal commands to the terminal or external commands through binary inputs. The start command is always a default for three-phase operation. CCBRBRF includes a three-phase conditional or unconditional re-trip function, and also a three-phase conditional back-up trip function.

CCBRBRF uses the same levels of current detection for both re-trip and back-up trip. The operating values of the current measuring elements can be set within a predefined setting range. The function has two independent timers for trip purposes: a re-trip timer for the repeated tripping of its own breaker and a back-up timer for the trip logic operation for upstream breakers. A minimum trip pulse length can be set independently for the trip output.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

## 5.2.4 Operation principle

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

The operation of breaker failure protection can be described by using a module diagram. All the blocks in the diagram are explained in the next sections. Also further information on retrip and back-up trip logics is given in sub-module diagrams.

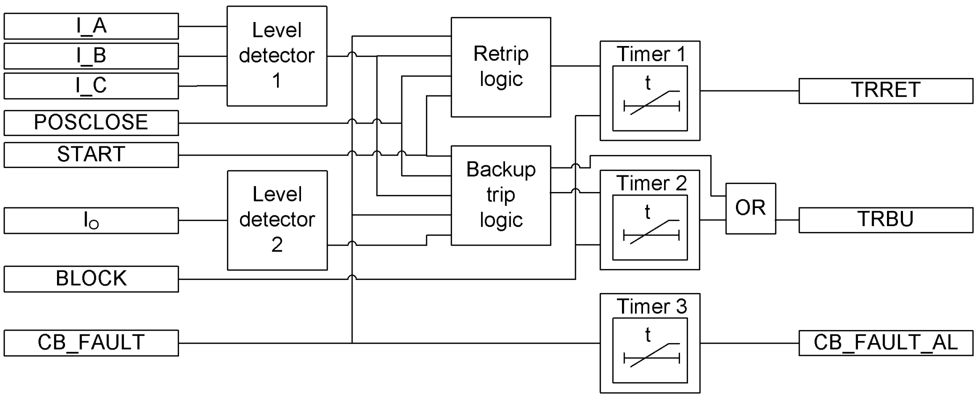



*Figure 155: Functional module diagram. I_A, I_B and I_C represent phase currents and $I_0$ residual current.*

### Level detector 1

The measured phase currents are compared phase-wise with the set *Current value*. If the measured value exceeds the set *Current value*, the level detector reports the exceeding of the value to the retrip and back-up trip logics. The parameter should be set low enough so that 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 with 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 back-up trip logic. In high impedance earthed systems, the residual current at phase to earth faults are 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 *CB failure trip mode* is set "1 out of 4". The current setting should be chosen in accordance with the setting of the sensitive earth-fault protection.

## Retrip logic

The operation of the retrip logic can be described by using a module diagram:

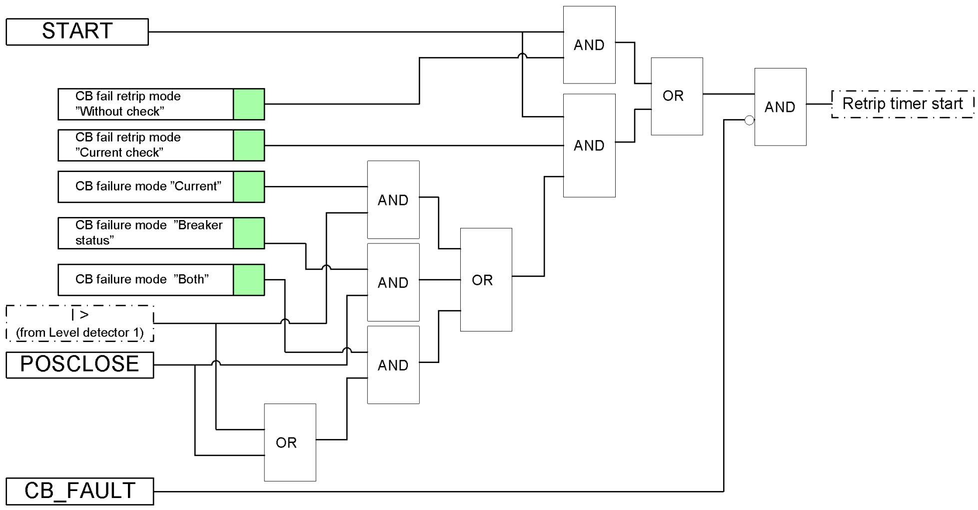



*Figure 156: Retrip logic internal design*

The retrip function operates with or without a current check selected with the *CB fail retrip mode* setting. In "Current check" mode, the retrip is only performed if the current through the circuit breaker exceeds the *Current value* level. In "Without check" mode, the retrip is done without checking the phase currents.

The *CB failure mode* setting is used to select the mode the breaker fault is detected with. In "Current" mode, the detection is based on the current level exceeding. In "Breaker status" mode, the detection is based on the closed position of the circuit breaker after a trip signal is issued, that is, after a long duration of the trip signal. In "Both" mode, the detection is based either on the exceeding of *Current value* level or on the long duration of the trip signal. When external information of a circuit breaker fault is connected to the active `CB_FAULT` input, the retrip function is not allowed to operate. The blocking is used to disable the whole function.

## Back-up trip logic

The operation of the back-up trip logic can be described by using a module diagram:

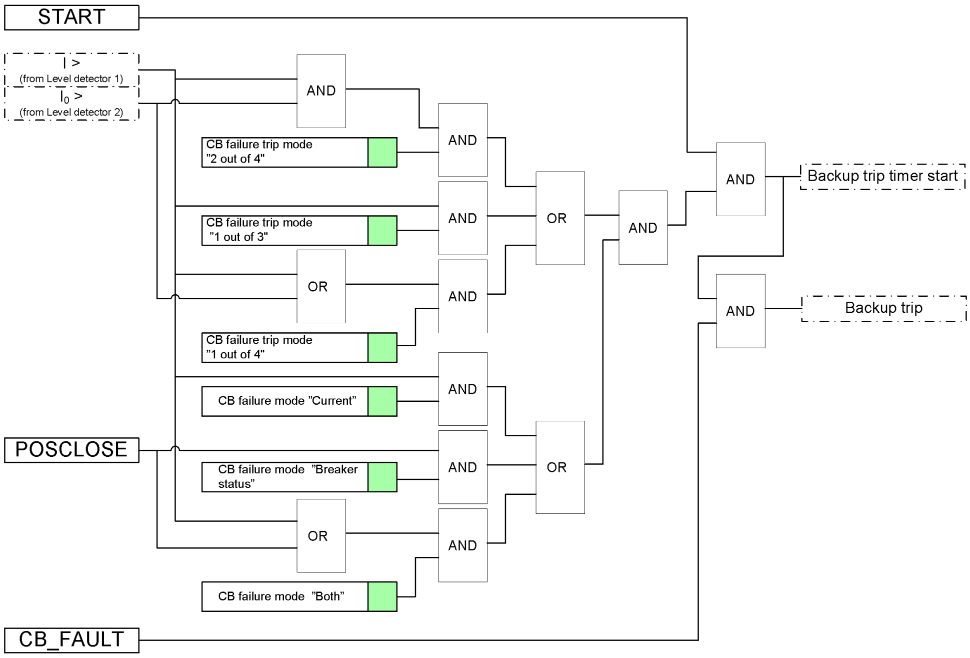



*Figure 157: Back-up trip logic internal design*

The current detection characteristics can be selected with the *CB failure trip mode* setting in three following options:

- "1 out of 3" in which detecting opening failure (high current) in one phase only is sufficient
- "1 out of 4" in which detecting opening failure (high current) or high residual current in one phase only is sufficient
- "2 out of 4" in which at least two high currents (phase current and residual current) are required for breaker failure detection.

In most applications, "1 out of 3" is sufficient. In the "Breaker status" mode, the back-up trip is done when the status inputs indicate that the circuit breaker is in closed state.

The setting *CB failure mode* is used to select the mode the breaker fault is detected with. In "Current" mode, the detection is based on the current level exceeding. In "Breaker status" mode, the detection is based on the closed position of the circuit breaker after a trip signal is issued, that is, after a long duration of the trip signal. In "Both" mode, the detection is based either on the exceeding of the *Current value Res* level, depending on the current detection mode, or on the long duration of the trip signal. When external information on a circuit breaker fault is connected to the active `CB_FAULT` input, the back-up trip function is issued to the upstream breaker without delay. The blocking is used for disabling the whole function.

### 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 maximum time value, the TRRET output is activated. A typical setting is 0 - 50 ms.

### Timer 2

Once activated, the timer runs until the set *CB failure delay* value is elapsed. The time characteristic is according to DT. When the operation timer has reached the set maximum time value *CB failure delay*, the TRBU output 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 retrip can be estimated as:

$$CBfailuredelay \geq Retriptime + t_{cbopen} + t_{BFP\_reset} + t_{margin}$$

(Equation 46)

| | |
|---|---|
| $t_{cbopen}$ | maximum opening time for the circuit breaker |
| $t_{BFP\_reset}$ | is the 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 is often dependent on the ability to maintain transient stability in case of a fault close to a power plant.

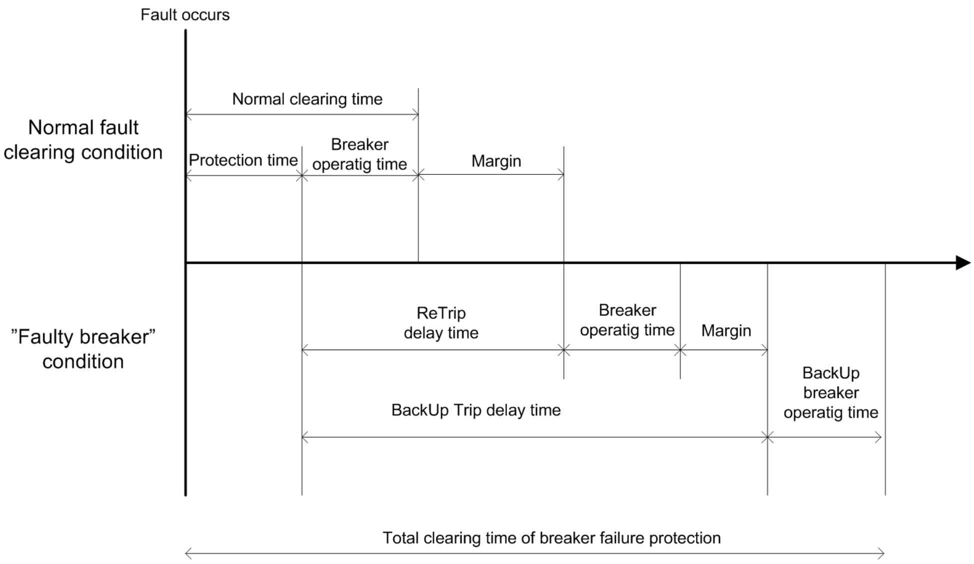



*Figure 158: Time line of breaker failure protection*

### Timer 3

This module is activated by the CB_FAULT signal. Once activated, the timer runs until the set *CB fault delay* value is elapsed. The time characteristic is according to DT. When the operation timer has reached the maximum time value, the CB_FAULT_AL output is activated. After the set time an alarm is given so that actions can be done to repair the circuit breaker. A typical value is 5 s.

## 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 back-up trip command to adjacent 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 back-up tripping of several breakers in case mistakes occur during relay maintenance and tests.

CCBRBRF is initiated by operating different protection functions or digital logics inside the IED. It is also possible to initiate the function externally through a binary input.

CCBRBRF can be blocked by using an internally assigned signal or an external signal from a binary input. This signal blocks the function of the breaker failure protection even when the timers have started or the timers are reset.

The retrip timer is initiated after the start input is set to true. When the pre-defined time setting is exceeded, CCBRBRF issues the retrip and sends a trip command, for example, to the circuit breaker's second trip coil. Both a retrip with current check and an unconditional retrip are available. When a retrip with current check is chosen, the retrip is performed only if there is a current flow through the circuit breaker.

The back-up 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 back-up delay time, which is longer than the retrip time, it sends a back-up trip signal to the chosen back-up breakers. The circuit breakers are normally upstream breakers which feed fault current to a faulty feeder.

The back-up 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 back-up delay time.

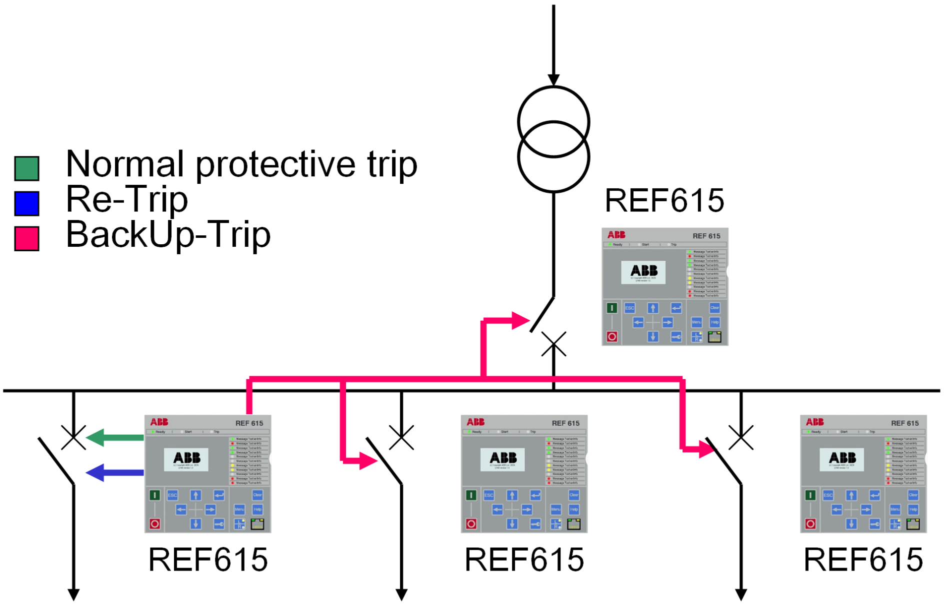



*Figure 159: Typical breaker failure protection scheme in distribution substations*

## 5.2.6 Signals

*Table 272: 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 |
| $I_0$ | SIGNAL | 0 | Residual current |
| 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 |
| BLOCK | BOOLEAN | 0=False | Block CBFP operation |

*Table 273: 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 274: CCBRBRF Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Current value | 0.05...1.00 | xIn | 0.05 | 0.30 | Operating phase current |
| Current value Res | 0.05...1.00 | xIn | 0.05 | 0.30 | Operating residual current |
| CB failure trip mode | 1=2 out of 4<br>2=1 out of 3<br>3=1 out of 4 | | | 1=2 out of 4 | Backup trip current check mode |
| CB failure mode | 1=Current<br>2=Breaker status<br>3=Both | | | 1=Current | Operating mode of function |
| CB fail retrip mode | 1=Off<br>2=Without Check<br>3=Current check | | | 1=Off | Operating mode of retrip logic |
| Retrip time | 0...60000 | ms | 10 | 20 | Delay timer for retrip |
| CB failure delay | 0...60000 | ms | 10 | 150 | Delay timer for backup trip |
| CB fault delay | 0...60000 | ms | 10 | 5000 | Circuit breaker faulty delay |
| Measurement mode | 2=DFT<br>3=Peak-to-Peak | | | 2=DFT | Phase current measurement mode of function |
| Trip pulse time | 0...60000 | ms | 10 | 20 | Pulse length of retrip and backup trip outputs |

## 5.2.8 Monitored data

*Table 275: CCBRBRF Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| CCBRBRF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 5.2.9 Technical data

*Table 276: CCBRBRF Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | ±1.5% of the set value or ±0.002 x $I_n$ |
| Operate time accuracy | ±1.0% of the set value or ±20 ms |

# 5.3 Protection trip conditioning TRPPTRC

## 5.3.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Protection trip conditioning | TRPPTRC | Master Trip | 94/86 |

## 5.3.2 Function block

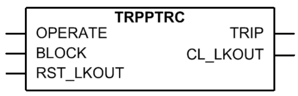



*Figure 160: Function block symbol*

## 5.3.3 Functionality

The protection trip conditioning function TRPPTRC is used as a trip command collector and handler after the protection functions. The features of this function influence the trip signal behavior of the circuit breaker. The user can set the minimum trip pulse length when the non-latched mode is selected. It is also possible to select the latched or lockout mode for the trip signal.

## 5.3.4 Principle of operation

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 which are intended to go through the function to the circuit breaker trip coil are blocked!

The operation of a trip logic function can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

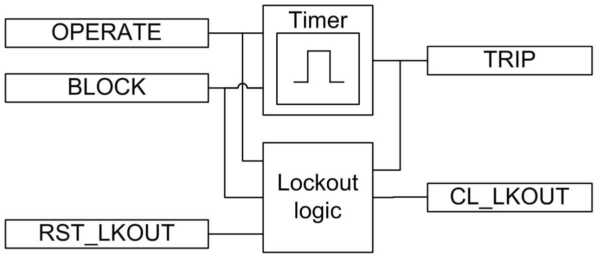



*Figure 161: Functional module diagram*

### Timer

The user can adjust the duration of the `TRIP` output signal from the TRPPTRC function 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 IED, or from external protection functions via one or more of the IED's binary inputs. The function has a single trip output `TRIP` for connecting the function to one or more of the IED's binary outputs, and also to other functions within the IED requiring this signal.

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 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 277: 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 clearing 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 alternative of a logic function is linking the trip signal and ensuring that the signal is long enough.

The tripping logic in the protection relay is intended to be used in the three-phase tripping for all fault types (3ph operating). To prevent the closing of a circuit breaker after a trip, the function can block the CBXCBR closing.

The TRPPTRC function is intended to be connected to one trip coil of the corresponding circuit breaker. If tripping is needed for another trip coil or another circuit breaker which needs, for example, different trip pulse time, another trip logic function can be used. The 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 IED, for example when starting the breaker failure protection.

TRPPTRC is used for simple three-phase tripping applications.

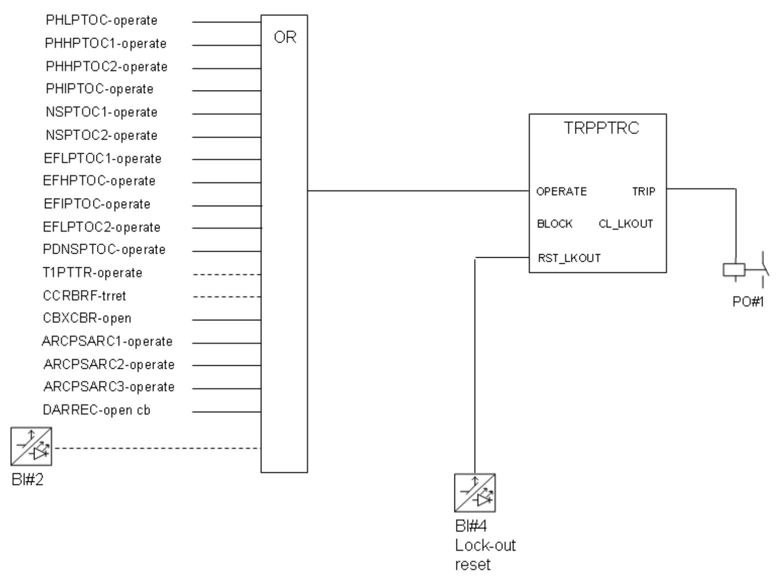



*Figure 162: Typical TRPPTRC connection*

### Lock-out

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 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 pulse function is not active when using the “Lockout” or “Latched” modes but only when the “Non-latched” mode is selected.

## 5.3.6 Signals

*Table 278: TRPPTRC Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| BLOCK | BOOLEAN | 0=False | Block of function |
| OPERATE | BOOLEAN | 0=False | Request to trip circuit breaker. |
| RST_LKOUT | BOOLEAN | 0=False | Input for resetting the circuit breaker lockout function |

*Table 279: TRPPTRC Output signals*

| Name | Type | Description |
|---|---|---|
| TRIP | BOOLEAN | General trip output signal |
| CL_LKOUT | BOOLEAN | Circuit breaker lockout output (set until reset) |

*Table 280: 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 281: TRPPTRC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Trip pulse time | 20...60000 | ms | 1 | 150 | Minimum duration of trip output signal |
| Trip output mode | 1=Non-latched<br>2=Latched<br>3=Lockout | | | 1=Non-latched | Select the operation mode for trip output |

## 5.3.8 Monitored data

*Table 282: TRPPTRC Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| TRPPTRC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

# 5.4 Binary signal transfer BSTGGIO

## 5.4.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Binary signal transfer | BSTGGIO | BST | BST |

## 5.4.2 Function block

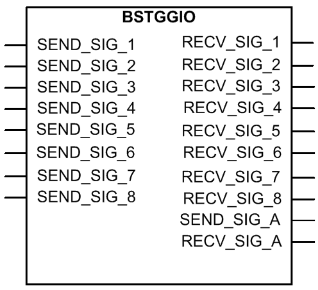



*Figure 163: Function block symbol*

## 5.4.3 Functionality

The binary signal transfer function BSTGGIO is used for transferring binary signals between the local and remote end line differential protection IEDs. The function includes eight binary signals that are transferred in the protection communication telegram and can be freely configured and used for any purpose in the line differential application.

BSTGGIO transfers binary data continuously over the protection communication channel between the terminals. Each of the eight signals are bidirectional and the binary data sent locally is available remotely as a received signal.

BSTGGIO includes a minimum pulse time functionality for the received binary signals. Each received signal has its own minimum pulse time setting parameter.

BSTGGIO includes two alarm output signals. The SEND_SIG_A output signal is updated according to the status of the sent binary signals. The RECV_SIG_A output signal is updated according to the status of the received binary signals. Each signal can be separately included or excluded from the alarm logic with a setting parameter.

## 5.4.4 Operation principle

The *Signal 1...8 mode* setting can be used for changing the operation of the bidirectional signal channel. The signal channel can be disabled by setting the corresponding parameter value to “Not in use”. When the signal channel is disabled locally or remotely, the corresponding RECV_SIG_1...8 signal status is always false on both ends.

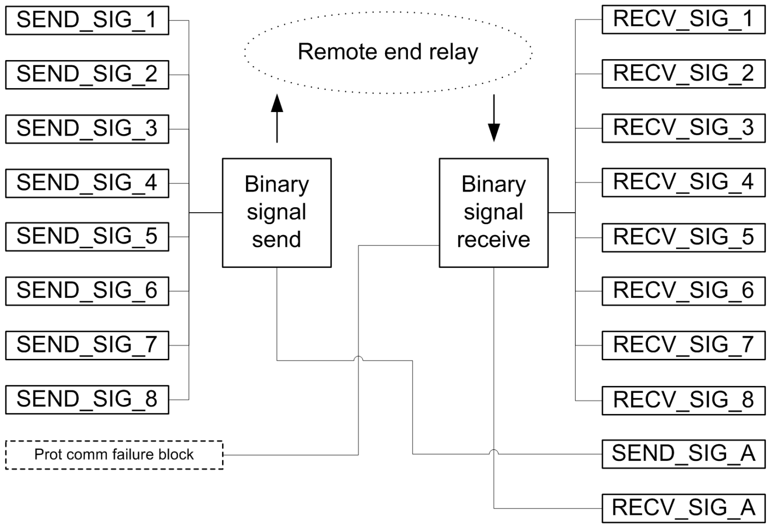



*Figure 164: Functional module diagram*

### Binary signal send

The status of the inputs is continuously sent in the line differential protection telegrams. SEND_SIG_A can be used for alarming based on the status of SEND_SIG_1...8. By selecting the signal mode as "In use, alarm sel.", the sending status of the corresponding signal affects also the activation criteria of SEND_SIG_A. Further, in case more than one signal channels are selected into the alarm logic, the activation criteria can be defined according to "Any of selected" (OR) or "All of selected" (AND).

### Binary signal receive

The function receives continuous binary data within the protection telegrams from the remote end IED. This received binary data status is then available as the

RECV_SIG_1...8 outputs on the local end IED. RECV_SIG_A can be used for alarming based on the status of RECV_SIG_1...8. By selecting the signal mode as "In use, alarm sel.", the received status of the corresponding signal affects the activation criteria of RECV_SIG_A. Further, in case more than one signal channels are selected into the alarm logic, the activation criteria can be defined according to "Any of selected" (OR) or "All of selected" (AND). Each signal has also the *Pulse time 1...8* setting that defines the minimum pulse length for RECV_SIG_1...8. Also, in case the protection communication supervision detects a failure in the communication, the RECV_SIG_1...8 outputs are not set to false sooner than the minimum pulse length defined is first ensured for each signal.

## 5.4.5 Application

Among with the analog data, the binary data can also be exchanged with the line differential protection IEDs. The usage of the binary data is application specific and can vary in each separate case. The demands for the speed of the binary signals vary depending on the usage of the data. When the binary data is used as blocking signals for the line differential protection, the transfer response is extremely high. Binary signal interchange can be used in applications such as:

- Remote position indications
- Inter-tripping of the circuit breakers on both line ends
- Blocking of the line differential protection during transformer inrush or current circuit supervision failure
- Protection schemes; blocking or permissive
- Remote alarming.

The figure shows the overall chain to transfer binary data in an example application. The position indication of the local circuit breaker is connected to the IED’s input interface and is then available for the IED configuration. The circuit breaker position indication is connected to the first input of BSTGGIO which is used to send information to the remote end via communication. In the remote end, this information is handled as a remote circuit breaker open position and it is available from the first output of BSTGGIO. This way the information can be exchanged.

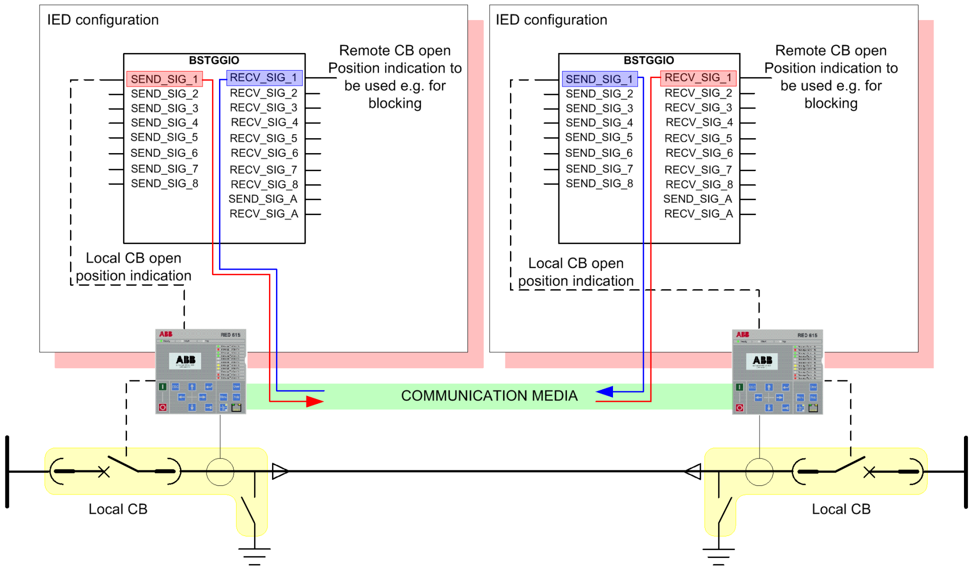



*Figure 165: Example of usage of binary signal transfer for position indication change*

## 5.4.6 Signals

*Table 283: BSTGGIO Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| SEND_SIG_1 | BOOLEAN | 0=False | Send signal 1 state |
| SEND_SIG_2 | BOOLEAN | 0=False | Send signal 2 state |
| SEND_SIG_3 | BOOLEAN | 0=False | Send signal 3 state |
| SEND_SIG_4 | BOOLEAN | 0=False | Send signal 4 state |
| SEND_SIG_5 | BOOLEAN | 0=False | Send signal 5 state |
| SEND_SIG_6 | BOOLEAN | 0=False | Send signal 6 state |
| SEND_SIG_7 | BOOLEAN | 0=False | Send signal 7 state |
| SEND_SIG_8 | BOOLEAN | 0=False | Send signal 8 state |

*Table 284: BSTGGIO Output signals*

| Name | Type | Description |
|---|---|---|
| RECV_SIG_1 | BOOLEAN | Receive signal 1 state |
| RECV_SIG_2 | BOOLEAN | Receive signal 2 state |
| RECV_SIG_3 | BOOLEAN | Receive signal 3 state |
| RECV_SIG_4 | BOOLEAN | Receive signal 4 state |
| RECV_SIG_5 | BOOLEAN | Receive signal 5 state |
| RECV_SIG_6 | BOOLEAN | Receive signal 6 state |
| RECV_SIG_7 | BOOLEAN | Receive signal 7 state |

Table continues on next page

| Name | Type | Description |
|---|---|---|
| RECV_SIG_8 | BOOLEAN | Receive signal 8 state |
| SEND_SIG_A | BOOLEAN | Binary signal transfer sending alarm state |
| RECV_SIG_A | BOOLEAN | Binary signal transfer receive alarm state |

## 5.4.7 Settings

*Table 285: BSTGGIO Group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Signal 1 mode | 1=In use<br>2=In use, alarm sel.<br>3=Not in use | | | 2=In use, alarm sel. | Operation mode for signal 1 |
| Signal 2 mode | 1=In use<br>2=In use, alarm sel.<br>3=Not in use | | | 2=In use, alarm sel. | Operation mode for signal 2 |
| Signal 3 mode | 1=In use<br>2=In use, alarm sel.<br>3=Not in use | | | 1=In use | Operation mode for signal 3 |
| Signal 4 mode | 1=In use<br>2=In use, alarm sel.<br>3=Not in use | | | 1=In use | Operation mode for signal 4 |
| Signal 5 mode | 1=In use<br>2=In use, alarm sel.<br>3=Not in use | | | 1=In use | Operation mode for signal 5 |
| Signal 6 mode | 1=In use<br>2=In use, alarm sel.<br>3=Not in use | | | 1=In use | Operation mode for signal 6 |
| Signal 7 mode | 1=In use<br>2=In use, alarm sel.<br>3=Not in use | | | 1=In use | Operation mode for signal 7 |
| Signal 8 mode | 1=In use<br>2=In use, alarm sel.<br>3=Not in use | | | 1=In use | Operation mode for signal 8 |
| Pulse time 1 | 0...60000 | ms | 1 | 0 | Minimum pulse time for received signal 1 |
| Pulse time 2 | 0...60000 | ms | 1 | 0 | Minimum pulse time for received signal 2 |
| Pulse time 3 | 0...60000 | ms | 1 | 0 | Minimum pulse time for received signal 3 |
| Pulse time 4 | 0...60000 | ms | 1 | 0 | Minimum pulse time for received signal 4 |
| Pulse time 5 | 0...60000 | ms | 1 | 0 | Minimum pulse time for received signal 6 |
| Pulse time 6 | 0...60000 | ms | 1 | 0 | Minimum pulse time for received signal 6 |
| Pulse time 7 | 0...60000 | ms | 1 | 0 | Minimum pulse time for received signal 7 |
| Pulse time 8 | 0...60000 | ms | 1 | 0 | Minimum pulse time for received signal 8 |

*Table 286: BSTGGIO Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Alarm mode | 1=Any of selected<br>2=All of selected | | | 1=Any of selected | Selects the used alarm logic mode for activating SEND_SIG_A and RECV_SIG_A |

## 5.4.8 Technical data

*Table 287: BSTGGIO Technical data*

| Characteristic | Value |
| --- | --- |
| Signalling delay | < 5 ms |

# 5.5 Emergency start function ESMGAPC

## 5.5.1 Identification

| Functional description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
| --- | --- | --- | --- |
| Emergency start function | ESMGAPC | ESTART | ESTART |

## 5.5.2 Function block

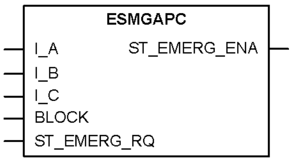



*Figure 166: Function block symbol*

## 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 function ESMGAPC allows motor startups during such emergency conditions. ESMGAPC is only to force the IED 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, if desired.

## 5.5.4 Operation principle

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

The operation of the emergency start function can be described using a module diagram. All the blocks in the diagram are explained in the next sections.

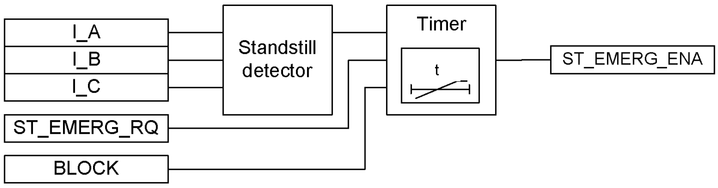



*Figure 167: Functional module diagram*

### 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 which 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 through 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 startup time counter exceeds the restart inhibit level, the value is set slightly below the restart disable value to allow at least one motor startup.

The activation of the ST_EMERG_RQ digital input allows to perform emergency start. The IED is forced to a state which allows the restart of motor, and the operator can now restart the motor. 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 288: 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 289: ESMGAPC Output signals*

| Name | Type | Description |
|---|---|---|
| ST_EMERG_ENA | BOOLEAN | Emergency start |

## 5.5.7 Settings

*Table 290: ESMGAPC Group settings*

| 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 291: ESMGAPC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |

## 5.5.8 Monitored data

*Table 292: ESMGAPC Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| T_ST_EMERG | Timestamp | | | Emergency start activation timestamp |
| ESMGAPC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

# Section 6 Supervision functions

## 6.1 Trip circuit supervision TCSSCBR

### 6.1.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Trip circuit supervision | TCSSCBR | TCS | TCM |

### 6.1.2 Function block

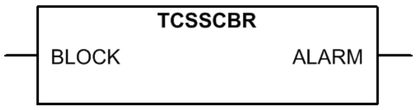



*Figure 168: Function block*

### 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 IED configuration.

The function starts and operates when TCS detects a trip circuit failure. The operate time characteristic for the function is of DT type. 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 trip circuit supervision can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

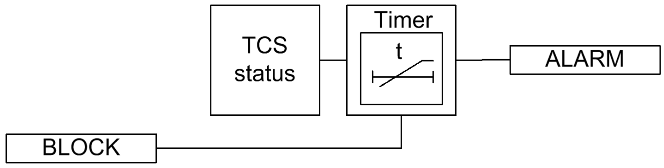



*Figure 169: Functional module diagram*

### 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 *Operate delay time* is 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 kind of supervision is necessary to find out the vitality of the control circuits continuously.

The following figure shows an application of the trip-circuit supervision function usage. 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.

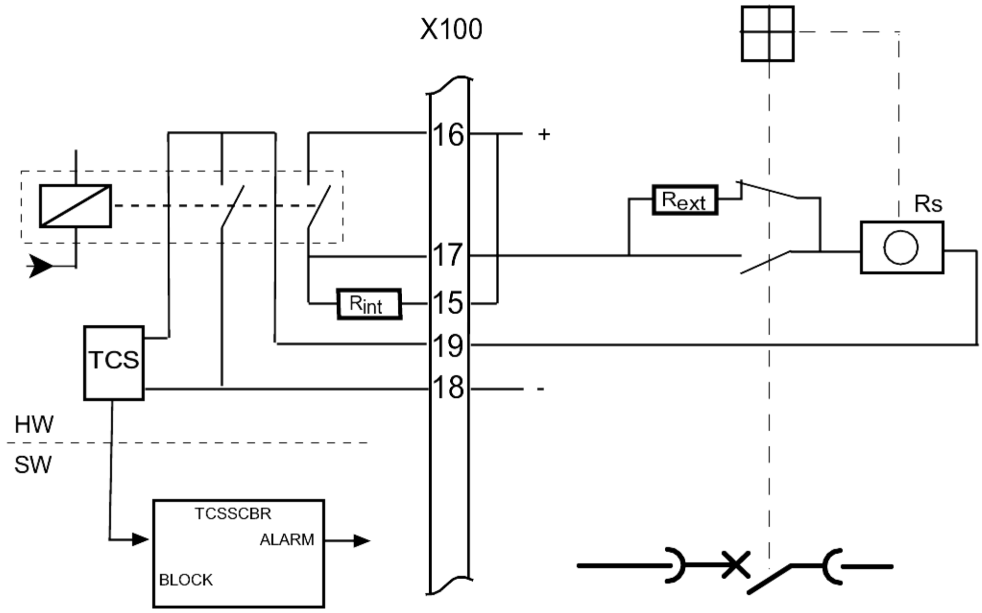



*Figure 170: Operating principle of the trip-circuit supervision with an external resistor. The TCSSCBR blocking switch is not required since the external resistor is used.*

If the TCS is required only in a closed position, the external shunt resistance may be omitted. When the circuit breaker is in the open position, the 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.

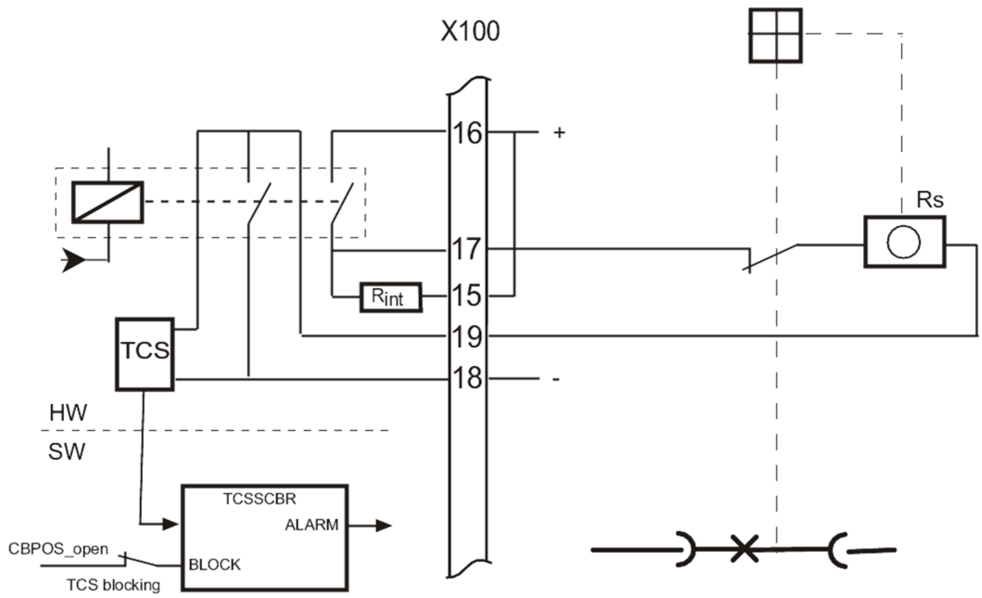



*Figure 171: Operating principle of the trip-circuit supervision without an external resistor. The circuit breaker open indication is set to block TCSSCBR when the circuit breaker is open.*

## 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 constant test current flow is shown in the following figure. The supervising current cannot detect if one or all the other contacts connected in parallel are not connected properly.

*Figure 172: 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 as shown in the following figure.

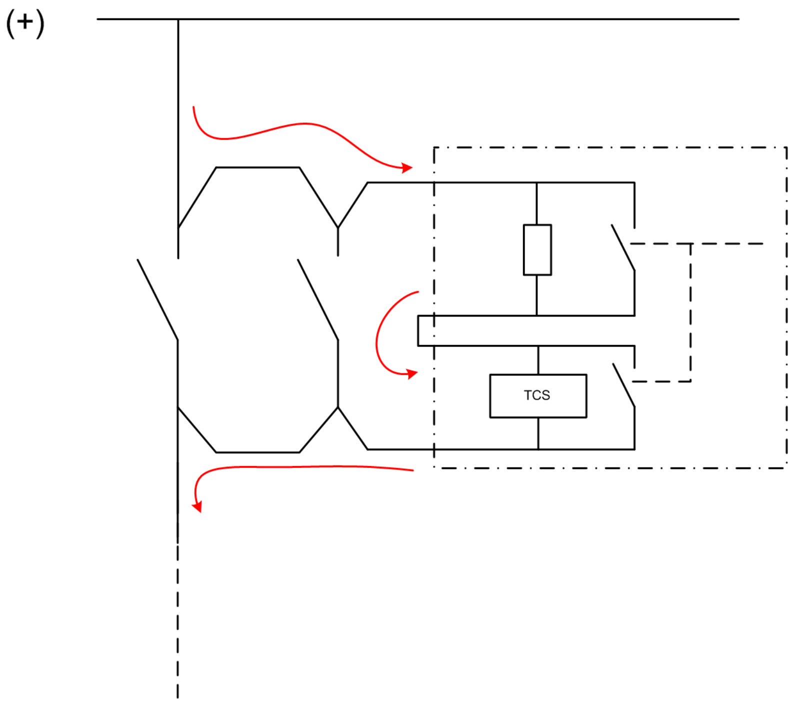



*Figure 173: Improved connection for parallel trip contacts*

## Several trip-circuit supervision functions parallel in circuit

Not only the trip circuit often have parallel trip contacts, it is also possible that the circuit has multiple TCS circuits in parallel. Each TCS circuit causes its own supervising current to flow through the monitored coil and the actual coil current is a sum of all TCS currents. This must be taken into consideration when determining the resistance of $R_{ext}$.

Setting the TCS function in a protection IED not-in-use does not typically effect 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 may be too high for the protection IED trip contact to break.

The circuit breaker coil current is normally cut by an internal contact of the circuit breaker. In case of a circuit breaker failure, there is a risk that the protection IED trip contact is destroyed since the contact is obliged to disconnect high level of electromagnetic energy accumulated in the trip coil.

An auxiliary relay can be used between the protection IED trip contact and the circuit breaker coil. This way the breaking capacity question is solved, but the TCS circuit in the protection IED monitors the healthy auxiliary relay coil, not the circuit breaker coil. The separate trip circuit supervision relay is applicable for this to supervise the trip coil of the circuit breaker.

### Dimensioning of the external resistor

Under normal operating conditions, the applied external voltage is divided between the relay’s internal circuit and the external trip circuit so that at the minimum 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, the 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 47)

| | |
|---|---|
| $U_c$ | 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, 1kΩ |
| $R_s$ | 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 will cause too high a voltage drop, jeopardizing the requirement of at least 20 V over the internal circuit, while a resistance too low may enable false operations of the trip coil.

Table 293: Values recommended for the external resistor $R_{ext}$

| Operating voltage $U_c$ | Shunt resistor $R_{ext}$ |
|---|---|
| 48 V DC | 1.2 kΩ, 5 W |
| 60 V DC | 5.6 kΩ, 5 W |
| 110 V DC | 22 kΩ, 5 W |
| 220 V DC | 33 kΩ, 5 W |

Due to the requirement that the voltage over the TCS contact must be 20V or higher, the correct operation is not guaranteed with auxiliary operating voltages lower than 48V DC because of the voltage drop in the $R_{int}$, $R_{ext}$ and 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 (<48V 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.

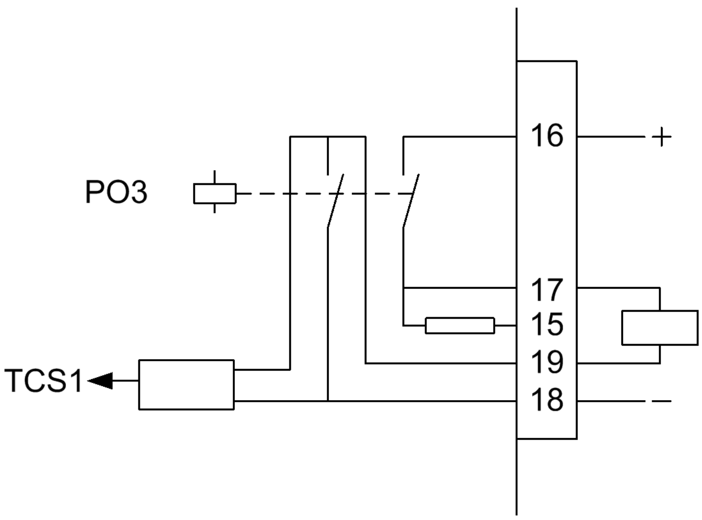



Figure 174: Connection of a power output in a case when TCS is not used and the internal resistor is disconnected

### Incorrect connections and usage 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 IED. 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 picture shows incorrect usage of a TCS circuit when only one of the contacts is used.

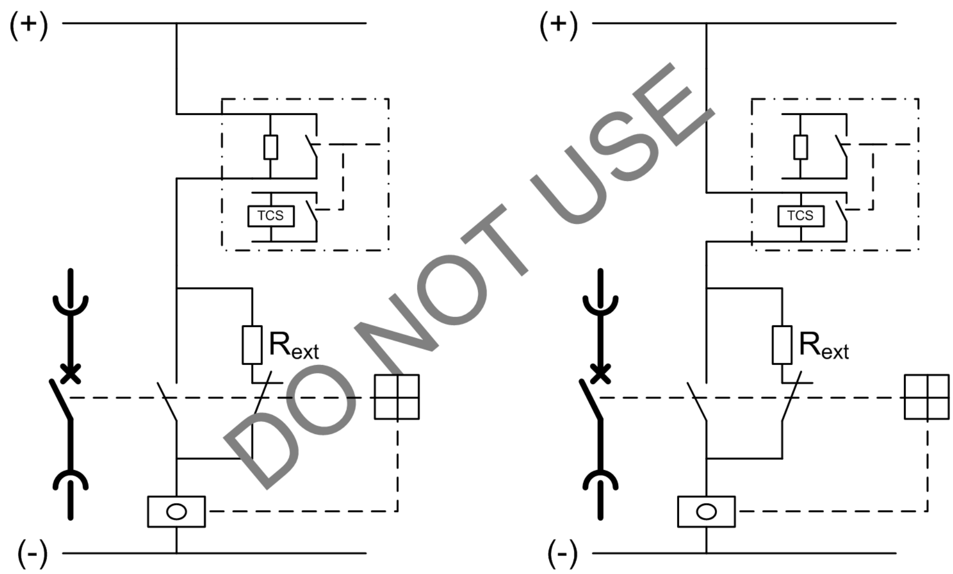



*Figure 175: Incorrect connection of trip-circuit supervision*

A connection of three protection IEDs with a double pole trip circuit is shown in the following figure. Only the IED R3 has an internal TCS circuit. In order to test the operation of the IED R2, but not to trip the circuit breaker, the upper trip contact of the IED R2 is disconnected, as shown in the figure, while the lower contact is still connected. When the IED R2 operates, the coil current starts to flow through the internal resistor of the IED 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 IED.

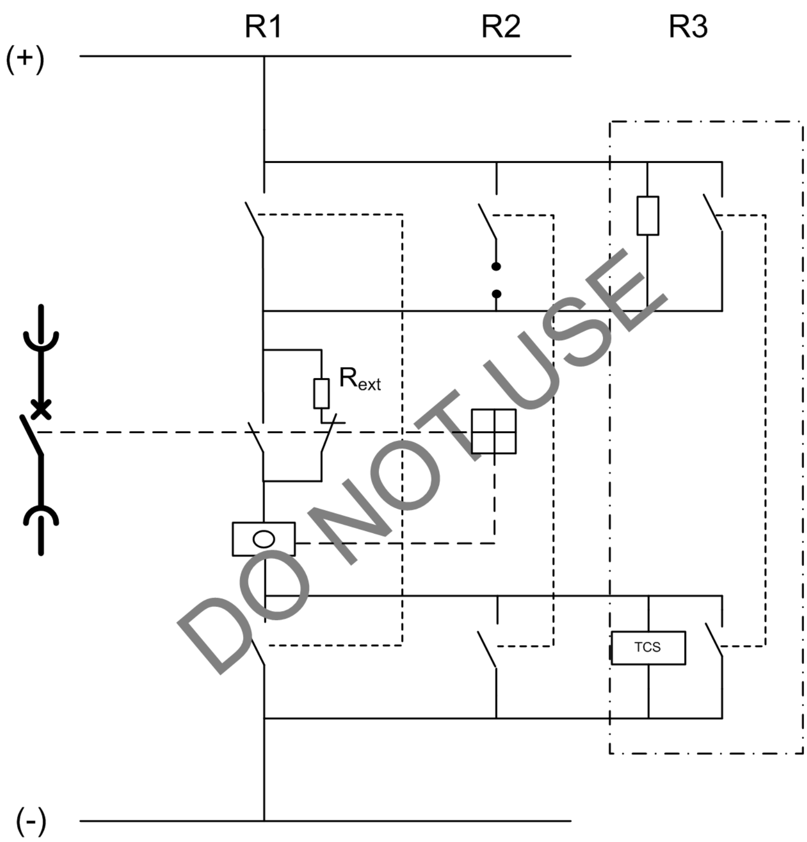



*Figure 176: Incorrect testing of IEDs*

## 6.1.6 Signals

*Table 294: TCSSCBR Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| BLOCK | BOOLEAN | 0=False | Block signal for all binary outputs |

*Table 295: TCSSCBR Output signals*

| Name | Type | Description |
|---|---|---|
| ALARM | BOOLEAN | Alarm output |

## 6.1.7 Settings

*Table 296: TCSSCBR Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Operate delay time | 20...300000 | ms | 1 | 3000 | Operate delay time |
| Reset delay time | 20...60000 | ms | 1 | 1000 | Reset delay time |

## 6.1.8 Monitored data

*Table 297: TCSSCBR Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| TCSSCBR | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

# 6.2 Current circuit supervision CCRDIF

## 6.2.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Current circuit supervision | CCRDIF | MCS 3I | MCS 3I |

## 6.2.2 Function block

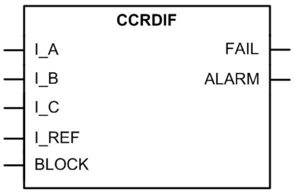



*Figure 177: Function block symbol*

## 6.2.3 Functionality

The current circuit supervision function CCRDIF is used for monitoring current transformer secondary circuits.

CCRDIF calculates internally the sum of phase currents (I_A, I_B and I_C) and compares the sum against the measured single reference current (I_REF). The reference current must originate from other three-phase CT cores than the phase currents (I_A, I_B and I_C) and it is to be externally summated, that is, outside the IED.

CCRDIF detects a fault in the measurement circuit and issues an alarm or blocks the protection functions to avoid unwanted tripping.

It must be remembered that the blocking of protection functions at an occurring open CT circuit means that the situation remains unchanged and extremely high voltages stress the secondary circuit.

## 6.2.4 Operation principle

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

The operation of current circuit supervision can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

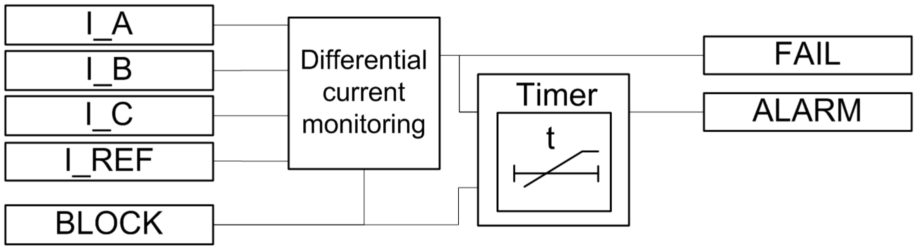



*Figure 178: Functional module diagram*

### 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 xIn, the differential current limit is defined with *Start value*. When the highest phase current is more that 1.0 xIn, the differential current limit is calculated with the formula:

$$MAX(I\_A, I\_B, I\_C) \times Startvalue$$

(Equation 48)

The differential current is limited to 1.0 xIn.

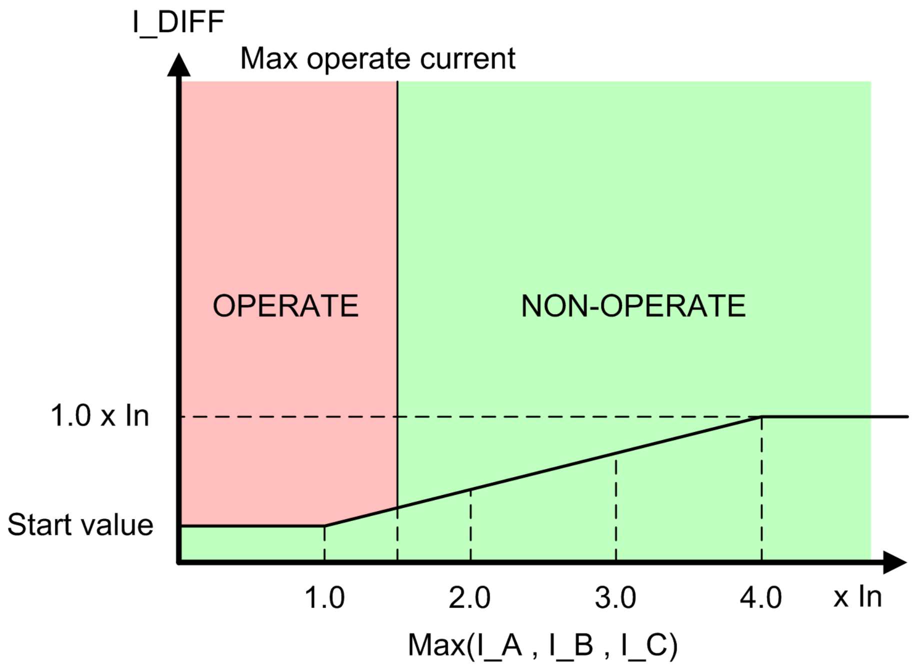



*Figure 179: CCRDIF operating characteristics*

When the differential current I_DIFF is in the operating region, the FAIL output is activated.

The function is internally blocked if any phase current is higher than the set *Max operate current*. When the internal blocking activates, the FAIL output is deactivated immediately. The internal blocking is used for avoiding false operation during a fault situation when the current transformers are saturated due to high fault currents.

The value of the differential current is available through the Monitored data view on the LHMI or through other communication tools. The value is calculated with the formula:

$$I\_DIFF = \left|\overline{I\_A} + \overline{I\_B} + \overline{I\_C}\right| - \left|\overline{I\_REF}\right|$$

(Equation 49)

The *Start value* setting is given in units of xIn 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 activates 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. The ALARM output is deactivated after a fixed 3 s delay, and the FAIL is deactivated.

The deactivation happens only when the highest phase current is more than 5 percent of the nominal current (0.05 xIn).

When the line is de-energized, the deactivation of the ALARM output 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 may result in differences in the secondary currents from the two CT cores. Unwanted blocking of protection functions during the transient stage must then be avoided.

The supervision function must be sensitive and have a short operate time in order to prevent unwanted tripping from fast-acting, sensitive numerical protections in case of faulty CT secondary circuits.

Open CT circuits create extremely high voltages in the circuits which may damage the insulation and cause further problems. This must be taken into consideration especially when the protection functions are blocked.

When the reference current is not connected to the IED, the function should be turned off. Otherwise, the FAIL output is activated when unbalance occurs in the phase currents even if there was nothing wrong with the measurement circuit.

### Reference current measured with core-balanced current transformer

The function compares the sum of phase currents to the current measured with the core-balanced CT.

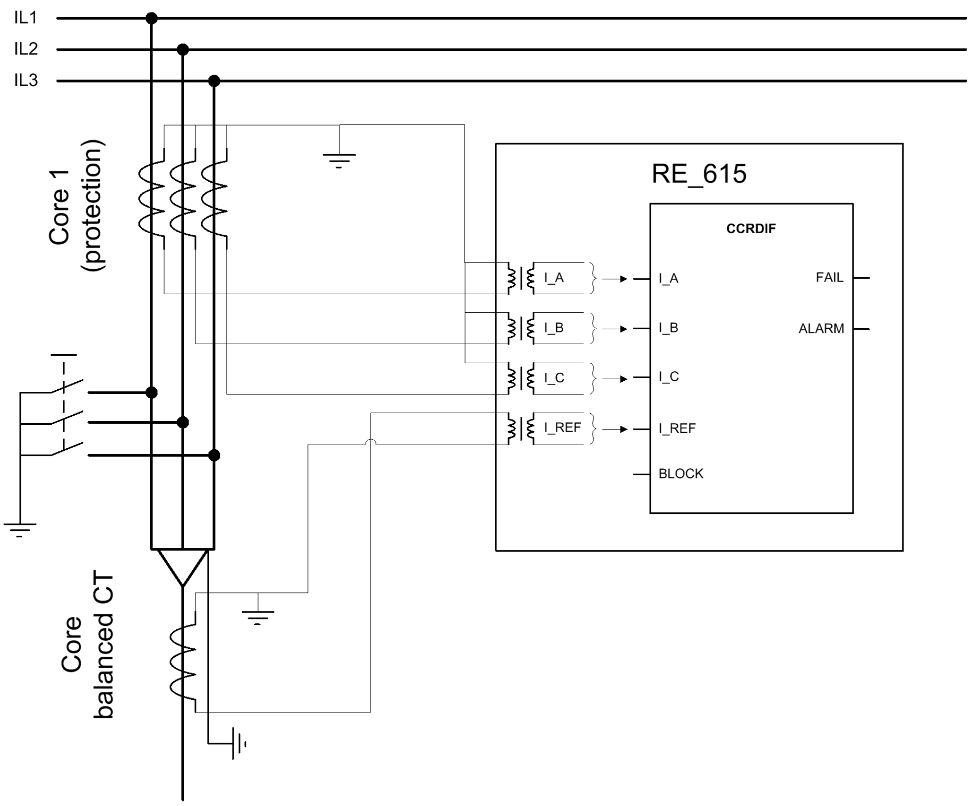



*Figure 180: Connection diagram for reference current measurement with core balanced current transformer*

### Current measurement with two independent three-phase sets of CT cores

The figures show diagrams of connections where the reference current is measured with two independent three-phase sets of CT cores.

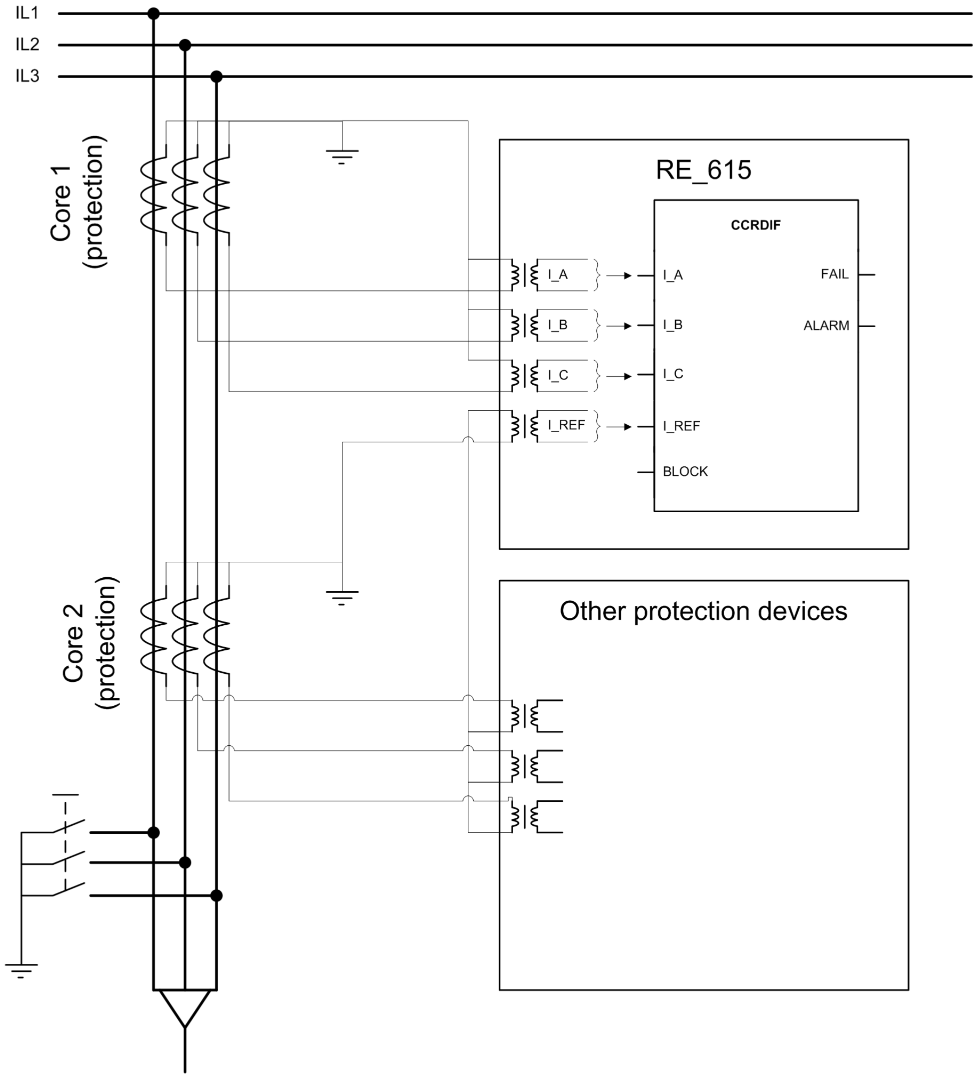



*Figure 181: Connection diagram for current circuit supervision with two sets of three-phase current transformer protection cores*

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.

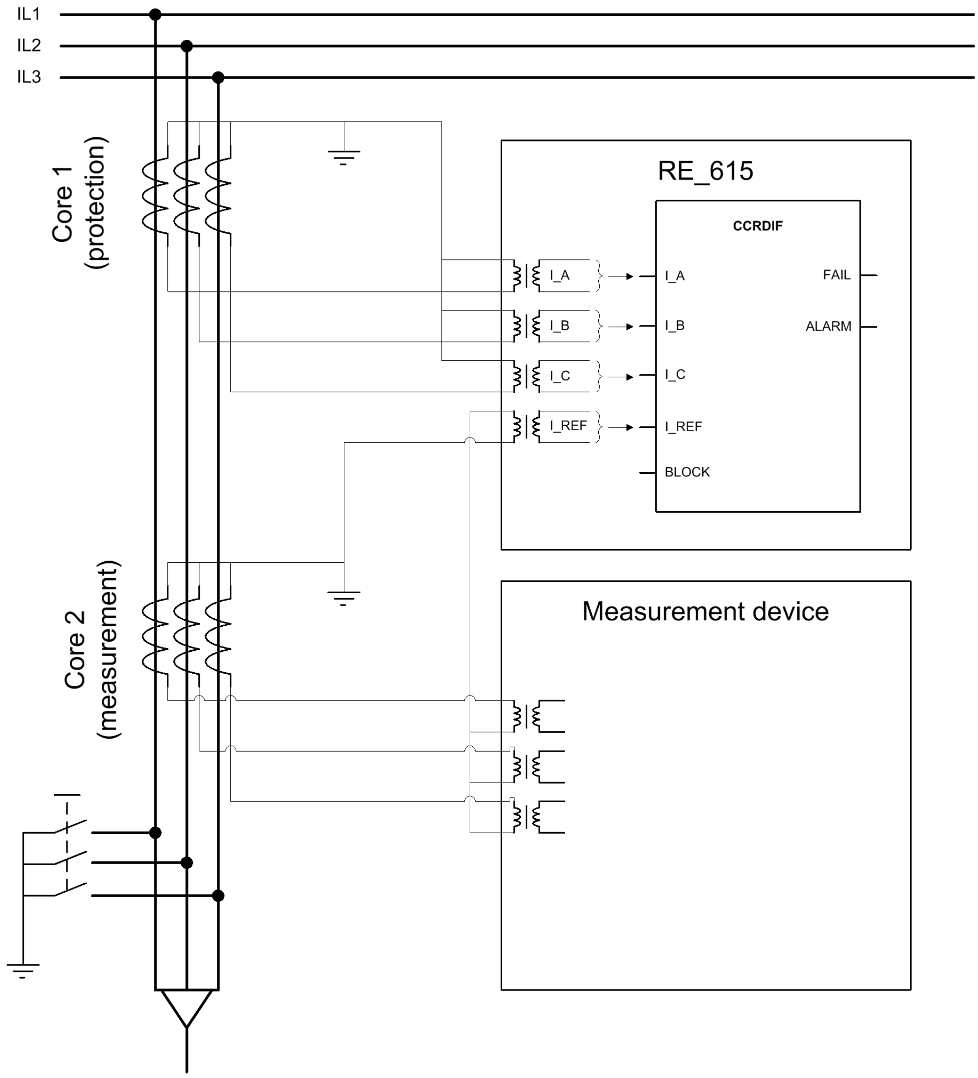



*Figure 182: Connection diagram for current circuit supervision with two sets of three-phase current transformer cores (protection and measurement)*

## 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.

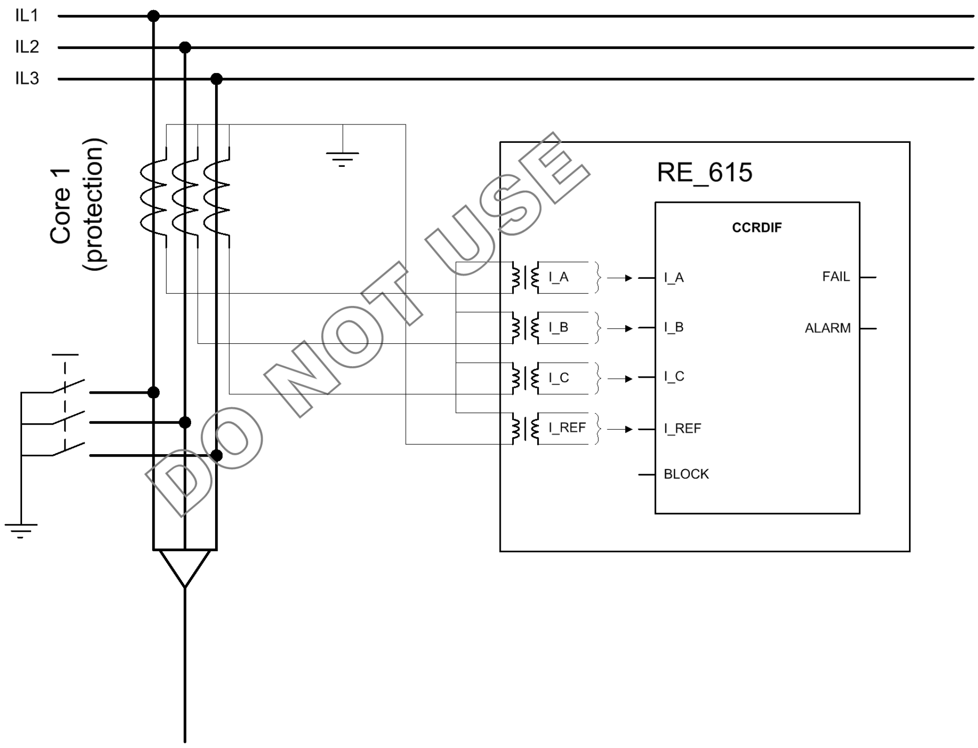





*Figure 183: Example of incorrect reference current connection*

## 6.2.6 Signals

*Table 298: CCRDIF 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 299: CCRDIF Output signals*

| Name | Type | Description |
|---|---|---|
| FAIL | BOOLEAN | Fail output |
| ALARM | BOOLEAN | Alarm output |

## 6.2.7 Settings

*Table 300: CCRDIF Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation On / Off |
| Start value | 0.05...0.20 | xIn | 0.01 | 0.05 | Minimum operate current differential level |
| 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 301: CCRDIF Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| IDIFF | FLOAT32 | 0.00...40.00 | xIn | Differential current |
| CCRDIF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 6.2.9 Technical data

*Table 302: CCRDIF Technical data*

| Characteristic | Value |
|---|---|
| Operate time[1)] | < 30 ms |

1) Including the delay of the output contact.

# 6.3 Protection communication supervision PCSRTPC

## 6.3.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Protection communication supervision | PCSRTPC | PCS | PCS |

## 6.3.2 Function block

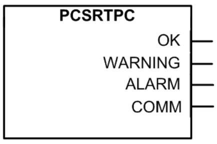



*Figure 184: Function block symbol*

## 6.3.3 Functionality

The protection communication supervision function PCSRTPC monitors the protection communication channel. PCSRTPC blocks the line differential protection functions when interference in the protection communication channel is detected. The blocking takes place automatically for the LNPLDF and BSTGGIO functions which are dependent on the continuous availability of the protection communication channel.

The protection communication channel is continuously monitored by PCSRTPC. The function detects missing or delayed protection telegrams. Protection telegrams are used for transferring the sampled analog and other protection related data. Missing or delayed protection telegrams can jeopardize the demand operate speed of the differential protection.

When a short-term interference is detected in the protection communication channel, the function issues a warning and the line differential functions are automatically and internally blocked. PCSRTPC reacts fast for the protection communication interferences and the blocking takes place within one fundamental network period, in case interruption is detected. When a severe and long lasting interference or total interruption in the protection communication channel is detected, an alarm is issued (after a five-second delay). The protection communication supervision quality status is exchanged continuously online by the local and remote PCSRTPC instances. This ensures that both local and remote ends protection blocking is issued coordinately. This further enhances the security of the line differential protection by forcing both line end IEDs to the same blocking state during a protection communication interference, even in cases where the interference is detected with only one line end IED. There is also the *Reset delay time* settings parameter available which is used for changing the required interference-free time before releasing the line-differential protection back in operation after a blocking due to an interference in communication.

## 6.3.4 Operation principle

The operation of protection communication supervision can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

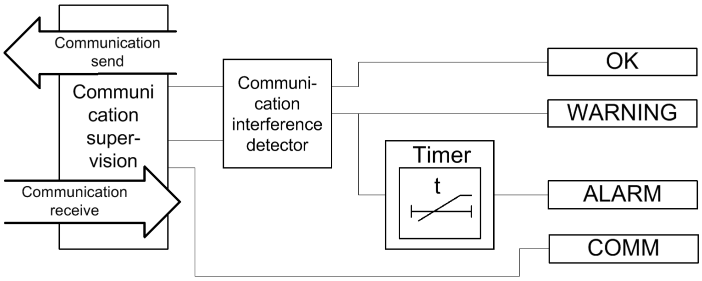



*Figure 185: Functional module diagram*

### Communication supervision

The protection communication is supervised because the differential calculation is dependent on the refreshing of new analog phasor samples from the remote terminal within the protection telegram. The new protection telegram also updates the status of the binary signals sent by the remote terminal. The calculation of the differential current is based on comparing the remote and local terminal measured current samples. It is therefore essential that the protection communication telegrams are supervised and the result of the sample latency calculation can be used further in the differential current calculation. When the communication is able to receive telegrams correctly from the remote end via the communication media, the communication is assumed to be operating correctly and the COMM output is kept active.

### Communication interference detector

The communication interference detector is continuously measuring and observing the sample latency of the protection telegrams. This value is also available as monitored data. The function provides three output signals of which only the corresponding one is active at a time depending on if the protection communication supervision is in OK, WARNING or ALARM. The OK state indicates the correct operation of the protection. The WARNING state indicates that the protection is internally blocked due to detected interference. The WARNING state is switched to ALARM if the interference lasts for a longer period. The protection communication supervision can sometimes be in the WAITING state. This state indicates that the terminal is waiting for the communication to start or restart from the remote end terminal.

### Timer

Once activated with the WARNING signal, the timer has a constant time delay value of five seconds. If the communication failure exists after the delay, the ALARM output is activated.

## 6.3.5 Application

### Communication principle

Analog samples, trip-, start- and user programmable signals are transferred in each protection telegram and the exchange of these protection telegrams is done eight times per power system cycle (every 2.5 ms when $F_n$ = 50 Hz).

Master-Master communication arrangement is used in the two-terminal line differential solution. Current samples are sent from both line ends and the protection algorithms are also executed on both line ends. The direct-intertrip, however, ensures that both ends are always operated simultaneously.

### Time synchronization

In numerical line differential protection, the current samples from the protections which are located geographically apart from each other must be time coordinated so that the current samples from both ends of the protected line can be compared without introducing irrelevant errors. The time coordination requires an extremely high accuracy.

As an example, an inaccuracy of 0.1 ms in a 50 Hz system gives a maximum amplitude error of approximately around 3 percent. An inaccuracy of 1 ms gives a maximum amplitude error of approximately 31 percent. The corresponding figures for a 60 Hz system are 4 and 38 percent respectively.

In the IED, the time coordination is done with an echo method. The IEDs create their own time reference between each other so that the system clocks do not need to synchronize.

The figure shows that in the time synchronization the transmission time to send a message from station B to station A, T1→T2, and the time to receive a message from A to B, T4→T5, are measured. The station A IED delay from the sampling to the start of send, T3→T4, and the local delay from receive to the station B IED sampling T5→T6 time, are also measured for the station B IED, and vice versa. This way the time alignment factor for the local and remote samples is achieved.

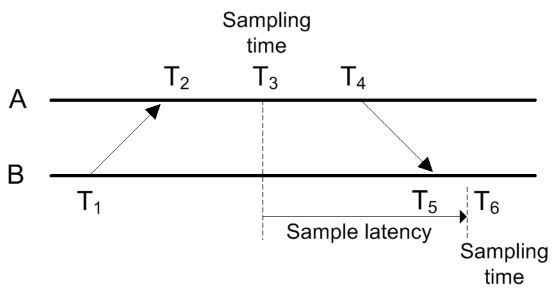



*Figure 186: Measuring sampling latency*

$$P_d = \frac{(T_2 - T_1) + (T_5 - T_4)}{2}$$

(Equation 50)

$$S_d = P_d + (T_4 - T_3) + (T_6 - T_5)$$

(Equation 51)

The sampling latency $S_d$ is calculated for each telegram on both ends. The algorithm assumes that the one-way propagation delay $P_d$ is equal for both directions.

The echo method without GPS can be used in telecommunication transmission networks as long as delay symmetry exists, that is, the sending and receiving delays are equal.

## 6.3.6 Signals

*Table 303: PCSRTPC Output signals*

| Name | Type | Description |
|---|---|---|
| OK | BOOLEAN | Protection communication ok |
| WARNING | BOOLEAN | Protection communication warning |
| ALARM | BOOLEAN | Protection communication alarm |
| COMM | BOOLEAN | Communication detected, active when data is received |

## 6.3.7 Settings

*Table 304: PCSRTPC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Reset delay time | 100...300000 | ms | 10 | 1000 | Reset delay time from alarm and warning into ok state |
| Alarm count | 0...99999 | | | 0 | Set new alarm count value |
| Warning count | 0...99999 | | | 0 | Set new warning count value |

## 6.3.8 Monitored data

*Table 305: PCSRTPC Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| HEALTH | Enum | 1=Ok<br>2=Warning<br>3=Alarm<br>-2=Waiting | | Communication link health |
| ALARM_CNT | INT32 | 0...99999 | | Number of alarms detected |
| WARN_CNT | INT32 | 0...99999 | | Number of warnings detected |
| SMPL_LATENCY | FLOAT32 | 0.000...99.999 | ms | Measured sample latency |
| Table continues on next page | | | | |

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| PROPAGTN_DLY | FLOAT32 | 0.000...99.999 | ms | Measured propagation delay |
| RND_TRIP_DLY | FLOAT32 | 0.000...99.999 | ms | Measured round trip delay |
| T_ALARM_CNT | Timestamp | | | Time when alarm count was last changed |
| T_WARN_CNT | Timestamp | | | Time when warning count was last changed |

## 6.3.9 Technical revision history

*Table 306: PCSTRPC Technical revision history*

| Technical revision | Change |
|---|---|
| B | Changes and additions to the monitored data |

# 6.4 Fuse failure supervision SEQRFUF

## 6.4.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Fuse failure supervision | SEQRFUF | FUSEF | 60 |

## 6.4.2 Function block

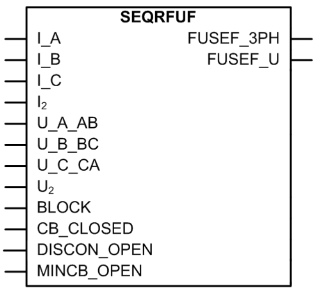



*Figure 187: Function block symbol*

## 6.4.3 Functionality

The fuse failure supervision function SEQRFUF is used to block the voltage measuring functions at failures in the secondary circuits between the voltage transformer and IED to avoid unwanted operations.

SEQRFUF has two algorithms, a negative phase-sequence based algorithm and 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.

## 6.4.4 Operation principle

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

The operation of the fuse failure supervision function can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

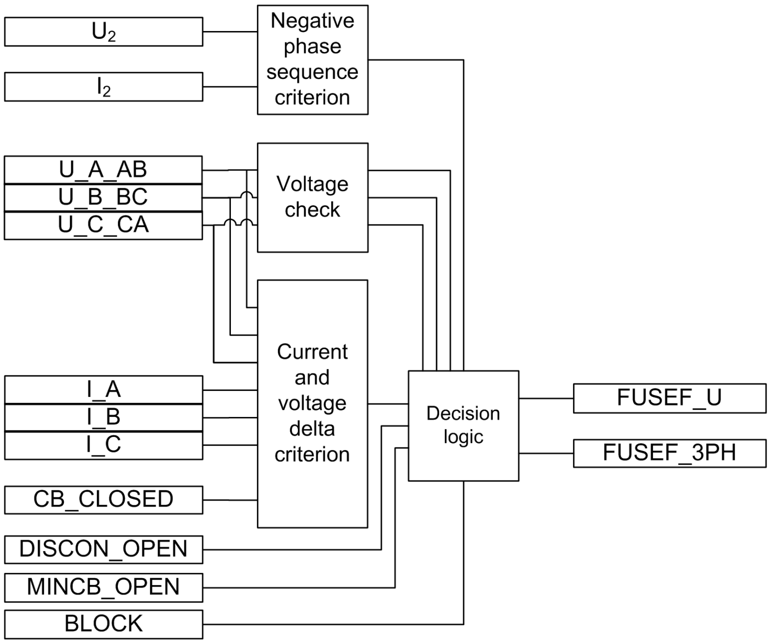



*Figure 188: Functional module diagram*

### Negative phase-sequence criterion

A fuse failure based on negative phase-sequence criterion is detected if the measured negative phase-sequence voltage exceeds the set *Neg Seq voltage Lev* value and the measured negative phase-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. In case 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 phase-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 ΔU exceeds the corresponding value of the *Min Op voltage delta* setting and the magnitude of ΔI is below the value of the *Min Op current delta* setting in any phase at the same time due to the closure of the circuit breaker, that is, `CB_CLOSED` = TRUE.
- The magnitude of ΔU exceeds the value of the *Min Op voltage delta* setting and the magnitude of ΔI is below the *Min Op current delta* setting in any phase at the same time since the magnitude of the phase current in the same phase exceeds the *Current level* setting.

The first condition requires the delta criterion to be fulfilled in any phase at the same time as the circuit breaker is closed. Opening the circuit breaker at one end and energizing the line from the other end onto a fault could lead to an improper operation of SEQRFUF with an open breaker. If this is considered to be an important disadvantage, the `CB_CLOSED` input is to be connected to FALSE.

The second condition requires the delta criterion to be fulfilled in one phase together with high current for the same phase. The measured phase current is used to reduce the risk of a false fuse-failure detection. If the current on the protected line is low, a voltage drop in the system (not caused by the fuse failure) is not followed by a current change and a false fuse failure can occur. To prevent this, the minimum phase current criterion is checked.

The fuse-failure detection is active until the voltages return above the *Min Op voltage delta* setting. If a voltage in a phase is below the *Min Op voltage delta* setting, a new fuse failure detection for that phase is not possible until the voltage returns above the setting value.

### Decision logic

The fuse failure detection outputs FUSEF_U and FUSEF_3PH are controlled according to the detection criteria or external signals.

*Table 307: Fuse failure output control*

| Fuse failure detection criterion | Conditions and function response |
|---|---|
| Negative phase-sequence criterion | If a fuse failure is detected based on the negative phase-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 "Yes", 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 "Yes", the function activates the FUSE_3PH output signal. |
| External fuse failure detection | The MINCB_OPEN input signal is supposed to be connected through an IED binary input to the N.C. auxiliary contact of the miniature circuit breaker protecting the VT secondary circuit. The MINCB_OPEN signal sets the FUSEF_U output signal to block all the voltage-related functions when MCB is in the open state. |
| | The DISCON_OPEN input signal is supposed to be connected through an IED binary input to the N.C. auxiliary contact of the line disconnector. The DISCON_OPEN signal sets the FUSEF_U output signal to block the voltage-related functions when the line disconnector is in the open state. |

It is recommended to always set *Enable seal in* to "Yes". 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.

## 6.4.5 Application

Some protection functions operate on the basis of the measured voltage value in the relay point. These functions can fail if there is a fault in the measuring circuits between the voltage transformers and the IED.

A fault in the voltage measuring circuit is referred to as a fuse failure. This term is misleading since a blown fuse is just one of the many possible reasons for a broken circuit. Since incorrectly measured voltage can result in a faulty operation of some of the protection functions, it is important to detect the fuse failures. A fast fuse failure detection is one of the means to block voltage-based functions before they operate.

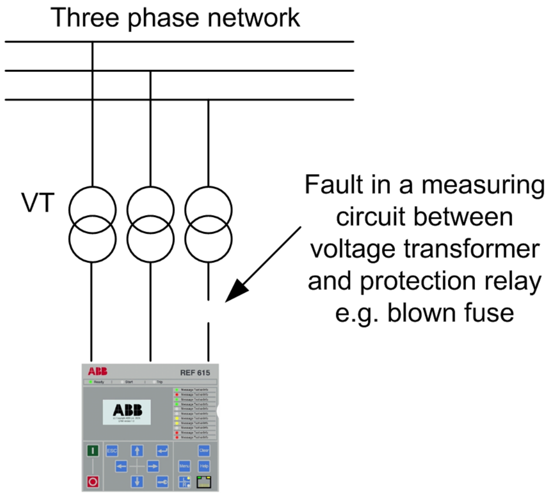



*Figure 189: Fault in a circuit from the voltage transformer to the IED*

A fuse failure occurs due to blown fuses, broken wires or intended substation operations. The negative sequence component-based function can be used to detect different types of single-phase or two-phase fuse failures. However, at least one of the three circuits from the voltage transformers must not be broken. The supporting delta-based function can also detect a fuse failure due to three-phase interruptions.

In the negative sequence component-based part of the function, a fuse failure is detected by comparing the calculated value of the negative sequence component voltage to the negative sequence component current. The sequence entities are calculated from the measured current and voltage data for all three phases. The purpose of this function is to block voltage-dependent functions when a fuse failure is detected. Since the voltage dependence differs between these functions, SEQRFUF has two outputs for this purpose.

## 6.4.6 Signals

*Table 308: SEQRFUF 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 309: SEQRFUF Output signals*

| Name | Type | Description |
|---|---|---|
| FUSEF_3PH | BOOLEAN | Three-phase start of function |
| FUSEF_U | BOOLEAN | General start of function |

## 6.4.7 Settings

*Table 310: SEQRFUF Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| 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 | 0.50...0.90 | xUn | 0.01 | 0.60 | Operate level of change in phase voltage |
| Change rate enable | 0=False<br>1=True | | | 0=False | Enabling operation of change based function |
| Min Op voltage delta | 0.01...1.00 | xUn | 0.01 | 0.70 | Minimum operate level of phase voltage for delta calculation |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| 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 | 0.70 | Operate level of seal-in phase voltage |
| Enable seal in | 0=False<br>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 |

## 6.4.8 Monitored data

*Table 311: SEQRFUF Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| SEQRFUF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 6.4.9 Technical data

*Table 312: SEQRFUF Technical data*

| Characteristic | Value | |
|---|---|---|
| Operate time[1] | | |
| • NPS function | $U_{Fault}$ = 1.1 x set *Neg Seq voltage Lev* | < 33 ms |
| | $U_{Fault}$ = 5.0 x set *Neg Seq voltage Lev* | < 18 ms |
| • Delta function | ΔU = 1.1 x set *Voltage change rate* | < 30 ms |
| | ΔU = 2.0 x set *Voltage change rate* | < 24 ms |

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

# 6.5 Operation time counter MDSOPT

## 6.5.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Operation time counter | MDSOPT | OPTS | OPTM |

## 6.5.2 Function block

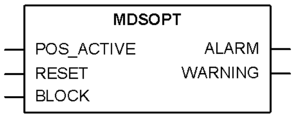



*Figure 190: Function block symbol*

## 6.5.3 Functionality

The generic operation time counter 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 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.

## 6.5.4 Operation principle

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

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

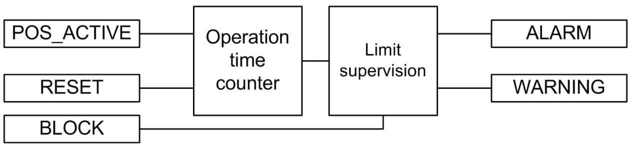



*Figure 191: Functional module diagram*

### 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.

## 6.5.5 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.

## 6.5.6 Signals

*Table 313: 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 314: MDSOPT Output signals*

| Name | Type | Description |
|---|---|---|
| ALARM | BOOLEAN | Alarm accumulated operation time exceeds Alarm value |
| WARNING | BOOLEAN | Warning accumulated operation time exceeds Warning value |

## 6.5.7 Settings

*Table 315: MDSOPT Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| 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 |
| 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<br>2=Timed Warn<br>3=Timed Warn Alm | | | 1=Immediate | Operating time mode for warning and alarm |

## 6.5.8 Monitored data

*Table 316: MDSOPT Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| MDSOPT | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |
| OPR_TIME | INT32 | 0...299999 | h | Total operation time in hours |

## 6.5.9 Technical data

*Table 317: MDSOPT Technical data*

| Description | Value |
| --- | --- |
| Motor run-time measurement accuracy[1)] | ±0.5% |

1) Of the reading, for a stand-alone IED, without time synchronization.

# Section 7 Condition monitoring functions

## 7.1 Circuit breaker condition monitoring SSCBR

### 7.1.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Circuit breaker condition monitoring | SSCBR | CBCM | CBCM |

### 7.1.2 Function block

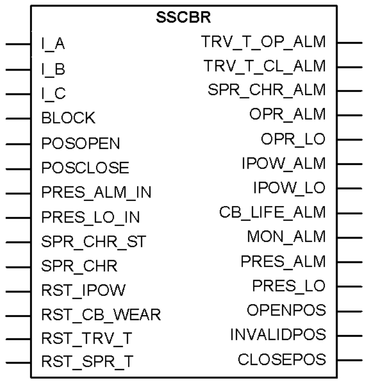



*Figure 192: Function block symbol*

### 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. For proper functioning of the circuit breaker, it is essential to monitor the circuit breaker operation, spring charge indication, breaker wear, travel time, number of operation cycles and accumulated energy. The energy is calculated from the measured input currents as a sum of $I^y t$ values. Alarms are generated when the calculated values exceed the threshold settings.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

## 7.1.4 Operation principle

The circuit breaker condition monitoring function includes different metering and monitoring subfunctions. The functions can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".The corresponding parameter values are "Enable" and "Disable". The operation counters are cleared when *Operation* is set to "Off".

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

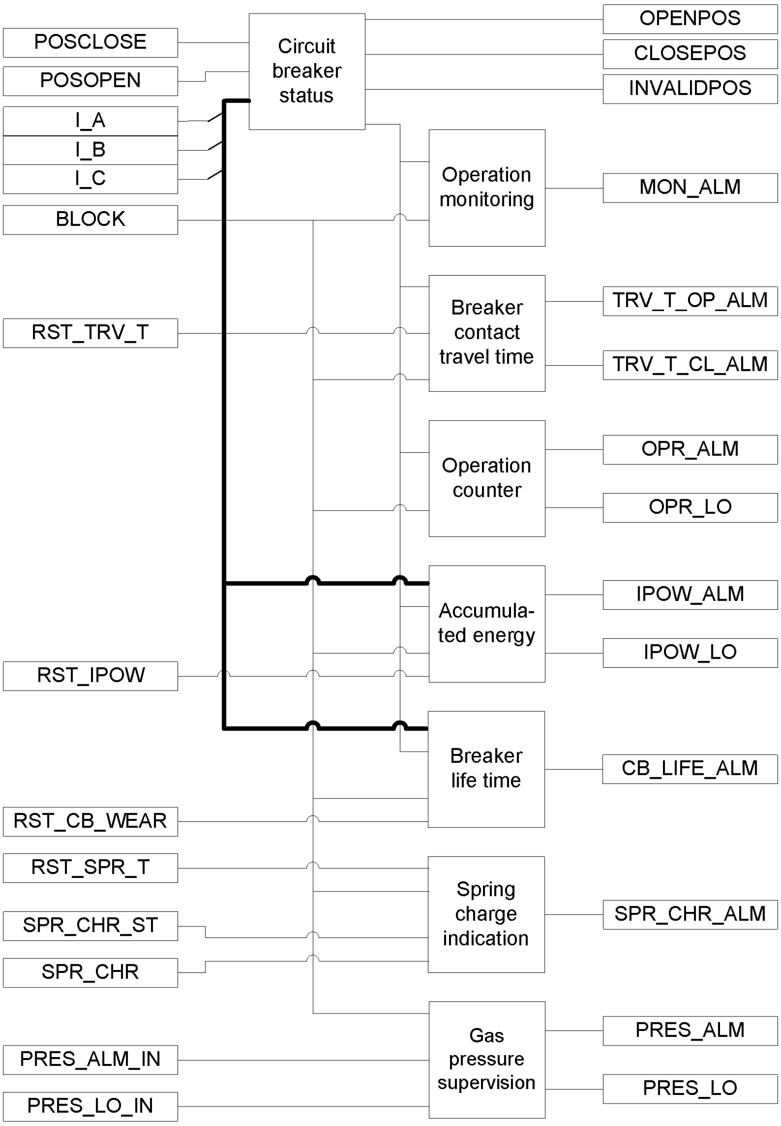



*Figure 193: Functional module diagram*

## 7.1.4.1 Circuit breaker status

The circuit breaker status subfunction monitors the position of the circuit breaker, that is, whether the breaker is in an open, closed or intermediate position. The operation of the breaker status monitoring can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

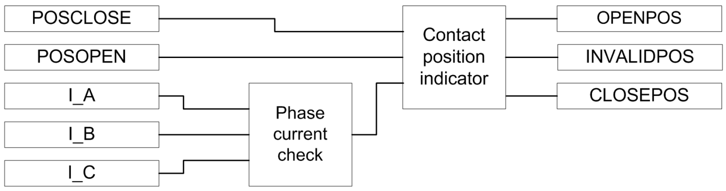



*Figure 194: Functional module diagram for monitoring circuit breaker status*

### Contact position indicator

The circuit breaker status is open if the auxiliary input contact `POSCLOSE` is low, the `POSOPEN` input is high and the current is zero. The circuit breaker is closed when the `POSOPEN` input is low and the `POSCLOSE` input is high. The breaker is in the intermediate position if both the auxiliary contacts have the same value, that is, both are in the logical level "0", or if the auxiliary input contact `POSCLOSE` is low and the `POSOPEN` input is high, but the current is not zero.

The status of the breaker is indicated with the binary outputs `OPENPOS`, `INTERMPOS`, and `CLOSEPOS` for open, intermediate, and closed position respectively.

### Phase current check

In addition to auxiliary input contacts, the module takes three phase currents to detect the position of the circuit breaker.

## 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 by using a module diagram. All the blocks in the diagram are explained in the next sections.

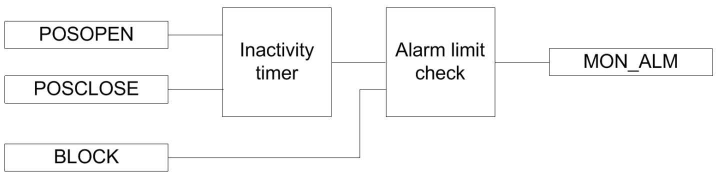



*Figure 195: Functional module diagram for calculating inactive days and alarm for circuit breaker operation monitoring*

### 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 as a service value. It is also possible to set the initial inactive days by using 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 by using a module diagram. All the blocks in the diagram are explained in the next sections.

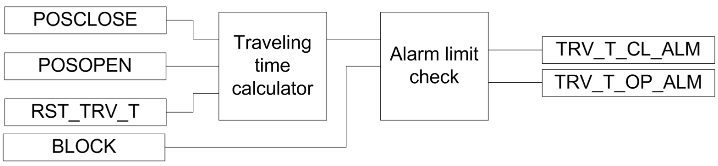



*Figure 196: Functional module diagram for breaker contact travel time*

### Traveling time calculator

The contact travel time of the breaker is calculated from the time between auxiliary contacts' state change. The open travel time is measured between the opening of the POSCLOSE auxiliary contact and the closing of the POSOPEN auxiliary contact. Travel time is also measured between the opening of the POSOPEN auxiliary contact and the closing of the POSCLOSE auxiliary contact.

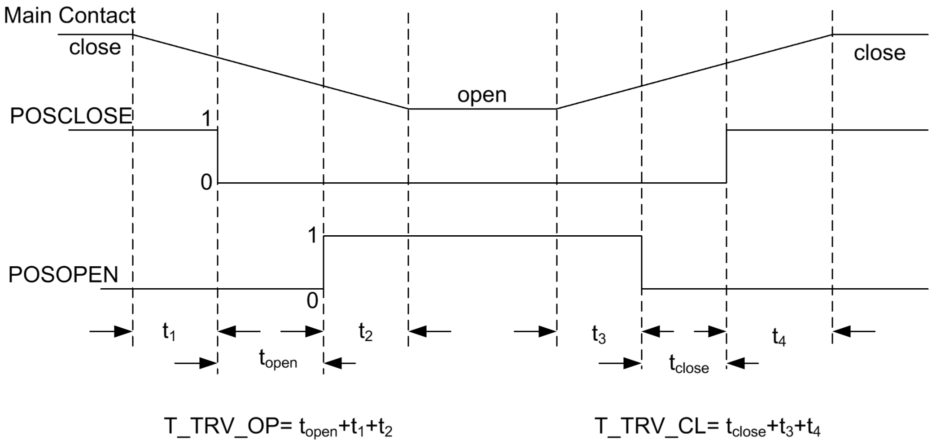



*Figure 197: Travel time calculation*

There is a time difference $t_1$ between the start of the main contact opening and the opening of the `POSCLOSE` auxiliary contact. Similarly, there is a time gap $t_2$ between the time when the `POSOPEN` auxiliary contact opens and the main contact is completely open. Therefore, in order 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* ($=t_1+t_2$). The closing time is calculated by adding the value set with the *Closing time Cor* ($t_3+t_4$) setting to the measured closing time.

The last measured opening travel time `T_TRV_OP` and the closing travel time `T_TRV_CL` are available through the Monitored data view on the LHMI or through tools via communications.

### Alarm limit check

When the measured open 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 close travel time is longer than the value set with the *Close alarm time* setting, the , 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 operation of the subfunction can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

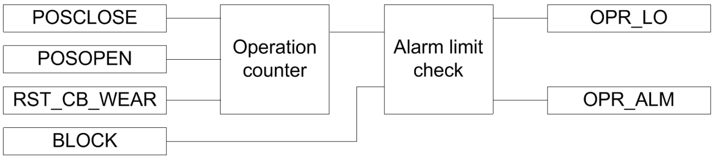



*Figure 198: Functional module diagram for counting circuit breaker operations*

### 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 through the Monitored data view on the LHMI or through tools via communications. The old circuit breaker operation counter value can be taken into use by writing the value to the *Counter initial Val* parameter and by setting the parameter *CB wear values* in the clear menu from WHMI or LHMI. .

### Alarm limit check

The OPR_ALM operation alarm is generated when the number of operations exceeds the value set with the *Alarm Op number* threshold setting. However, if the number of operations increases further and exceeds the limit value set with the *Lockout Op number* setting, the OPR_LO output is activated.

The binary outputs OPR_LO and OPR_ALM are deactivated when the BLOCK input is activated.

## 7.1.4.5 Accumulation of $I^yt$

Accumulation of the $I^yt$ module calculates the accumulated energy.

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

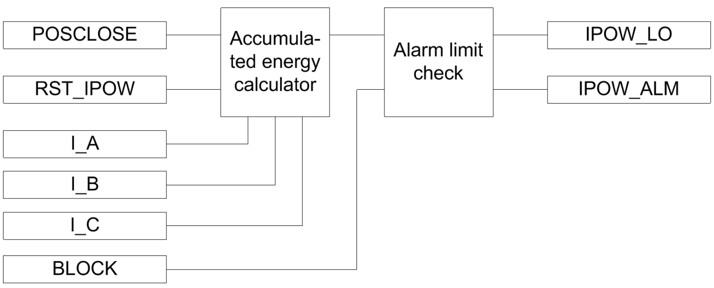



*Figure 199: Functional module diagram for calculating accumulative energy and alarm*

### Accumulated energy calculator

This module calculates the accumulated energy $I^y t$. The factor y is set with the *Current exponent* setting.

The calculation is initiated with the POSCLOSE input open events. It ends when the RMS current becomes lower than the *Acc stop current* setting value.

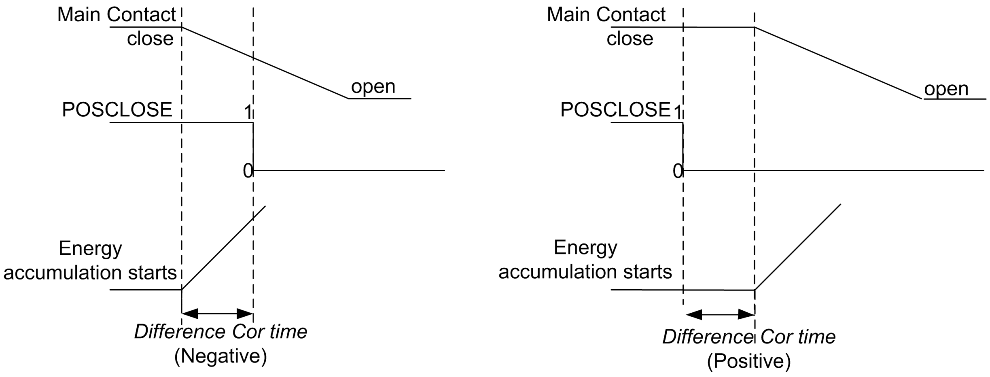



*Figure 200: Significance of theDifference Cor time setting*

The *Difference Cor time* setting is used instead of the auxiliary contact to accumulate the energy from the time the main contact opens. If the setting is positive, the calculation of energy starts after the auxiliary contact has opened and when the delay is equal to the value set with the *Difference Cor time* setting. When the setting is negative, the calculation starts in advance by the correction time before the auxiliary contact opens.

The accumulated energy outputs IPOW_A (_B, _C) are available through the Monitored data view on the LHMI or through tools via communications. The values can be reset by setting the parameter *CB accum. currents power* to true in the clear menu from WHMI or LHMI.

### Alarm limit check

The IPOW_ALM alarm is activated when the accumulated energy exceeds the value set with the *Alm Acc currents Pwr* threshold setting. However, when the energy exceeds the limit value set with the *LO Acc currents Pwr* threshold setting, the IPOW_LO output is activated.

The IPOW_ALM and IPOW_LO outputs can be blocked by activating the binary input BLOCK.

## 7.1.4.6 Remaining life of the circuit breaker

Every time the breaker operates, the life of the circuit breaker reduces due to wearing. The wearing in the breaker depends on the tripping current, and the remaining life of the breaker is estimated from the circuit breaker trip curve provided by the manufacturer. The remaining life is decremented at least with one when the circuit breaker is opened.

The operation of the remaining life of the circuit breaker subfunction can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

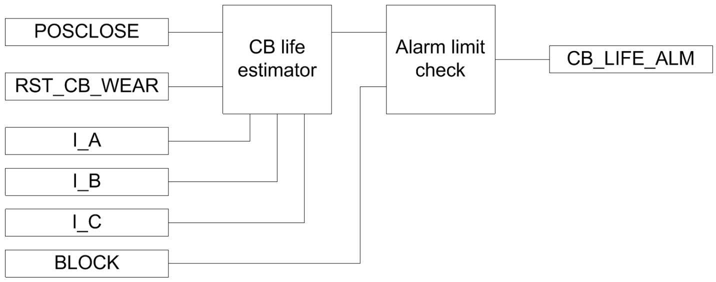



*Figure 201: Functional module diagram for estimating the life of the circuit breaker*

### 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)`.

### 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 *Operation cycle* parameter and by setting the parameter *SSCBRx rem.life* to true in 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 by using a module diagram. All the blocks in the diagram are explained in the next sections.

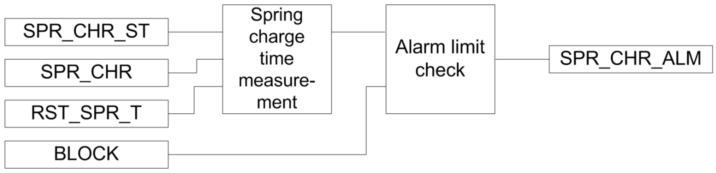



*Figure 202: Functional module diagram for circuit breaker spring charged indication and alarm*

### 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 through 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 by using a module diagram. All the blocks in the diagram are explained in the next sections.

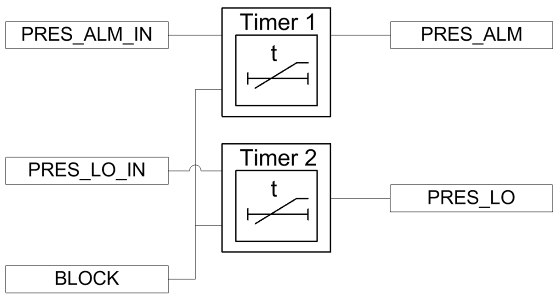



*Figure 203: Functional module diagram for circuit breaker gas pressure alarm*

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 travelling times indicate the need for maintenance of the circuit breaker mechanism. Therefore, detecting excessive travelling time is needed. During the opening cycle operation, the main contact starts opening. The auxiliary contact A opens, the auxiliary contact B closes, and the main contact reaches its opening position. During the closing cycle, the first main contact starts closing. The auxiliary contact B opens, the auxiliary contact A closes, and the main contact reaches its close position. The travel times are calculated based on the state changes of the auxiliary contacts and the adding correction factor to consider the time difference of the main contact's and the auxiliary contact's position change.

#### Operation counter

Routine maintenance of the breaker, such as lubricating breaker mechanism, is generally based on a number of operations. A suitable threshold setting, to raise an alarm when the number of operation cycle exceeds the set limit, helps preventive maintenance. This can also be used to indicate the requirement for oil sampling for dielectric testing in case of an oil circuit breaker.

The change of state can be detected from the binary input of the auxiliary contact. There is a possibility to set an initial value for the counter which can be used to initialize this functionality after a period of operation or in case of refurbished primary equipment.

### Accumulation of $I^y t$

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**

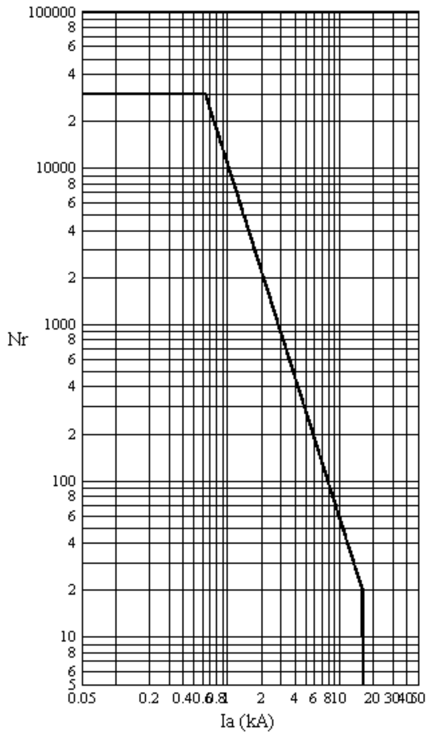



*Figure 204: Trip Curves for a typical 12 kV, 630 A, 16 kA vacuum interrupter*

| | |
|---|---|
| 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 52)

| | |
|---|---|
| $I_r$ | Rated operating current = 630 A |
| $I_f$ | Rated fault current = 16 kA |
| A | Op number rated = 30000 |
| B | Op number fault = 20 |

#### Calculation for estimating the remaining life

The equation shows that there are 30,000 possible operations at the rated operating current of 630 A and 20 operations at the rated fault current 16 kA. Therefore, if the tripping current is 10 kA, one operation at 10 kA is equivalent to 30,000/500=60 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 15,000-60=14,940 at the rated operating current.

### Spring charged indication

For normal operation of the circuit breaker, the circuit breaker spring should be charged within a specified time. Therefore, detecting long spring charging time indicates that it is time for the circuit breaker maintenance. The last value of the spring charging time can be used as a service value.

### Gas pressure supervision

The gas pressure supervision monitors the gas pressure inside the arc chamber. When the pressure becomes too low compared to the required value, the circuit breaker operations are locked. A binary input is available based on the pressure levels in the function, and alarms are generated based on these inputs.

## 7.1.6 Signals

*Table 318: 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 |
| Table continues on next page | | | |

| Name | Type | Default | Description |
|---|---|---|---|
| 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 closeposition of apparatus from I/O |
| 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 |
| 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 319: 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 320: SSCBR Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>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 |
| Opening time Cor | 0...100 | ms | 1 | 10 | Correction factor for open travel time in ms |
| Closing time Cor | 0...100 | ms | 1 | 10 | Correction factor for CB close travel time in ms |
| Spring charge time | 0...60000 | ms | 10 | 1000 | Setting of alarm for spring charging time of CB in ms |
| Counter initial Val | 0...9999 | | 1 | 0 | The operation numbers counter initialization value |
| Alarm Op number | 0...9999 | | 1 | 200 | Alarm limit for number of operations |
| Lockout Op number | 0...9999 | | 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 |
| Ini Acc currents Pwr | 0.00...20000.00 | | 0.01 | 0.00 | Initial value for accumulation energy (Iyt) |
| Directional Coef | -3.00...-0.50 | | 0.01 | -1.50 | Directional coefficient for CB life calculation |
| Operation cycle | 0...9999 | | 1 | 5000 | Operation cycle at rated current |
| 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 |
| 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 |
| Inactive Alm days | 0...9999 | | 1 | 2000 | Alarm limit value of the inactive days counter |
| 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 321: 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 | -9999...9999 | | CB Remaining life phase A |
| CB_LIFE_B | INT32 | -9999...9999 | | CB Remaining life phase B |
| CB_LIFE_C | INT32 | -9999...9999 | | CB Remaining life phase C |
| IPOW_A | FLOAT32 | 0.00...1000000.00 | | Accumulated currents power (Iyt), phase A |
| IPOW_B | FLOAT32 | 0.00...1000000.00 | | Accumulated currents power (Iyt), phase B |
| IPOW_C | FLOAT32 | 0.00...1000000.00 | | Accumulated currents power (Iyt), phase C |
| SSCBR | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 7.1.9 Technical data

*Table 322: SSCBR Technical data*

| | |
|---|---|
| Current measuring accuracy | ±1.5% or ±0.002 x $I_n$<br>(at currents in the range of 0.1…10 x In)<br>±5.0%<br>(at currents in the range of 10…40 x In) |
| 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 323: 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 DIFTRVTCLALM outputs and the corresponding *Open Dif alarm time* and *Close Dif alarm time* setting parameters |

# Section 8 Measurement functions

## 8.1 Basic measurements

### 8.1.1 Functions

The three-phase current measurement function, CMMXU, is used for monitoring and metering the phase currents of the power system.

The three-phase voltage measurement 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 residual current measurement function, RESCMMXU, is used for monitoring and metering the residual current of the power system.

The residual voltage measurement function, RESVMMXU, is used for monitoring and metering the residual voltage of the power system.

The sequence current measurement, CSMSQI, is used for monitoring and metering the phase sequence currents.

The sequence voltage measurement, VSMSQI, is used for monitoring and metering the phase sequence voltages.

The three-phase power and energy measurement PEMMXU is used for monitoring and metering the active power P, reactive power Q, apparent power S, power factor PF and for calculating the accumulated energy separately as forward active, reverse active, forward reactive and reverse reactive. PEMMXU calculates these quantities with 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 and remotely to a network control center with communication.

### 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 value is calculated separately for each phase. The demand function is implemented by means of a function that calculates the linear average of the signal measured over a settable demand time interval. A new demand value is obtained once in a minute, indicating the analog signal demand over the demand time interval preceding 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 switching of the demand interval without the loss of data is done by storing the one minute demand values in the memory until the longest demand interval is available. The maximum demand values for each phase are recorded with time stamps. The recorded values are reset with a command.

The demand value calculation is only available in the three-phase current measurement function, CMMXU.

### Value reporting

The measurement functions are capable to report new values for network control center (SCADA system) based on the following 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 together with the phase-to-phase voltages.

### Zero point clamping

A measured value under 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 zero clamping limit, new values are reported.

*Table 324: 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) |

Table continues on next page

| Function | Zero clamping limit |
| --- | --- |
| 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) |

### 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.

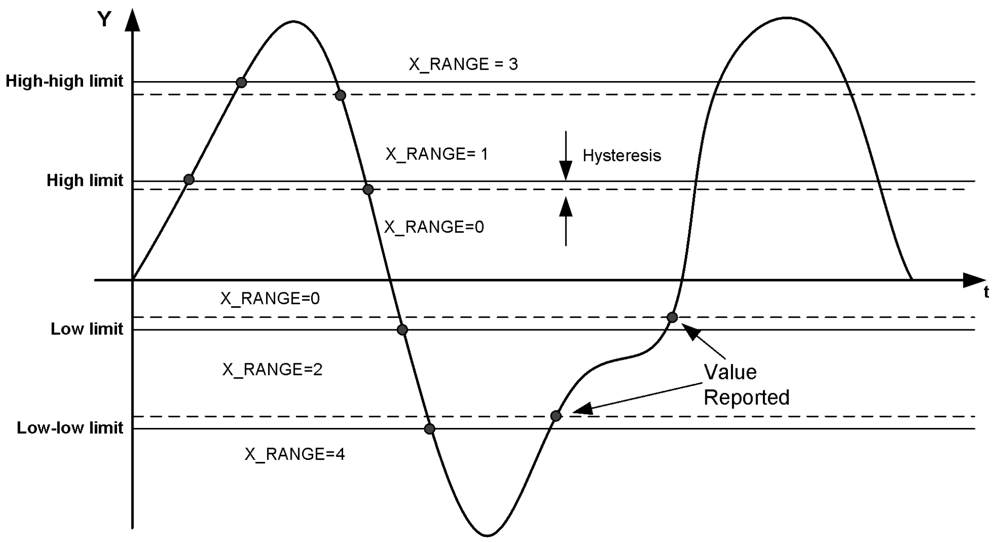



*Figure 205: Presentation of operating limits*

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. The settings involved for limit value supervision are :

*Table 325: 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 (RESCMMXU) | High limit | *A high limit res* |
| | Low limit | - |
| | High-high limit | *A Hi high limit res* |
| | Low-low limit | - |
| Residual voltage measurement (RESVMMXU) | High limit | *V high limit res* |
| | 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.

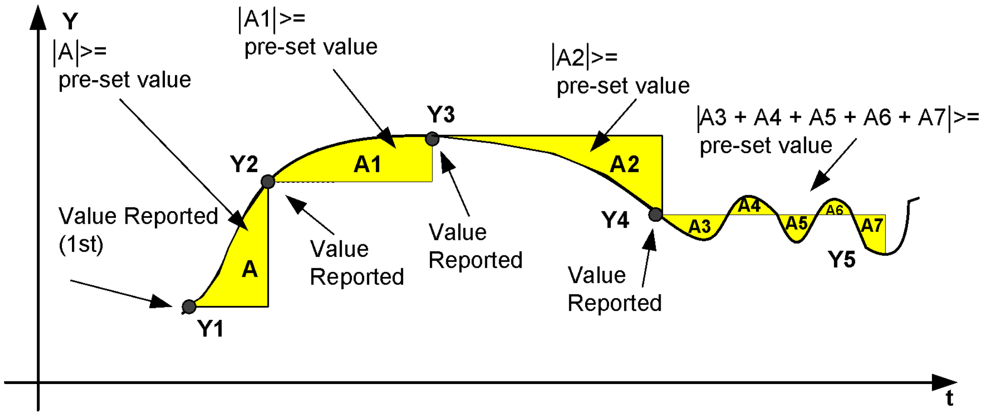



*Figure 206: Integral deadband supervision*

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 * 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 53)

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:

$$t(s) = \frac{(40 - 0) \times 2500 / 1000}{|0.40 - 0.30| \times 100\%} = 10s$$

*Table 326: 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)* |
| 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 pre-set value of fixed 10 percent of the Sn and the power factor PF, with the pre-set 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 pre-set 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 complex power based on the fundamental frequency component phasors (DFT).

$$\overline{S} = (\overline{U}_A \cdot \overline{I}^*_A + \overline{U}_B \cdot \overline{I}^*_B + \overline{U}_C \cdot \overline{I}^*_C)$$

(Equation 54)

Once the complex apparent power is calculated, P, Q, S and PF are calculated with the equations:

$$Q = \mathrm{Im}(\overline{S})$$

(Equation 55)

$$Q = \mathrm{Im}(\overline{S})$$

(Equation 56)

$$S = \left|\overline{S}\right| = \sqrt{P^2 + Q^2}$$

(Equation 57)

$$Cos\varphi = \frac{P}{S}$$

(Equation 58)

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.

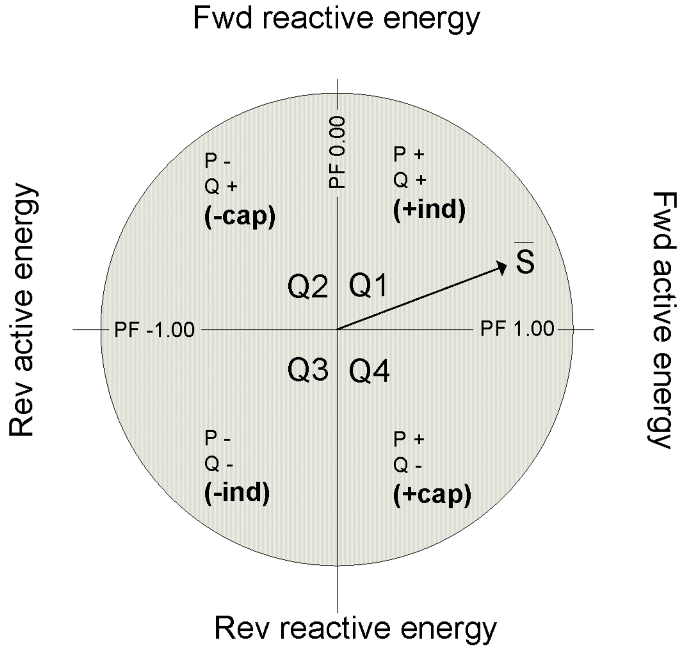



*Figure 207: Complex power and power quadrants*

*Table 327: 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 active (`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 maximum value defined, the counter value is reset and restarted from the 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 WArh Initial* and ER_RV_ACM to *Reverse WArh 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 current components are calculated from the phase currents according to:

$$\overline{I}_0 = (\overline{I}_A + \overline{I}_B + \overline{I}_C)/3$$

(Equation 59)

$$\overline{I}_1 = (\overline{I}_A + a \cdot \overline{I}_B + a^2 \cdot \overline{I}_C)/3$$

(Equation 60)

$$\overline{I}_2 = (\overline{I}_A + a^2 \cdot \overline{I}_B + a \cdot \overline{I}_C)/3$$

(Equation 61)

The phase-sequence voltage components are calculated from the phase-to-earth voltages when *VT connection* is selected as “Wye” with the formulae:

$$\overline{U}_0 = (\overline{U}_A + \overline{U}_B + \overline{U}_C)/3$$

(Equation 62)

$$\overline{U}_1 = (\overline{U}_A + a \cdot \overline{U}_B + a^2 \cdot \overline{U}_C)/3$$

(Equation 63)

$$\overline{U}_2 = (\overline{U}_A + a^2 \cdot \overline{U}_B + a \cdot \overline{U}_C)/3$$

(Equation 64)

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 formulae:

$$\overline{U}_1 = (\overline{U}_{AB} - a^2 \cdot \overline{U}_{BC})/3$$

(Equation 65)

$$\overline{U}_2 = (\overline{U}_{AB} - a \cdot \overline{U}_{BC})/3$$

(Equation 66)

## 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 and control IEDs 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 IED analog measurement chain can be verified during normal service by a periodic comparison of the measured value from the IED 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 CMMXU

### 8.1.4.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Three-phase current | CMMXU | 3I | 3I |

### 8.1.4.2 Function block

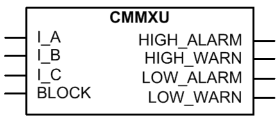



*Figure 208: Function block symbol*

### 8.1.4.3 Signals

*Table 328: 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 329: 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 330: CMMXU Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Measurement mode | 1=RMS<br>2=DFT | | | 2=DFT | Selects used measurement mode |
| Num of phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 | | | 1=1 out of 3 | Number of phases required by limit supervision |
| Demand interval | 0=1 minute<br>1=5 minutes<br>2=10 minutes<br>3=15 minutes<br>4=30 minutes<br>5=60 minutes<br>6=180 minutes | | | 0=1 minute | Time interval for demand calculation |
| A high high limit | 0.00...40.00 | xIn | | 1.40 | High alarm current limit |
| A high limit | 0.00...40.00 | xIn | | 1.20 | High warning current limit |
| A low limit | 0.00...40.00 | xIn | | 0.00 | Low warning current limit |
| A low low limit | 0.00...40.00 | xIn | | 0.00 | Low alarm current limit |
| A deadband | 100...100000 | | | 2500 | Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s) |

### 8.1.4.5 Monitored data

*Table 331: 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 |
| Time max demand IL1 | Timestamp | | | Time of maximum demand phase A |
| Time max demand IL2 | Timestamp | | | Time of maximum demand phase B |
| Time max demand IL3 | Timestamp | | | Time of maximum demand phase C |
| I_INST_A | FLOAT32 | 0.00...40.00 | xIn | IL1 Amplitude, magnitude of instantaneous value |
| 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<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | IL1 Amplitude range |
| I_INST_B | FLOAT32 | 0.00...40.00 | xIn | IL2 Amplitude, magnitude of instantaneous value |
| 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<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | IL2 Amplitude range |
| I_INST_C | FLOAT32 | 0.00...40.00 | xIn | IL3 Amplitude, magnitude of instantaneous value |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| 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<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | IL3 Amplitude range |

### 8.1.4.6 Technical data

*Table 332: CMMXU Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f_n$ ±2Hz |
| | ±0.5% or ±0.002 x $I_n$<br>(at currents in the range of 0.01...4.00 x $I_n$) |
| Suppression of harmonics | DFT: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5,…<br>RMS: No suppression |

### 8.1.4.7 Technical revision history

*Table 333: CMMXU Technical revision history*

| Technical revision | Change |
|---|---|
| B | Menu changes |

## 8.1.5 Three-phase voltage VMMXU

### 8.1.5.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Three-phase voltage | VMMXU | 3U | 3U |

## 8.1.5.2 Function block

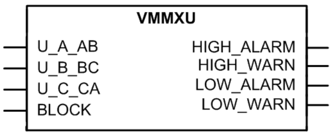



*Figure 209: Function block symbol*

## 8.1.5.3 Signals

*Table 334: 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 335: 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 336: VMMXU Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Measurement mode | 1=RMS<br>2=DFT | | | 2=DFT | Selects used measurement mode |
| Num of phases | 1=1 out of 3<br>2=2 out of 3<br>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 | | 1.40 | High alarm voltage limit |
| V high limit | 0.00...4.00 | xUn | | 1.20 | High warning voltage limit |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| V low limit | 0.00...4.00 | xUn | | 0.00 | Low warning voltage limit |
| V low low limit | 0.00...4.00 | xUn | | 0.00 | Low alarm voltage limit |
| V deadband | 100...100000 | | | 10000 | Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s) |

## 8.1.5.5 Monitored data

*Table 337: VMMXU Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| U12-kV | FLOAT32 | 0.00...4.00 | xUn | Measured phase to phase voltage 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_DB_AB | FLOAT32 | 0.00...4.00 | xUn | U12 Amplitude, magnitude of reported value |
| U_RANGE_AB | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | U12 Amplitude range |
| U_INST_BC | FLOAT32 | 0.00...4.00 | xUn | U23 Amplitude, magnitude of instantaneous value |
| U_DB_BC | FLOAT32 | 0.00...4.00 | xUn | U23 Amplitude, magnitude of reported value |
| U_RANGE_BC | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | U23 Amplitude range |
| U_INST_CA | FLOAT32 | 0.00...4.00 | xUn | U31 Amplitude, magnitude of instantaneous value |
| U_DB_CA | FLOAT32 | 0.00...4.00 | xUn | U31 Amplitude, magnitude of reported value |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| U_RANGE_CA | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | U31 Amplitude range |
| U_INST_A | FLOAT32 | 0.00...4.00 | xUn | UL1 Amplitude, magnitude of instantaneous value |
| U_INST_B | FLOAT32 | 0.00...4.00 | xUn | UL2 Amplitude, magnitude of instantaneous value |
| U_INST_C | FLOAT32 | 0.00...4.00 | xUn | UL3 Amplitude, magnitude of instantaneous value |

### 8.1.5.6 Technical data

*Table 338: VMMXU Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the voltage measured: $f_n$ ±2Hz<br>At voltages in range 0.01…1.15 x $U_n$ |
| | ±0.5% or ±0.002 x $U_n$ |
| Suppression of harmonics | DFT: -50 dB at f = n x $f_n$, where n = 2, 3, 4, 5,…<br>RMS: No suppression |

## 8.1.6 Neutral current RESCMMXU

### 8.1.6.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Neutral current | RESCMMXU | I0 | I0 |

### 8.1.6.2 Function block

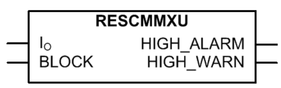



*Figure 210: Function block symbol*

### 8.1.6.3 Signals

*Table 339: RESCMMXU Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $I_0$ | SIGNAL | 0 | Residual current |
| BLOCK | BOOLEAN | 0=False | Block signal for all binary outputs |

*Table 340: RESCMMXU Output signals*

| Name | Type | Description |
|---|---|---|
| HIGH_ALARM | BOOLEAN | High alarm |
| HIGH_WARN | BOOLEAN | High warning |

### 8.1.6.4 Settings

*Table 341: RESCMMXU Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Measurement mode | 1=RMS<br>2=DFT | | | 2=DFT | Selects used measurement mode |
| A Hi high limit res | 0.00...40.00 | xIn | | 0.20 | High alarm current limit |
| A high limit res | 0.00...40.00 | xIn | | 0.05 | High warning current limit |
| A deadband res | 100...100000 | | | 2500 | Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s) |

### 8.1.6.5 Monitored data

*Table 342: RESCMMXU Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| I0-A | FLOAT32 | 0.00...40.00 | xIn | Measured residual current |
| I0_INST | FLOAT32 | 0.00...40.00 | xIn | Residual current Amplitude, magnitude of instantaneous value |
| I0_DB | FLOAT32 | 0.00...40.00 | xIn | Residual current Amplitude, magnitude of reported value |
| I0_RANGE | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | Residual current Amplitude range |

### 8.1.6.6 Technical data

*Table 343: RESCMMXU Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f/f_n$ = ±2Hz |
| | ±0.5% or ±0.002 x $I_n$<br>at currents in the range of 0.01...4.00 x $I_n$ |
| Suppression of harmonics | DFT: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5,…<br>RMS: No suppression |

## 8.1.7 Residual voltage RESVMMXU

### 8.1.7.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Residual voltage | RESVMMXU | U0 | U0 |

### 8.1.7.2 Function block

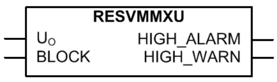



*Figure 211: Function block symbol*

### 8.1.7.3 Signals

*Table 344: RESVMMXU Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| $U_0$ | SIGNAL | 0 | Residual voltage |
| BLOCK | BOOLEAN | 0=False | Block signal for all binary outputs |

*Table 345: RESVMMXU Output signals*

| Name | Type | Description |
|---|---|---|
| HIGH_ALARM | BOOLEAN | High alarm |
| HIGH_WARN | BOOLEAN | High warning |

### 8.1.7.4 Settings

*Table 346: RESVMMXU Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Measurement mode | 1=RMS<br>2=DFT | | | 2=DFT | Selects used measurement mode |
| V Hi high limit res | 0.00...4.00 | xUn | | 0.20 | High alarm voltage limit |
| V high limit res | 0.00...4.00 | xUn | | 0.05 | High warning voltage limit |
| V deadband res | 100...100000 | | | 10000 | Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s) |

### 8.1.7.5 Monitored data

*Table 347: RESVMMXU Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| U0-kV | FLOAT32 | 0.00...4.00 | xUn | Measured residual voltage |
| U0_INST | FLOAT32 | 0.00...4.00 | xUn | Residual voltage Amplitude, magnitude of instantaneous value |
| U0_DB | FLOAT32 | 0.00...4.00 | xUn | Residual voltage Amplitude, magnitude of reported value |
| U0_RANGE | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | Residual voltage Amplitude range |

### 8.1.7.6 Technical data

*Table 348: RESVMMXU Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f/f_n$ = ±2Hz |
| | ±0.5% or ±0.002 x $U_n$ |
| Suppression of harmonics | DFT: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5,…<br>RMS: No suppression |

## 8.1.8 Phase sequence current CSMSQI

### 8.1.8.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Phase sequence current | CSMSQI | I1, I2, I0 | I1, I2, I0 |

### 8.1.8.2 Function block

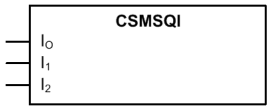



*Figure 212: Function block symbol*

### 8.1.8.3 Signals

*Table 349: 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 |

### 8.1.8.4 Settings

*Table 350: CSMSQI Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Ps Seq A Hi high Lim | 0.00...40.00 | xIn | | 1.40 | High alarm current limit for positive sequence current |
| Ps Seq A high limit | 0.00...40.00 | xIn | | 1.20 | High warning current limit for positive sequence current |
| Ps Seq A low limit | 0.00...40.00 | xIn | | 0.00 | Low warning current limit for positive sequence current |
| Ps Seq A low low Lim | 0.00...40.00 | xIn | | 0.00 | Low alarm current limit for positive sequence current |
| Ps Seq A deadband | 100...100000 | | | 2500 | Deadband configuration value for positive sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s) |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Ng Seq A Hi high Lim | 0.00...40.00 | xIn | | 0.20 | High alarm current limit for negative sequence current |
| Ng Seq A High limit | 0.00...40.00 | xIn | | 0.05 | High warning current limit for negative sequence current |
| Ng Seq A low limit | 0.00...40.00 | xIn | | 0.00 | Low warning current limit for negative sequence current |
| Ng Seq A low low Lim | 0.00...40.00 | xIn | | 0.00 | Low alarm current limit for negative sequence current |
| Ng Seq A deadband | 100...100000 | | | 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 | | 0.20 | High alarm current limit for zero sequence current |
| Zro A High limit | 0.00...40.00 | xIn | | 0.05 | High warning current limit for zero sequence current |
| Zro A low limit | 0.00...40.00 | xIn | | 0.00 | Low warning current limit for zero sequence current |
| Zro A low low Lim | 0.00...40.00 | xIn | | 0.00 | Low alarm current limit for zero sequence current |
| Zro A deadband | 100...100000 | | | 2500 | Deadband configuration value for zero sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s) |

### 8.1.8.5 Monitored data

*Table 351: CSMSQI Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| Ng-Seq-A | FLOAT32 | 0.00...40.00 | xIn | Measured negative sequence current |
| Ps-Seq-A | FLOAT32 | 0.00...40.00 | xIn | Measured positive sequence current |
| Zro-Seq-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_DB | FLOAT32 | 0.00...40.00 | xIn | Negative sequence current amplitude, reported value |
| I2_RANGE | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | Negative sequence current amplitude range |
| I1_INST | FLOAT32 | 0.00...40.00 | xIn | Positive sequence current amplitude, instantaneous value |
| Table continues on next page | | | | |

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| I1_DB | FLOAT32 | 0.00...40.00 | xIn | Positive sequence current amplitude, reported value |
| I1_RANGE | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | Positive sequence current amplitude range |
| I0_INST | FLOAT32 | 0.00...40.00 | xIn | Zero sequence current amplitude, instantaneous value |
| I0_DB | FLOAT32 | 0.00...40.00 | xIn | Zero sequence current amplitude, reported value |
| I0_RANGE | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | Zero sequence current amplitude range |

### 8.1.8.6 Technical data

*Table 352: CSMSQI Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the current measured: $f/f_n$ = ±2Hz |
| | ±1.0% or ±0.002 x $I_n$<br>at currents in the range of 0.01...4.00 x $I_n$ |
| Suppression of harmonics | DFT: -50dB at f = n x $f_n$, where n = 2, 3, 4, 5,… |

## 8.1.9 Phase sequence voltage VSMSQI

### 8.1.9.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Phase sequence voltage | VSMSQI | U1, U2, U0 | U1, U2, U0 |

### 8.1.9.2 Function block

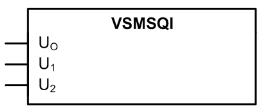



*Figure 213: Function block symbol*

### 8.1.9.3 Signals

*Table 353: 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 |

### 8.1.9.4 Settings

*Table 354: VSMSQI Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Ps Seq V Hi high Lim | 0.00...4.00 | xUn | | 1.40 | High alarm voltage limit for positive sequence voltage |
| Ps Seq V high limit | 0.00...4.00 | xUn | | 1.20 | High warning voltage limit for positive sequence voltage |
| Ps Seq V low limit | 0.00...4.00 | xUn | | 0.00 | Low warning voltage limit for positive sequence voltage |
| Ps Seq V low low Lim | 0.00...4.00 | xUn | | 0.00 | Low alarm voltage limit for positive sequence voltage |
| Ps Seq V deadband | 100...100000 | | | 10000 | Deadband configuration value for positive sequence 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 | | 0.20 | High alarm voltage limit for negative sequence voltage |
| Ng Seq V High limit | 0.00...4.00 | xUn | | 0.05 | High warning voltage limit for negative sequence voltage |
| Ng Seq V low limit | 0.00...4.00 | xUn | | 0.00 | Low warning voltage limit for negative sequence voltage |
| Ng Seq V low low Lim | 0.00...4.00 | xUn | | 0.00 | Low alarm voltage limit for negative sequence voltage |
| Ng Seq V deadband | 100...100000 | | | 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 | | 0.20 | High alarm voltage limit for zero sequence voltage |
| Zro V High limit | 0.00...4.00 | xUn | | 0.05 | High warning voltage limit for zero sequence voltage |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Zro V low limit | 0.00...4.00 | xUn | | 0.00 | Low warning voltage limit for zero sequence voltage |
| Zro V low low Lim | 0.00...4.00 | xUn | | 0.00 | Low alarm voltage limit for zero sequence voltage |
| Zro V deadband | 100...100000 | | | 10000 | Deadband configuration value for zero sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s) |

## 8.1.9.5 Monitored data

*Table 355: VSMSQI Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| Ng-Seq-kV | FLOAT32 | 0.00...4.00 | xUn | Measured negative sequence voltage |
| Ps-Seq-kV | FLOAT32 | 0.00...4.00 | xUn | Measured positive sequence voltage |
| Zro-Seq-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_DB | FLOAT32 | 0.00...4.00 | xUn | Negative sequence voltage amplitude, reported value |
| U2_RANGE | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | Negative sequence voltage amplitude range |
| U1_INST | FLOAT32 | 0.00...4.00 | xUn | Positive sequence voltage amplitude, instantaneous value |
| U1_DB | FLOAT32 | 0.00...4.00 | xUn | Positive sequence voltage amplitude, reported value |
| U1_RANGE | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | Positive sequence voltage amplitude range |
| U0_INST | FLOAT32 | 0.00...4.00 | xUn | Zero sequence voltage amplitude, instantaneous value |
| U0_DB | FLOAT32 | 0.00...4.00 | xUn | Zero sequence voltage amplitude, reported value |
| U0_RANGE | Enum | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low | | Zero sequence voltage amplitude range |

### 8.1.9.6 Technical data

*Table 356: VSMSQI Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | Depending on the frequency of the voltage measured: $f_n$ ±2Hz<br>At voltages in range 0.01…1.15 x $U_n$ |
| | ±1.0% or ±0.002 x $U_n$ |
| Suppression of harmonics | DFT: -50 dB at f = n x $f_n$, where n = 2, 3, 4, 5,… |

## 8.1.10 Three-phase power and energy measurement PEMMXU

### 8.1.10.1 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 |

### 8.1.10.2 Function block

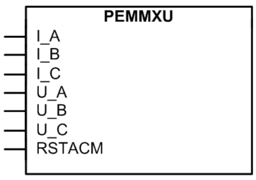



*Figure 214: Function block symbol*

### 8.1.10.3 Signals

*Table 357: 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 |

### 8.1.10.4 Settings

*Table 358: PEMMXU Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Power unit Mult | 3=Kilo<br>6=Mega | | | 3=Kilo | Unit multiplier for presentation of the power related values |
| Energy unit Mult | 3=Kilo<br>6=Mega | | | 3=Kilo | Unit multiplier for presentation of the energy related values |
| Active power Dir | 1=Forward<br>2=Reverse | | | 1=Forward | Direction of active power flow: Forward, Reverse |
| Reactive power Dir | 1=Forward<br>2=Reverse | | | 1=Forward | Direction of reactive power flow: Forward, Reverse |
| 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 WArh Initial | 0...999999999 | | 1 | 0 | Preset Initial value for forward reactive energy |
| Reverse WArh Initial | 0...999999999 | | 1 | 0 | Preset Initial value for reverse reactive energy |

### 8.1.10.5 Monitored data

*Table 359: 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 |
| 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 |
| 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 |
| Q_INST | FLOAT32 | -999999.9...999999.9 | kVAr | Reactive power, magnitude of instantaneous value |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| Q_DB | FLOAT32 | -999999.9...999999.9 | kVAr | Reactive power, magnitude of reported value |
| PF_INST | FLOAT32 | -1.00...1.00 | | Power factor, magnitude of instantaneous value |
| PF_DB | FLOAT32 | -1.00...1.00 | | Power factor, magnitude of reported value |
| EA_RV_ACM | INT128 | 0...999999999 | kWh | Accumulated reverse active energy value |
| ER_RV_ACM | INT128 | 0...999999999 | kVArh | Accumulated reverse reactive energy value |
| EA_FWD_ACM | INT128 | 0...999999999 | kWh | Accumulated forward active energy value |
| ER_FWD_ACM | INT128 | 0...999999999 | kVArh | Accumulated forward reactive energy value |

### 8.1.10.6 Technical data

*Table 360: PEMMXU Technical data*

| Characteristic | Value |
|---|---|
| Operation accuracy | At all three currents in range 0.10…1.20 x $I_n$<br>At all three voltages in range 0.50…1.15 x $U_n$<br>At the frequency $f_n$ ±1Hz<br>Active power and energy in range \|PF\| > 0.71<br>Reactive power and energy in range \|PF\| < 0.71 |
| | ±1.5% for power (S, P and Q)<br>±0.015 for power factor<br>±1.5% for energy |
| Suppression of harmonics | DFT: -50 dB at f = n x $f_n$, where n = 2, 3, 4, 5,… |

# 8.2 Disturbance recorder

## 8.2.1 Functionality

The IED 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 voltage 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 can be set to start a recording on the rising or the falling edge of the binary signal or both.

By default, the binary channels are set to record external or internal IED signals, for example the start or trip signals of the IED stages, or external blocking or control signals. Binary IED signals such as a protection start or trip signal, or an external IED control signal over a binary input can be set to trigger the recording.

The recorded information is stored in a non-volatile 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 IED 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 events through state changes of the *Recording started*, *Recording made* and *Recording stored* status parameters. The *Recording stored* parameter 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. A state change in any of these parameters also generates an event that gives individual information about the reason of the triggering. COMTRADE files provide unambiguous information about the reason of the triggering, usually only for the binary channels but in some cases also for the analog channels.

#### 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.

#### 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.

### 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 361: 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 IED stores COMTRADE files to the `C:\COMTRADE\` folder. The files can be uploaded with the PCM tool 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.

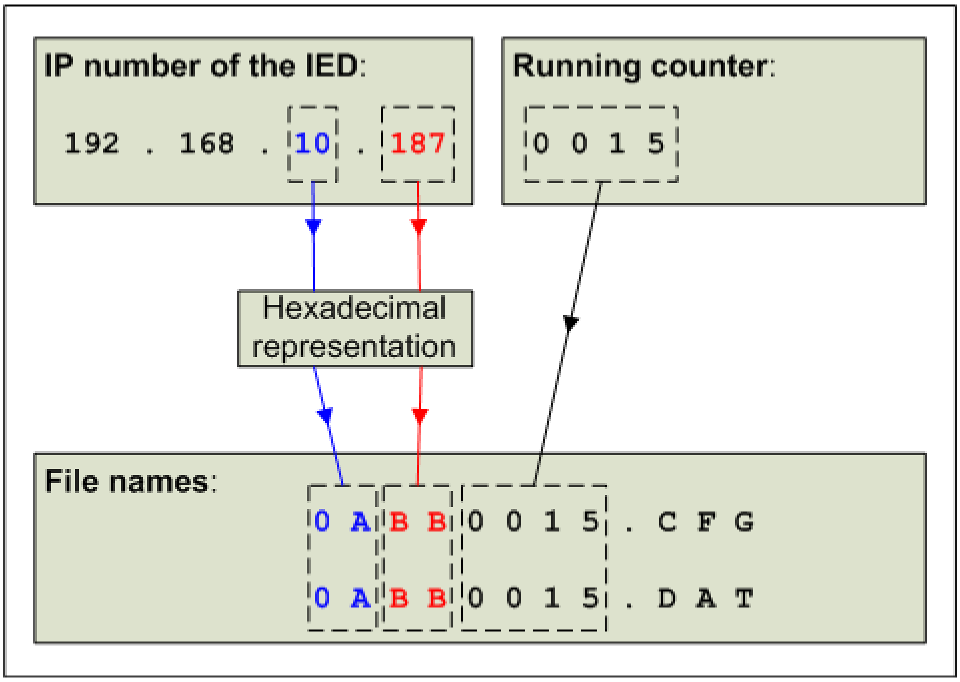



*Figure 215: Disturbance recorder file naming*

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 IED'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 the PCM tool or any appropriate computer software, which can access the IED's `C:\COMTRADE` folder. The disturbance recording is not removed from the IED 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 the PCM tool 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 RMS value is recorded for each enabled analog channel, once per fundamental cycle. 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 of the corresponding analog or binary channel. The *Exclusion time rem* parameter counts downwards.

### 8.2.2 Configuration

The user can configure the disturbance recorder with the PCM600 tool or any tool supporting the IEC 61850 standard.

The user can enable or disable the disturbance recorder with the *Operation* parameter under the **Configuration/Disturbance recorder/General** menu.

One analog signal type of the IED 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. The user can modify it by writing the new name to the *Channel id text* parameter of the corresponding analog channel.

Any external or internal digital signal of the IED 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 IED. The connection is made with dynamic mapping to the binary channel of the disturbance recorder using 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 user can configure the name of the binary channel and modify it 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 a binary channel of the disturbance recorder, the user can set the *Operation* parameter of the corresponding binary channel to the values "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 *Recording started* parameter can be used to control the indication LEDs of the IED. The output of the *Recording started* parameter is TRUE due to the triggering of the disturbance recorder, until all the data for the corresponding recording is recorded.

The IP number of the IED 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 IEDs 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 IED converts the recordings to the COMTRADE format.

COMTRADE is the general standard format used in 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 362: Non-group general settings for disturbance recorder*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>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 |
| Operation mode | 1=Saturation<br>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<br>1=Trend / cycle | | 1 | 0 | Storage mode for periodic triggering |
| Stor. mode manual | 0=Waveform<br>1=Trend / cycle | | 1 | 0 | Storage mode for manual triggering |

*Table 363: Non-group analog channel settings for disturbance recorder*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | 1 | 1=on | Analog channel is enabled or disabled |
| Channel selection | 0=Disabled,<br>1=I0A<br>2=IL1A<br>3=IL2A<br>4=IL3A<br>5=I0B<br>6=IL1B<br>7=IL2B<br>8=IL3B<br>9=U0A<br>10=U1A<br>11=U2A<br>12=U3A<br>13=U0B<br>14=U1B<br>15=U2B<br>16=U3B<br>17=SI0A<br>18=SI1A<br>19=SI2A<br>20=SU0A<br>21=SU1A<br>22=SU2A<br>23=SI0B<br>24=SI1B<br>25=SI2B<br>26=SU0B<br>27=SU1B<br>28=SU2B | | 0 | 0=Disabled | Select the signal to be recorded by this channel |
| 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<br>1=Trend / cycle | | 1 | 0 | Storage mode for the analog channel |

*Table 364: Non-group binary channel settings for disturbance recorder*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | 1 | 5=off | Binary channel is enabled or disabled |
| Level trigger mode | 1=Positive or Rising<br>2=Negative or Falling<br>3=Both<br>4=Level trigger off | | 1 | 1=Rising | Level trigger mode for the binary channel |
| Storage mode | 0=Waveform<br>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 365: Control data for disturbance recorder*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Trig recording | 0=Cancel<br>1=Trig | | | | Trigger the disturbance recording |
| Clear recordings | 0=Cancel<br>1=Clear | | | | Clear all recordings currently in memory |

## 8.2.5 Monitored data

*Table 366: Monitored data for disturbance recorder*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Number of recordings | 0...100 | | | | Number of recordings currently 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 367: RDRE Technical revision history*

| Technical revision | Change |
|---|---|
| B | ChNum changed to EChNum (RADR's).<br>RADR9...12 added (Analog channel 9 -12).<br>RBDR33...64 added (Binary channel 33 - 64). |
| C | Enum update for Channel selection parameters (DR.RADRx.EChNum.setVal)<br>Std. enum changes to Clear and Manual Trig |

# 8.3 Tap position TPOSSLTC

## 8.3.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Tap position | TPOSSLTC | TPOSM | 84M |

## 8.3.2 Function block

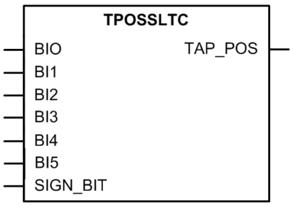



*Figure 216: Function block symbol*

## 8.3.3 Functionality

The binary converter function TPOSSLTC is used for converting binary-coded tap position inputs to their decimal equivalent when a tap position indication is received from the I/O board with the help of the coded binary inputs.

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 tap position indication function can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

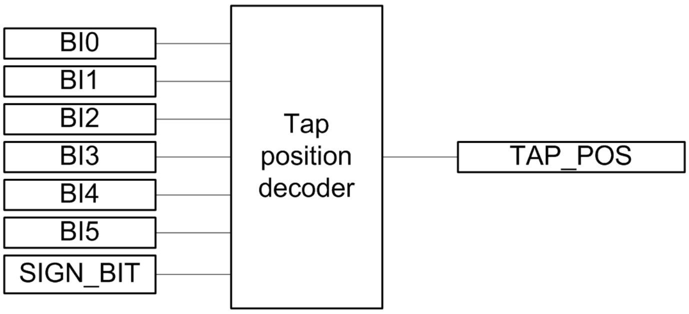



*Figure 217: Functional module diagram*

## Tap position decoder

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...BI10) 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 numbers. This function is based on the common binary-reflected GRAY code, which is used with some tap changers. Changing the bit closest to the right side bit gives a new pattern.

An additional separate input, SIGN_BIT, can be used for negative values. If the values are positive, the input 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 and the TAP_POS output is in this case “9”. 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 and the TAP_POS output is in this case “-19”.

*Table 368: 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 | —3 |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | —2 | —2 | —2 |
| Table continues on next page | | | | | | | | | |

| Inputs | | | | | | | TAP_POS outputs | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 1 | —1 | —1 | —1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 3 |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 3 | 2 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 | 4 | 7 |
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 5 | 5 | 6 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 6 | 6 | 4 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 7 | 7 | 5 |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 8 | 8 | 15 |
| 0 | 0 | 0 | 1 | 0 | 0 | 1 | 9 | 9 | 14 |
| 0 | 0 | 0 | 1 | 0 | 1 | 0 | 10 | 9 | 12 |
| 0 | 0 | 0 | 1 | 0 | 1 | 1 | 11 | 9 | 13 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 12 | 9 | 8 |
| 0 | 0 | 0 | 1 | 1 | 0 | 1 | 13 | 9 | 9 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 14 | 9 | 11 |
| 0 | 0 | 0 | 1 | 1 | 1 | 1 | 15 | 9 | 10 |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 16 | 10 | 31 |
| 0 | 0 | 1 | 0 | 0 | 0 | 1 | 17 | 11 | 30 |
| 0 | 0 | 1 | 0 | 0 | 1 | 0 | 18 | 12 | 28 |
| 0 | 0 | 1 | 0 | 0 | 1 | 1 | 19 | 13 | 29 |
| 0 | 0 | 1 | 0 | 1 | 0 | 0 | 20 | 14 | 24 |
| 0 | 0 | 1 | 0 | 1 | 0 | 1 | 21 | 15 | 25 |
| 0 | 0 | 1 | 0 | 1 | 1 | 0 | 22 | 16 | 27 |
| 0 | 0 | 1 | 0 | 1 | 1 | 1 | 23 | 17 | 26 |
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 24 | 18 | 16 |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | 25 | 19 | 17 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 26 | 19 | 19 |
| 0 | 0 | 1 | 1 | 0 | 1 | 1 | 27 | 19 | 18 |
| 0 | 0 | 1 | 1 | 1 | 0 | 0 | 28 | 19 | 23 |
| 0 | 0 | 1 | 1 | 1 | 0 | 1 | 29 | 19 | 22 |
| 0 | 0 | 1 | 1 | 1 | 1 | 0 | 30 | 19 | 20 |
| 0 | 0 | 1 | 1 | 1 | 1 | 1 | 31 | 19 | 21 |
| 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 |

Table continues on next page

| Inputs | | | | | | | TAP_POS outputs | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 0 | 1 | 1 | 35 | 23 | 61 |
| 0 | 1 | 0 | 0 | 1 | 0 | 0 | 36 | 24 | 56 |
| ... | | ... | | ... | | ... | ... | ... | ... |

## 8.3.5 Application

TPOSSLTC provides tap position information for other functions as a signed integer value that can be fed to the tap position input.

For many applications, for example differential protection algorithms, the position information of the tap changer can be coded in various methods. In this function, the binary inputs in the transformer terminal connector are used as inputs to the function. The user can choose the coding method by setting the mode parameter. The available coding methods are BCD, GRAY and Natural binary coding. Since the number of binary inputs is limited to seven, the coding functions are limited to 7–bit, including the sign bit, and thus the 6 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.

## 8.3.6 Signals

*Table 369: TPOSSLTC 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 |

## 8.3.7 Settings

*Table 370: TPOSSLTC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off / On |
| Operation mode | 1=NAT2INT<br>2=BCD2INT<br>3=GRAY2INT | | | 2=BCD2INT | Operation mode selection |

## 8.3.8 Monitored data

*Table 371: TPOSSLTC Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| TAP_POS | INT8 | -63...63 | | Tap position indication |

## 8.3.9 Technical data

*Table 372: TPOSSLTC Technical data*

| Descrpition | Value |
|---|---|
| Response time | Typical 100 ms |

# Section 9 Control functions

## 9.1 Circuit breaker control CBXCBR

### 9.1.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Circuit breaker control | CBXCBR | I<->0 CB | I<->0 CB |

### 9.1.2 Function block

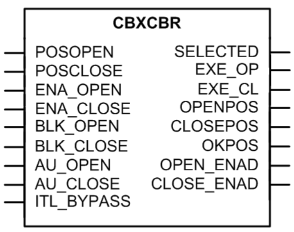



*Figure 218: Function block symbol*

### 9.1.3 Functionality

The circuit breaker control function CBXCBR is intended for circuit breaker control and status information purposes. This function executes commands and evaluates block conditions and different time supervision conditions. The function performs an execution command only if all conditions indicate that a switch operation is allowed. If erroneous conditions occur, the function indicates an appropriate cause value. The function is designed according to the IEC 61850-7-4 standard with logical nodes CILO, CSWI and XCBR.

The circuit breaker control function has an operation counter for closing and opening cycles. The operator can read and write the counter value remotely from an operator place 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 information. 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 circuit breaker contacts occurs after the *Event delay* setting, assuming that the circuit breaker is still in a corresponding state.

*Table 373: Status indication*

| Status (POSITION) | POSOPEN/OPENPOS | POSCLOSE/ CLOSEPOS | OKPOS |
|---|---|---|---|
| 1=Open | 1=True | 0=False | 1=True |
| 2=Closed | 0=False | 1=True | 1=True |
| 3=Faulty/Bad (11) | 1=True | 1=True | 0=False |
| 0=Intermediate (00) | 0=False | 0=False | 0=False |

## Blocking

CBXCBR has a blocking functionality to prevent human errors that can cause serious injuries for the operator and damages for the system components.

The basic principle for all blocking signals is that they affect the commands of other clients: the operator place and protection and auto-reclose functions, for example. The blocking principles are the following:

- Enabling the open command: the function is used to block the operation of the open command. Note that this block signal also affects the `OPEN` input of immediate command.
- Enabling the close command: the function is used to block the operation of the close command. Note that this block signal also affects the `CLOSE` input of immediate command.

The `ITL_BYPASS` input is used if the interlocking functionality needs to be bypassed. When `INT_BYPASS` is TRUE, the circuit breaker control is made possible by discarding the `ENA_OPEN` and `ENA_CLOSE` input states. However, the `BLK_OPEN` and `BLK_CLOSE` input signals are not bypassed with the interlocking bypass functionality since they always have higher priority.

## Open and close operations

The corresponding open and close operations are available via communication, binary inputs or LHMI commands. As a prerequisite for control commands, there are enable and block functionalities for both the close and open commands. If the control command is executed against the blocking, or if the enabling of the corresponding command is not valid, CBXCBR generates an error message.

### Open and close 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 circuit breaker has entered the correct state. When the *Adaptive pulse* is set to FALSE, the function always uses 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 circuit breaker already is in the right position, the maximum pulse length is given. Note that 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 following 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 cancelling: cancels the controlling of a selected object.

In direct operate, a single message is used to initiate the control action of a physical device. The direct operate method uses less communication network capacity and bandwidth than the SBO method, because the procedure needs fewer messages for accurate operation.

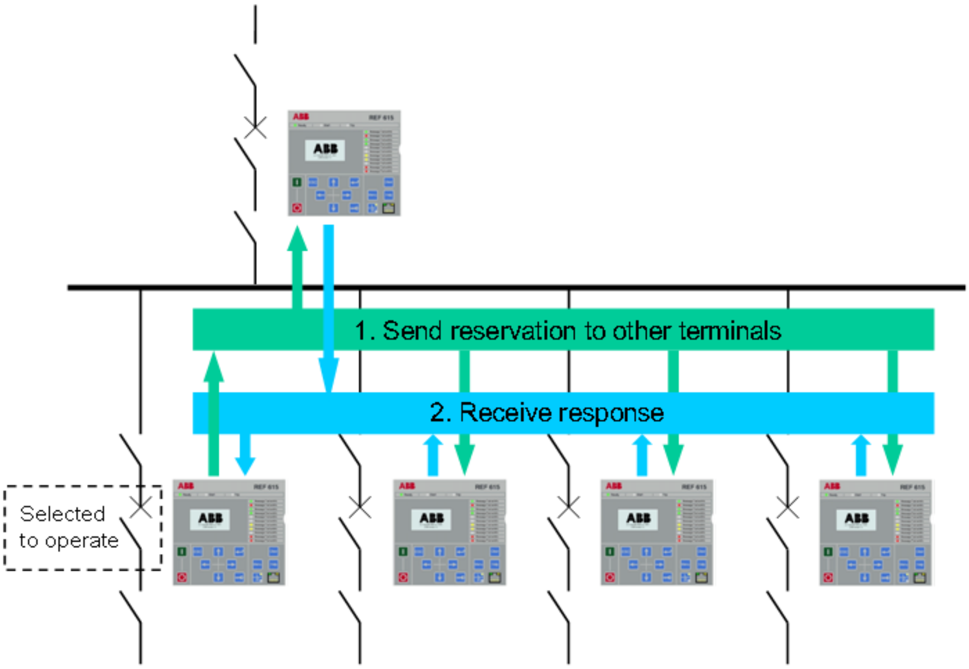



*Figure 219: Control procedure in SBO method*

## 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. When primary components are controlled in the energizing phase, for example, the user must ensure that the control commands are executed in a correct sequence. This can be achieved, for example, with interlocking based on the status indication of the related primary components. An example of how the interlocking on substation level can be applied by using the IEC61850 GOOSE messages between feeders is as follows:

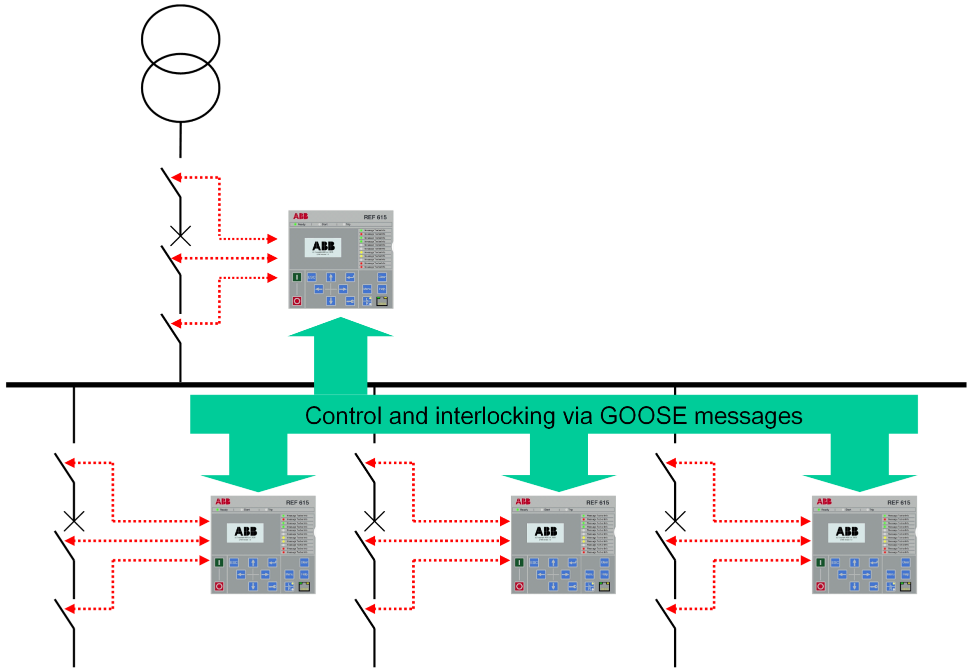



*Figure 220: Status indication based interlocking via GOOSE messaging*

## 9.1.6 Signals

*Table 374: CBXCBR Input signals*

| Name | Type | Default | Description |
|---|---|---|---|
| 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 |
| ITL_BYPASS | BOOLEAN | 0=False | Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE |
| AU_OPEN | BOOLEAN | 0=False | Input signal used to open the breaker[1)] |
| AU_CLOSE | BOOLEAN | 0=False | Input signal used to close the breaker[1)] |
| 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)] |

1) Not available for monitoring

*Table 375: CBXCBR 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 |

Table continues on next page

| Name | Type | Description |
|---|---|---|
| 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 376: CBXCBR Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Select timeout | 10000...300000 | ms | 10000 | 60000 | Select timeout in ms |
| Pulse length | 10...60000 | ms | 1 | 100 | Open and close pulse length |
| Operation | 1=on<br>5=off | | | 1=on | Operation mode on/off/test |
| Operation counter | 0...10000 | | | 0 | Breaker operation cycles |
| Control model | 0=status-only<br>1=direct-with-normal-security<br>4=sbo-with-enhanced-security | | | 4=sbo-with-enhanced-security | Select control model |
| Adaptive pulse | 0=False<br>1=True | | | 1=True | Stop in right position |
| Event delay | 0...10000 | ms | 1 | 100 | Event delay of the intermediate position |
| Operation timeout | 10...60000 | ms | | 500 | Timeout for negative termination |

## 9.1.8 Monitored data

*Table 377: CBXCBR Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| POSITION | Dbpos | 0=intermediate<br>1=open<br>2=closed<br>3=faulty | | Apparatus position indication |

## 9.1.9 Technical revision history

*Table 378: 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. |

# 9.2 Disconnector DCSXSWI and earthing switch ESSXSWI

## 9.2.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Disconnector | DCSXSWI | I<->0 DC | I<->0 DC |
| Earthing switch | ESSXSWI | I<->0 ES | I<->0 ES |

## 9.2.2 Function block

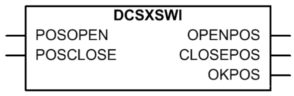



*Figure 221: Function block symbol*

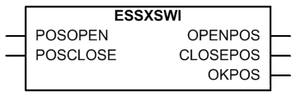



*Figure 222: Function block symbol*

## 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`. 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 379: Status indication*

| State | OPEN | CLOSE |
|---|---|---|
| Open | ON | OFF |
| Close | OFF | ON |
| Bad/Faulty 11 | ON | ON |
| Intermediate 00 | OFF | OFF |

## 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 380: 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)] |

1) Not available for monitoring

*Table 381: 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)] |

1) Not available for monitoring

*Table 382: DCSXSWI Output signals*

| Name | Type | Description |
|---|---|---|
| OPENPOS | BOOLEAN | Apparatus open position |
| CLOSEPOS | BOOLEAN | Apparatus closed position |
| OKPOS | BOOLEAN | Apparatus position is ok |

*Table 383: ESSXSWI Output signals*

| Name | Type | Description |
|---|---|---|
| OPENPOS | BOOLEAN | Apparatus open position |
| CLOSEPOS | BOOLEAN | Apparatus closed position |
| OKPOS | BOOLEAN | Apparatus position is ok |

## 9.2.7 Settings

*Table 384: DCSXSWI Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Event delay | 0...10000 | ms | 1 | 100 | Event delay of the intermediate position |

*Table 385: ESSXSWI Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Event delay | 0...10000 | ms | 1 | 100 | Event delay of the intermediate position |

## 9.2.8 Monitored data

*Table 386: DCSXSWI Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| POSITION | Dbpos | 0=intermediate<br>1=open<br>2=closed<br>3=faulty | | Apparatus position indication |

*Table 387: ESSXSWI Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| POSITION | Dbpos | 0=intermediate<br>1=open<br>2=closed<br>3=faulty | | Apparatus position indication |

# 9.3 Auto-recloser DARREC

## 9.3.1 Identification

| Function description | IEC 61850 logical node name | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|---|---|---|
| Auto-recloser | DARREC | O-->I | 79 |

## 9.3.2 Function block

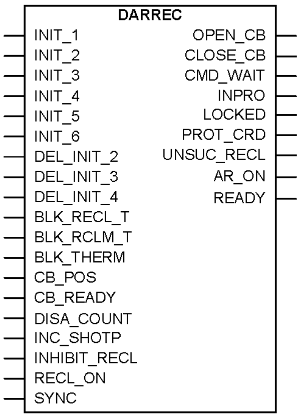



*Figure 223: Function block symbol*

## 9.3.3 Functionality

About 80 to 85 percent of faults in the MV overhead lines are transient and automatically cleared with a momentary de-energization of the line. The rest of the faults, 15 to 20 percent, can be cleared by longer interruptions. The de-energization of the fault location for a selected time period is implemented through automatic reclosing, during which most of the faults can be cleared.

In case of a permanent fault, the automatic reclosing is followed by final tripping. A permanent fault must be located and cleared before the fault location can be re-energized.

The auto-reclose function (AR) can be used with any circuit breaker suitable for auto-reclosing. The function provides five programmable auto-reclose shots which can perform one to five successive auto-reclosings of desired type and duration, for instance one high-speed and one delayed auto-reclosing.

When the reclosing is initiated with starting of the protection function, the auto-reclose function can execute the final trip of the circuit breaker in a short operate time, provided that the fault still persists when the last selected reclosing has been carried out.

### 9.3.3.1 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 388: 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).

### 9.3.3.2 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.

### 9.3.3.3 Master and slave scheme

With the co-operation between the AR units in the same relay or between relays, the user can achieve sequential reclosings of two breakers at a line end in a 1½-breaker, double breaker or ring-bus arrangement. 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.

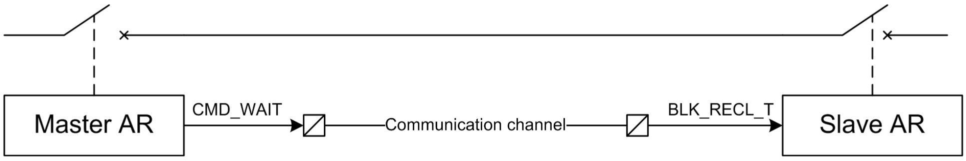



*Figure 224: Master and slave scheme*

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 auto-reclose shot.

If the terminal priority of the AR unit is set to "none", the AR unit skips all these actions.

#### 9.3.3.4 Thermal overload blocking

An alarm or start signal from the thermal overload protection (T1PTTR) can be routed to the input BLK_THERM to block and hold the reclose sequence. The BLK_THERM signal does not affect the starting of the sequence. When the reclose time has elapsed and the BLK_THERM input is active, the shot is not ready until the BLK_THERM input deactivates. Should the BLK_THERM input remain active longer than the time set by the setting *Max block time*, the AR function goes to lockout.

If the BLK_THERM input is activated when the auto wait timer is running, the auto wait timer is reset and the timer restarted when the BLK_THERM input deactivates.

### 9.3.4 Operation principle

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

The reclosing operation can be enabled and disabled with the *Reclosing operation* setting. This setting does not disable the function, only the reclosing functionality. The setting has three parameter values: “On”, “External Ctl” and ”Off”. The setting value “On” enables the reclosing operation and “Off” disables it. When the setting value “External Ctl” is selected, the reclosing operation is controlled with the RECL_ON input .

The operation of the auto-reclose function can be described by using a module diagram. All the blocks in the diagram are explained in the next sections.

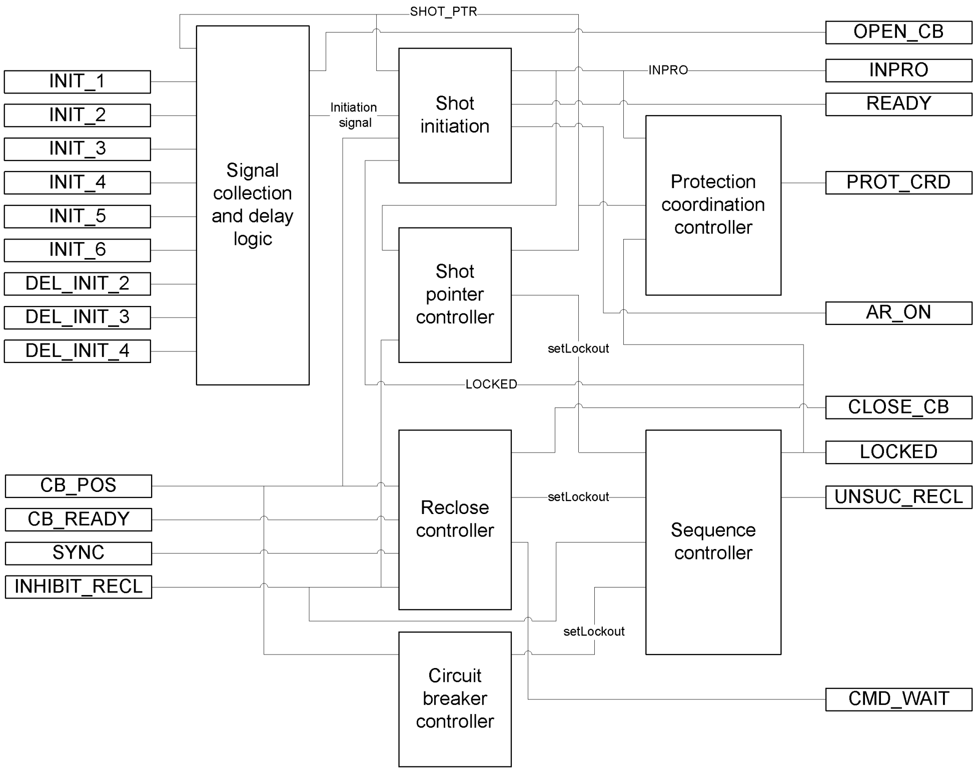



*Figure 225: Functional module diagram*

## 9.3.4.1 Signal collection and delay logic

When the protection trips, the initiation of auto-reclose shots is in most applications executed with the INIT_1...6 inputs. The DEL_INIT2...4 inputs are not used. In some countries, starting the protection stage is also used for the shot initiation. This is the only time when the DEL_INIT inputs are used.

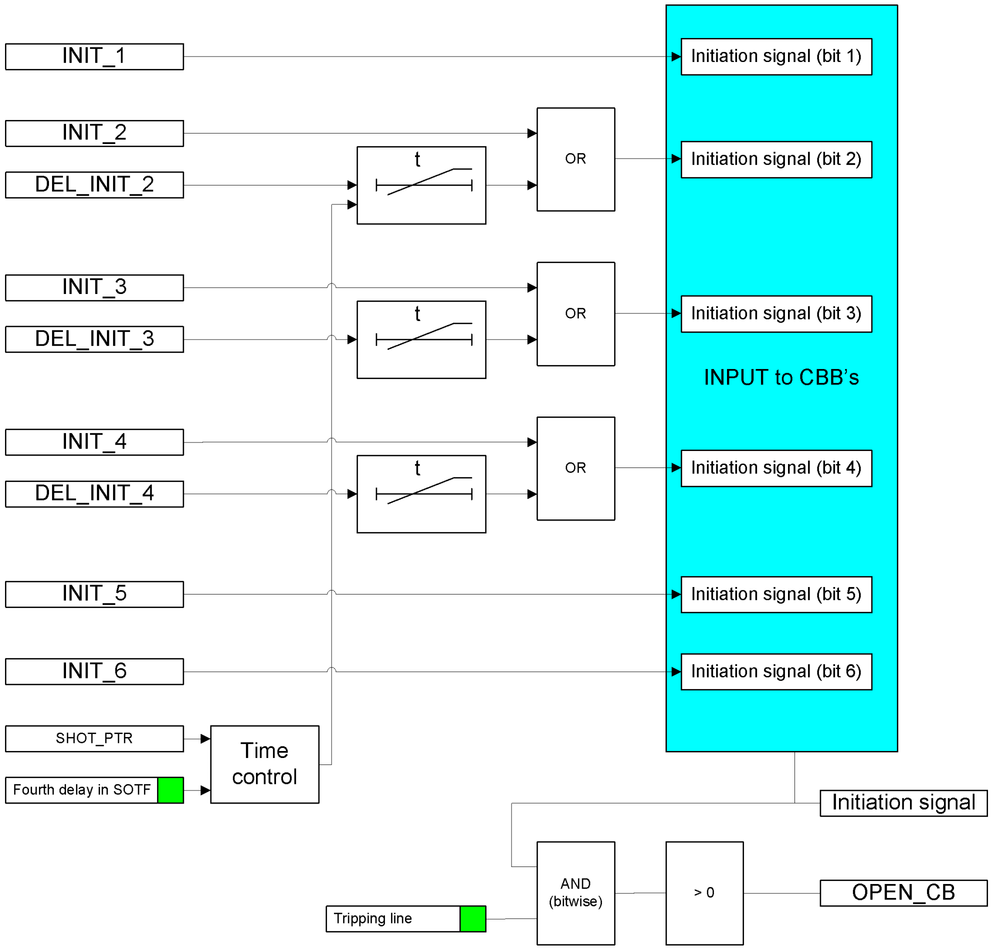



*Figure 226: Schematic diagram of delayed initiation input signals*

In total, the AR function contains six separate initiation lines used for the initiation or blocking of the auto-reclose shots. These lines are divided into two types of channels. In three of these channels, the signal to the AR function can be delayed, whereas the other three channels do not have any delaying capability.

Each channel that is capable of delaying a start signal has four time delays. The time delay is selected based on the shot pointer in the AR function. For the first reclose attempt, the first time delay is selected; for the second attempt, the second time delay and so on. For the fourth and fifth attempts, the time delays are the same.

Time delay settings for the `DEL_INIT_2` signal are as follows:

- *Str 2 delay shot 1*
- *Str 2 delay shot 2*
- *Str 2 delay shot 3*
- *Str 2 delay shot 4*

Time delay settings for the `DEL_INIT_3` signal are as follows:

- *Str 3 delay shot 1*
- *Str 3 delay shot 2*
- *Str 3 delay shot 3*
- *Str 3 delay shot 4*

Time delay settings for the `DEL_INIT_4` signal are as follows:

- *Str 4 delay shot 1*
- *Str 4 delay shot 2*
- *Str 4 delay shot 3*
- *Str 4 delay shot 4*

Normally, only two or three reclose attempts are made. The third and fourth times are used to provide the so called fast final trip to lockout.

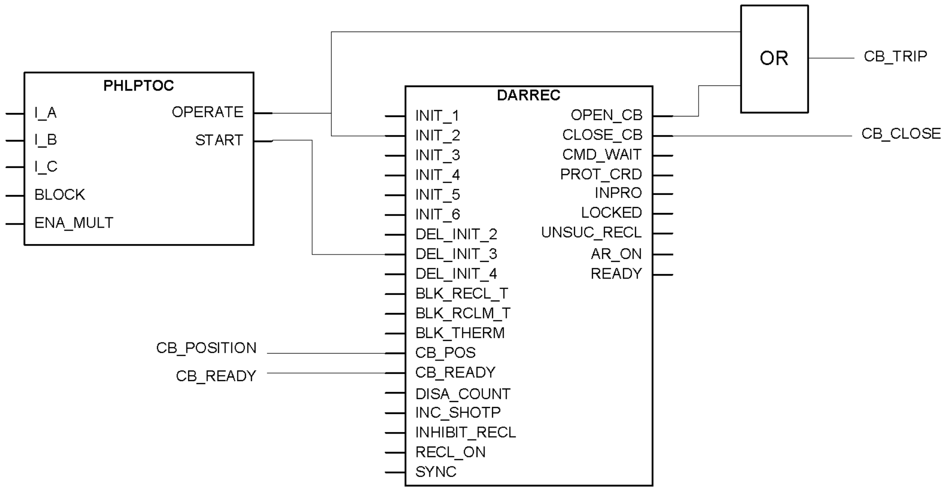



*Figure 227: Auto-reclose configuration example*

Delayed `DEL_INIT_2...4` signals are used only when the auto-reclose shot is initiated with the start signal of a protection stage. After a start delay, the AR function opens the circuit breaker and an auto-reclose shot is initiated. When the shot is initiated with the trip signal of the protection, the protection function trips the circuit breaker and simultaneously initiates the auto-reclose shot.

If the circuit breaker is manually closed against the fault, that is, if SOTF is used, the fourth time delay can automatically be taken into use. This is controlled with the internal logic of the AR function and the *Fourth delay in SOTF* parameter.

A typical auto-reclose situation is where one auto-reclose shot has been performed after the fault was detected. There are two types of such cases: operation initiated with protection start signal and operation initiated with protection trip signal. In both cases, the auto-reclose sequence is successful: the reclaim time elapses and no new sequence is started.

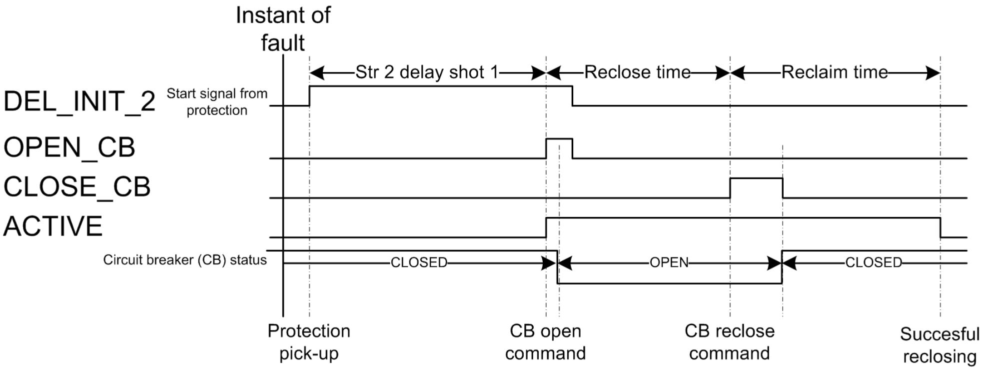



*Figure 228: Signal scheme of auto-reclose operation initiated with protection start signal*

The auto-reclose shot is initiated with a start signal of the protection function after the start delay time has elapsed. The auto-reclose starts when the *Str 2 delay shot 1* setting elapses.

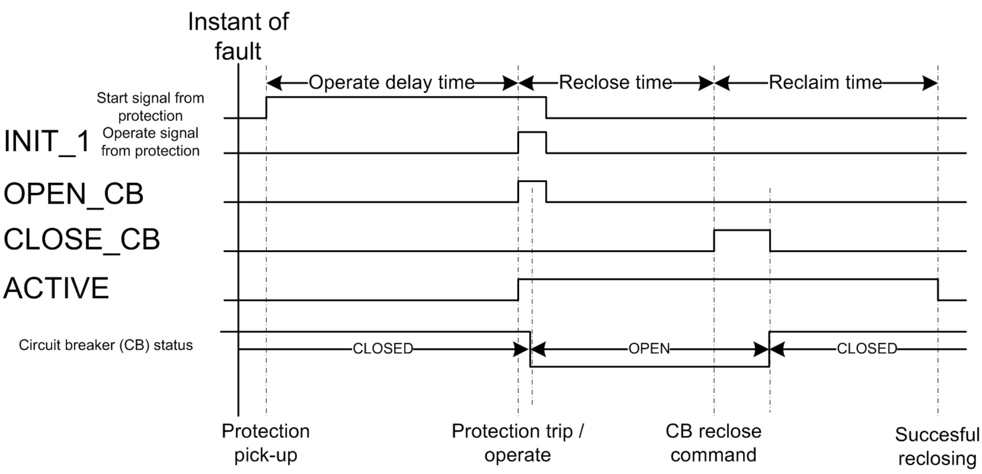



*Figure 229: Signal scheme of auto-reclose operation initiated with protection operate signal*

The auto-reclose shot is initiated with a trip signal of the protection function. The auto-reclose starts when the protection operate delay time elapses.

Normally, all trip and start signals are used to initiate an auto-reclose shot and trip the circuit breaker. If any of the input signals `INIT_X` or `DEL_INIT_X` are used for blocking, the corresponding bit in the *Tripping line* setting must be FALSE. This is to ensure that the circuit breaker does not trip from that signal, that is, the signal does not activate the `OPEN_CB` output. The default value for the setting is "63", which means that all initiation signals activate the `OPEN_CB` output. The lowest bit in the *Tripping line* setting corresponds to the `INIT_1` input, the highest bit to the `INIT_6` line.

### 9.3.4.2 Shot initiation

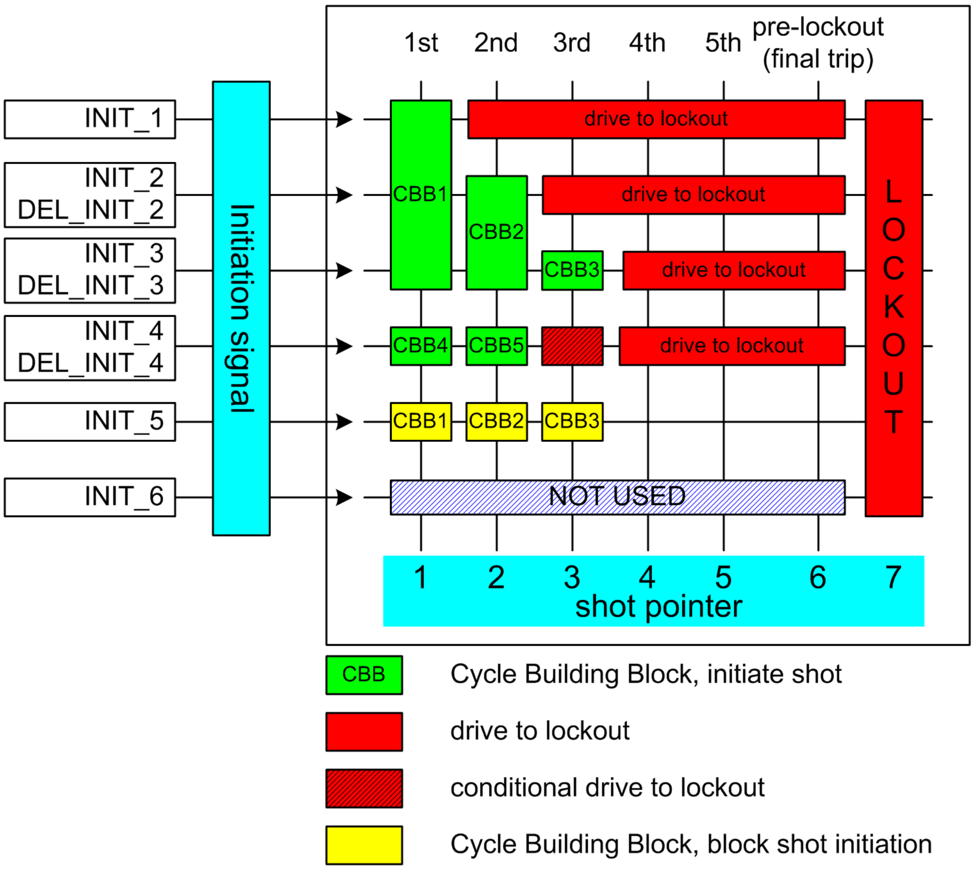



*Figure 230: Example of an auto-reclose program with a reclose scheme matrix*

In the AR function, each shot can be programmed to locate anywhere in the reclose scheme matrix. The shots are like building blocks used to design the reclose program. The building blocks are called CBBs. All blocks are alike and have settings which give the attempt number (columns in the matrix), the initiation or blocking signals (rows in the matrix) and the reclose time of the shot.

The settings related to CBB configuration are:

- *First...Seventh reclose time*
- *Init signals CBB1…CBB7*
- *Blk signals CBB1…CBB7*
- *Shot number CBB1…CBB7*

The reclose time defines the open and dead times, that is, the time between the `OPEN_CB` and the `CLOSE_CB` commands. The *Init signals CBBx* setting defines the initiation signals. The *Blk signals CBBx* setting defines the blocking signals that are related to the CBB (rows in the matrix). The *Shot number CBB1…CBB7* setting defines which shot is related to the CBB (columns in the matrix). For example, CBB1 settings are:

- *First reclose time* = 1.0s
- *Init signals CBB1* = 7 (three lowest bits: 111000 = 7)
- *Blk signals CBB1* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB1* = 1

CBB2 settings are:

- *Second reclose time* = 10s
- *Init signals CBB2* = 6 (the second and third bits: 011000 = 6)
- *Blk signals CBB2* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB2* = 2

CBB3 settings are:

- *Third reclose time* = 30s
- *Init signals CBB3* = 4 (the third bit: 001000 = 4)
- *Blk signals CBB3* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB3* = 3

CBB4 settings are:

- *Fourth reclose time* = 0.5s
- *Init signals CBB4* = 8 (the fourth bit: 000100 = 8)
- *Blk signals CBB4* = 0 (no blocking signals related to this CBB)
- *Shot number CBB4* = 1

If a shot is initiated from the `INIT_1` line, only one shot is allowed before lockout. If a shot is initiated from the `INIT_3` line, three shots are allowed before lockout.

A sequence initiation from the `INIT_4` line leads to a lockout after two shots. In a situation where the initiation is made from both the `INIT_3` and `INIT_4` lines, a third shot is allowed, that is, CBB3 is allowed to start. This is called conditional lockout. If the initiation is made from the `INIT_2` and `INIT_3` lines, an immediate lockout occurs.

The `INIT_5` line is used for blocking purposes. If the `INIT_5` line is active during a sequence start, the reclose attempt is blocked and the AR function goes to lockout.

If more than one CBBs are started with the shot pointer, the CBB with the smallest individual number is always selected. For example, if the `INIT_2` and `INIT_4` lines are active for the second shot, that is, the shot pointer is 2, CBB2 is started instead of CBB5.

Even if the initiation signals are not received from the protection functions, the AR function can be set to continue from the second to the fifth reclose shot. The AR function can, for example, be requested to automatically continue with the sequence when the circuit breaker fails to close when requested. In such a case, the AR function issues a CLOSE_CB command. When the wait close time elapses, that is, the closing of the circuit breaker fails, the next shot is automatically started. Another example is the embedded generation on the power line, which can make the synchronism check fail and prevent the reclosing. If the auto-reclose sequence is continued to the second shot, a successful synchronous reclosing is more likely than with the first shot, since the second shot lasts longer than the first one.

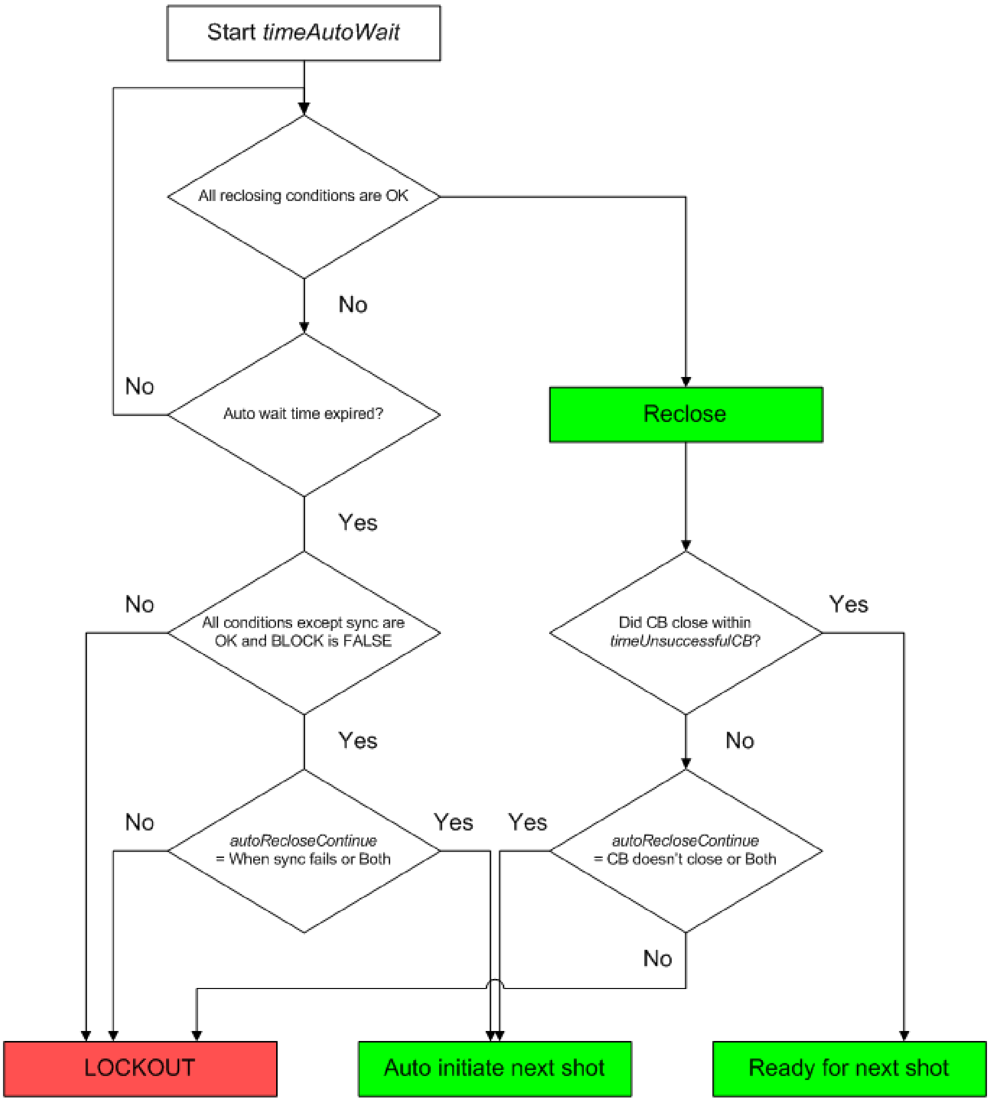



*Figure 231: Logic diagram of auto-initiation sequence detection*

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.

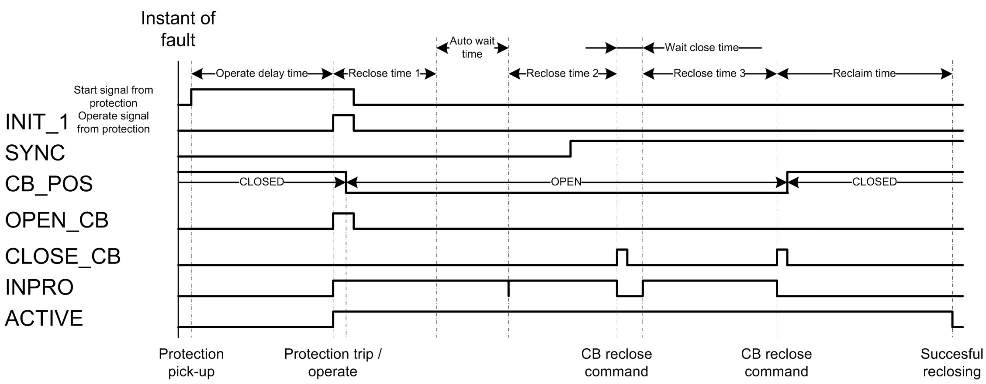



*Figure 232: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot*

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.

### 9.3.4.3 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.

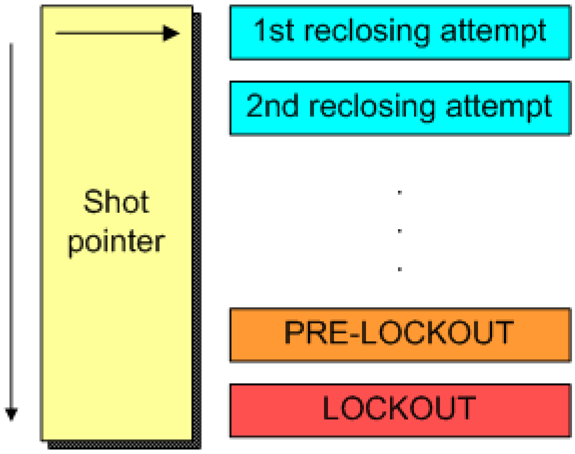



*Figure 233: Shot pointer function*

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.

### 9.3.4.4 Reclose controller

The reclose controller calculates the reclose, discrimination and reclaim times. The reclose time is started when the `INPRO` signal is activated, that is, when the sequence starts and the activated CBB defines the reclose time.

When the reclose time has elapsed, the `CLOSE_CB` output is not activated until the following conditions are fulfilled:

- The SYNC input must be TRUE if the particular CBB requires information about the synchronism
- All AR initiation inputs that are defined protection lines (using the *Control line* setting) are inactive
- The circuit breaker is open
- The circuit breaker is ready for the close command, that is, the CB_READY input is TRUE.

If at least one of the conditions is not fulfilled within the time set with the *Auto wait time* parameter, the auto-reclose sequence is locked.

The synchronism requirement for the CBBs can be defined with the *Synchronisation set* setting, which is a bit mask. The lowest bit in the *Synchronisation set* setting is related to CBB1 and the highest bit to CBB7. For example, if the setting is set to "1", only CBB1 requires synchronism. If the setting is it set to "7", CBB1, CBB2 and CBB3 require the SYNC input to be TRUE before the reclosing command can be given.

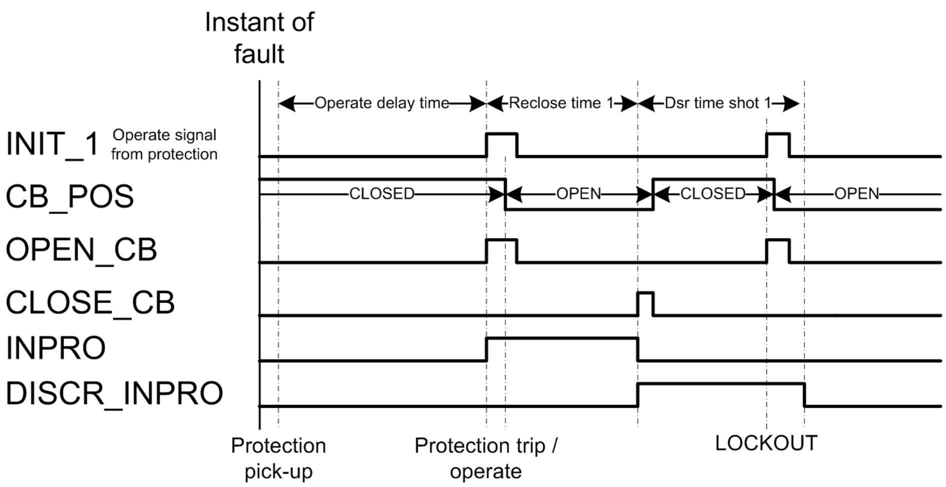



*Figure 234: Initiation during discrimination time - AR function goes to lockout*

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.

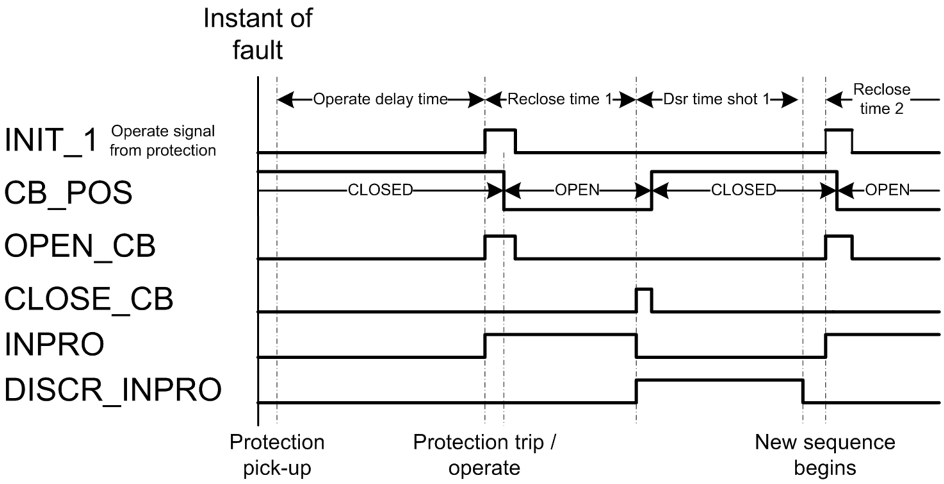



*Figure 235: Initiation after elapsed discrimination time - new shot begins*

### 9.3.4.5 Sequence controller

When the LOCKED output is active, the AR function is in lockout. This means that new sequences cannot be initialized, because AR is insensitive to initiation commands. It can be released from the lockout state in the following ways:

- The function is reset through communication with the *RsRec* parameter
- The lockout is automatically reset after the reclaim time, if the *Auto lockout reset* setting is in use.

If the *Auto lockout reset* setting is not in use, the lockout can be released only with the *RsRec* parameter.

The AR function can go to lockout for many reasons:

- The INHIBIT_RECL input is active
- All shots have been executed and a new initiation is made (final trip)
- The time set with the *Auto wait time* parameter expires and the automatic sequence initiation is not allowed because of a synchronization failure
- The time set with the *Wait close time* parameter expires, that is, the circuit breaker does not close or the automatic sequence initiation is not allowed due to a closing failure of the circuit breaker
- A new shot is initiated during the discrimination time
- The time set with the *Max wait time* parameter expires, that is, the master unit does not release the slave unit

- The frequent operation counter limit is reached and new sequence is initiated. The lockout is released when the recovery timer elapses
- The protection trip signal has been active longer than the time set with the *Max wait time* parameter since the shot initiation
- The circuit breaker is closed manually during an auto-reclose sequence and the manual close mode is FALSE.

### 9.3.4.6 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

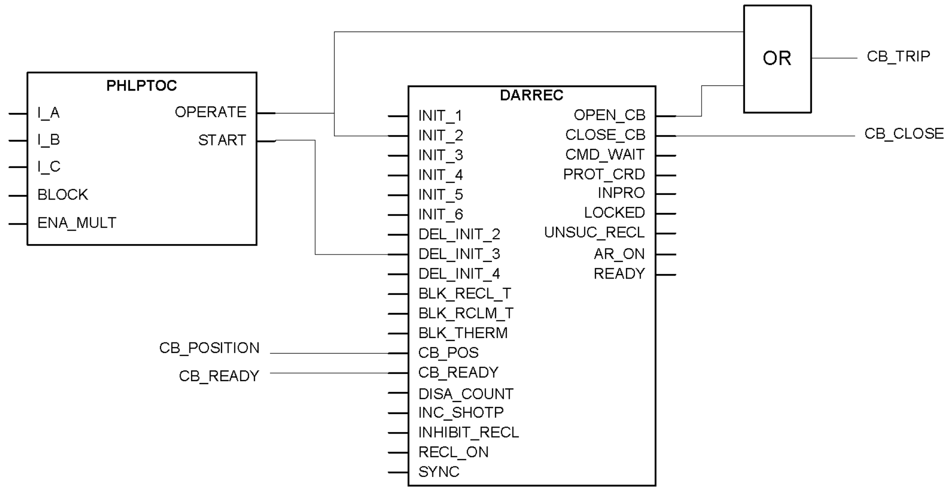



*Figure 236: Configuration example of using the* `PROT_CRD` *output for protection blocking*

If the *Protection crd limit* setting has the value "1", the instantaneous three-phase over-current protection function PHIPTOC is disabled or blocked after the first shot.

### 9.3.4.7 Circuit breaker controller

Circuit breaker controller contains two features: SOTF and frequent-operation counter. SOTF protects the AR function in permanent faults.

The circuit breaker position information is controlled with the *CB closed Pos status* setting. The setting value "TRUE" means that when the circuit breaker is closed, the `CB_POS` input is TRUE. When the setting value is "FALSE", the `CB_POS` input is FALSE, provided that the circuit breaker is closed. The reclose command pulse time can be controlled with the *Close pulse time* setting: the `CLOSE_CB` output is active for the time set with the *Close pulse time* setting. The `CLOSE_CB` output is deactivated also when the circuit breaker is detected to be closed, that is, when the `CB_POS` input changes from open state to closed state. The *Wait close time* setting defines the time after the `CLOSE_CB` command activation, during which the circuit breaker should be closed. If the closing of circuit breaker does not happen during this time, the auto-reclose function is driven to lockout or, if allowed, an auto-initiation is activated.

The main motivation for auto-reclosing to begin with is the assumption that the fault is temporary by nature, and that a momentary de-energizing of the power line and an automatic reclosing restores the power supply. However, when the power line is manually energized and an immediate protection trip is detected, it is very likely that the fault is of a permanent type. An example of a permanent fault is, for example, energizing a power line into a forgotten earthing after a maintenance work along the power line. In such cases, SOTF is activated, but only for the reclaim time after energizing the power line and only when the circuit breaker is closed manually and not by the AR function.

SOTF disables any initiation of an auto-reclose shot. The energizing of the power line is detected from the CB_POS information.

SOTF is activated when the AR function is enabled or when the AR function is started and the SOTF should remain active for the reclaim time.

When SOTF is detected, the parameter *SOTF* is active.

If the *Manual close mode* setting is set to FALSE and the circuit breaker has been manually closed during an auto-reclose shot, the AR unit goes to an immediate lockout.

If the *Manual close mode* setting is set to TRUE and the circuit breaker has been manually closed during an auto-reclose shot (the INPRO is active), the shot is considered as completed.

When SOTF starts, reclaim time is restarted, provided that it is running.

The frequent-operation counter is intended for blocking the auto-reclose function in cases where the fault causes repetitive auto-reclose sequences during a short period of time. For instance, if a tree causes a short circuit and, as a result, there are auto-reclose shots within a few minutes interval during a stormy night. These types of faults can easily damage the circuit breaker if the AR function is not locked by a frequent-operation counter.

The frequent-operation counter has three settings:

- *Frq Op counter limit*
- *Frq Op counter time*
- *Frq Op recovery time*

The *Frq Op counter limit* setting defines the number of reclose attempts that are allowed during the time defined with the *Frq Op counter time* setting. If the set value is reached within a pre-defined period defined with the *Frq Op counter time* setting, the AR function goes to lockout when a new shot begins, provided that the counter is still above the set limit. The lockout is released after the recovery time has elapsed. The recovery time can be defined with the *Frq Op recovery time* setting .

If the circuit breaker is manually closed during the recovery time, the reclaim time is activated after the recovery timer has elapsed.

## 9.3.5 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 reclose command. The counters count the following situations:

- COUNTER: counts every reclose command activation
- CNT_SHOT1: counts reclose commands that are executed from shot 1
- CNT_SHOT2: counts reclose commands that are executed from shot 2
- CNT_SHOT3: counts reclose commands that are executed from shot 3
- CNT_SHOT4: counts reclose commands that are executed from shot 4
- CNT_SHOT5: counts reclose commands that are executed from shot 5

The counters are disabled through communication with the *DsaCnt* parameter. When the counters are disabled, the values are not updated.

The counters are reset through communication with the *RsCnt* parameter.

## 9.3.6 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, auto-reclose shots are allowed. If none of the trials is successful and the fault persists, definite final tripping follows.

The auto-reclose function can be used with every circuit breaker that has the ability for a reclosing sequence. In DARREC auto-reclose function the implementing method of auto-reclose sequences is patented by ABB

*Table 389: Important definitions related to auto-reclosing*

| | |
|---|---|
| auto-reclose shot | an operation where after a preset time the breaker is closed from the breaker tripping caused by protection |
| auto-reclose sequence | a predefined method to do reclose attempts (shots) to restore the power system |
| SOTF | If the protection detects a fault immediately after an open circuit breaker has been closed, it indicates that the fault was already there. It can be, for example, a forgotten earthing after maintenance work. Such closing of the circuit breaker is known as switch on to fault. Autoreclosing in such conditions is prohibited. |
| final trip | Occurs in case of a permanent fault, when the circuit breaker is opened for the last time after all programmed auto-reclose operations. Since no auto-reclosing follows, the circuit breaker remains open. This is called final trip or definite trip. |

### 9.3.6.1 Shot initiation

In some applications, the `START` signal is used for initiating or blocking autoreclose shots, in other applications the `OPERATE` command is needed. In its simplest, the auto-reclose function is initiated after the protection has detected a fault, issued a trip and opened the breaker. One input is enough for initiating the function.

The function consists of six individual initiation lines `INIT_1, INIT_2 .. INIT_6` and delayed initiation lines `DEL_INIT_x`. The user can use as many of the initiation lines as required. Using only one line makes setting easier, whereas by using multiple lines, higher functionality can be achieved. Basically, there are no differences between the initiation lines, except that the lines 2, 3 and 4 have the delayed initiation `DEL_INIT` inputs, and lines 1, 5 and 6 do not.

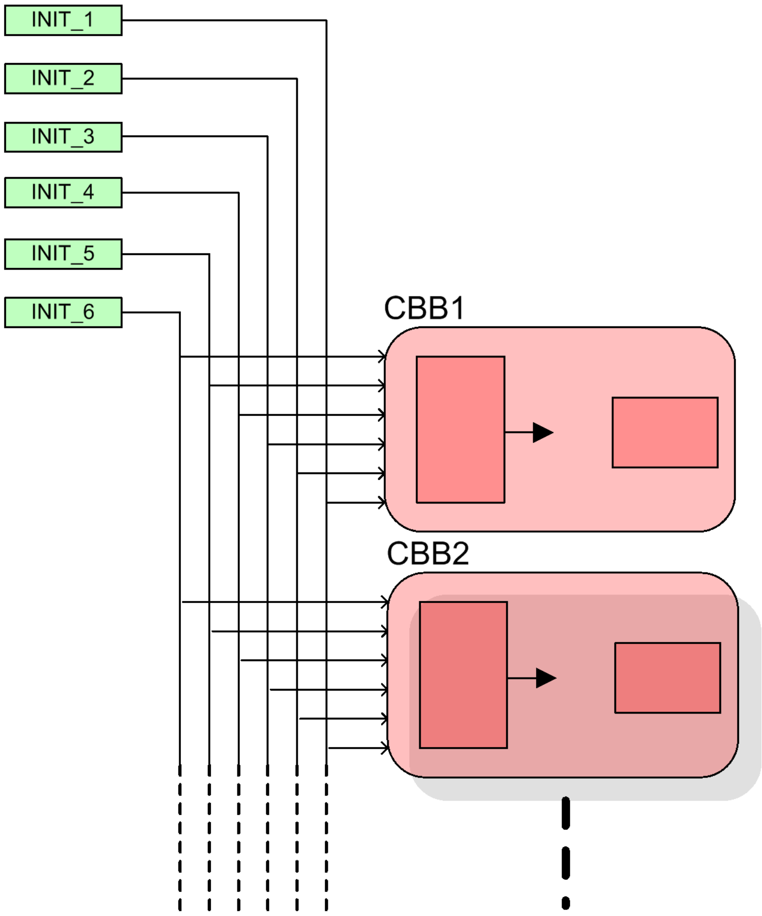



*Figure 237: Simplified CBB initiation diagram*

| | |
|---|---|
| `INIT_1...6` | initiation lines |
| CBB1...CBB2 | first two cycle building blocks |

The operation of a CBB consists of two parts: initiation and execution. In the initiation part, the status of the initiation lines is compared to the CBB settings. In order to allow the initiation at any of the initiation line activation, the corresponding switch in the *Init signals CBB_* parameter must be set to TRUE. In order to block the initiation, the corresponding switch in the *Blk signals CBB_* parameter must be set to TRUE.

If any of the initiation lines set with the *Init signals CBB_* parameter is active and no initiation line causes blocking, the CBB requests for execution.

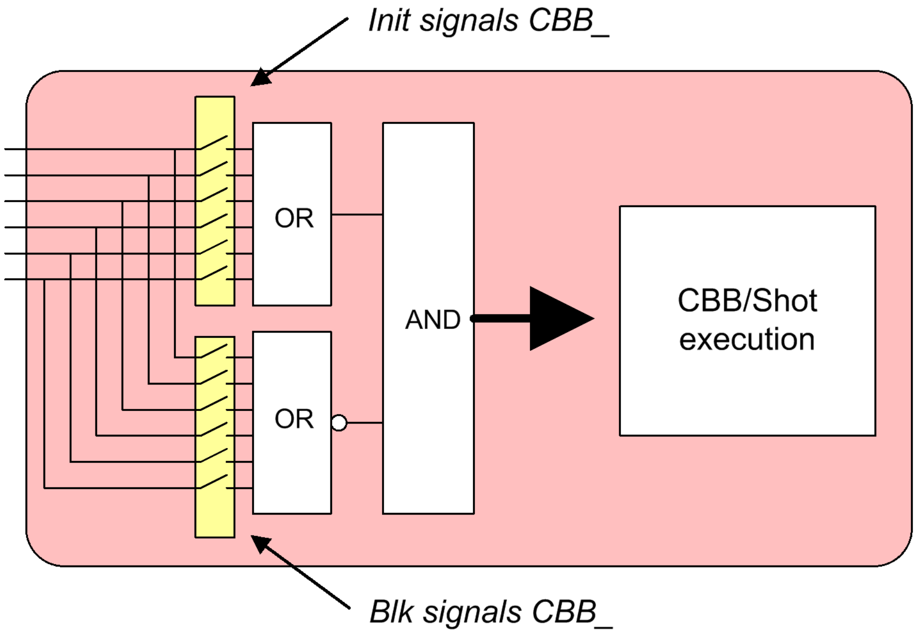



*Figure 238: Simplified CBB diagram*

Each CBB has individual *Init signals CBB_* and *Blk signals CBB_* settings. Therefore, each initiation line can be used for both initiating and blocking any or all auto-reclose shots.

Other conditions that must be fulfilled before any CBB can be initiated are, for example, the closed position of the circuit breaker.

### 9.3.6.2 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.

### 9.3.6.3 Configuration examples

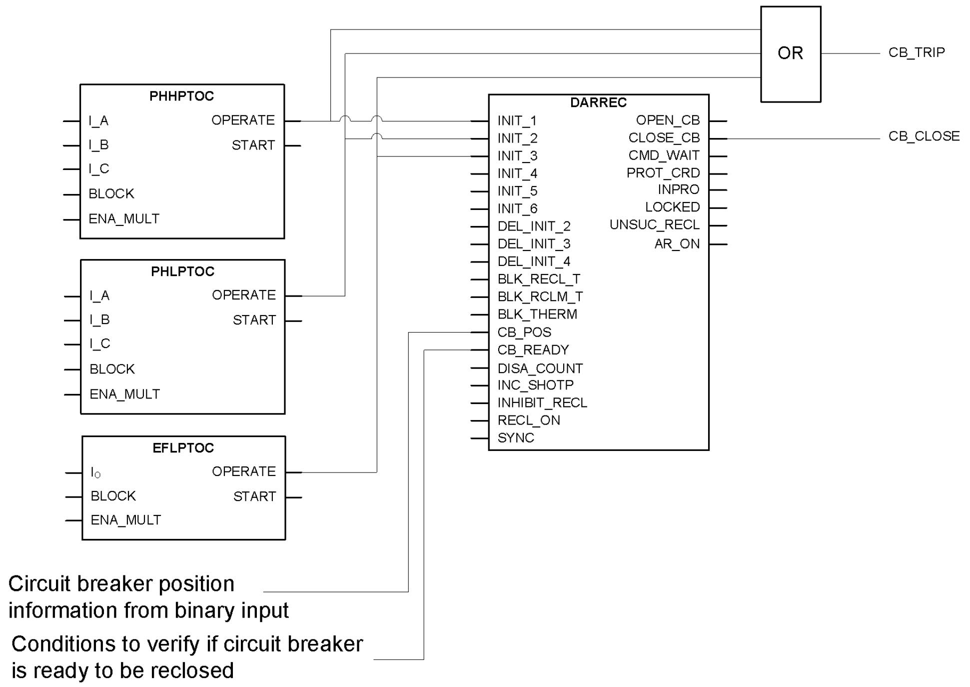



*Figure 239: Example connection between protection and auto-reclose functions in IED configuration*

It is possible to create several sequences for a configuration.

Auto-reclose sequences for overcurrent and non-directional earth-fault protection applications where high speed and delayed auto-reclosings are needed can be as follows:

### Example 1.

The sequence is implemented by two shots which have the same reclose time for all protection functions, namely I>>, I> and $I_0$>. The initiation of the shots is done by activating the operate signals of the protection functions.

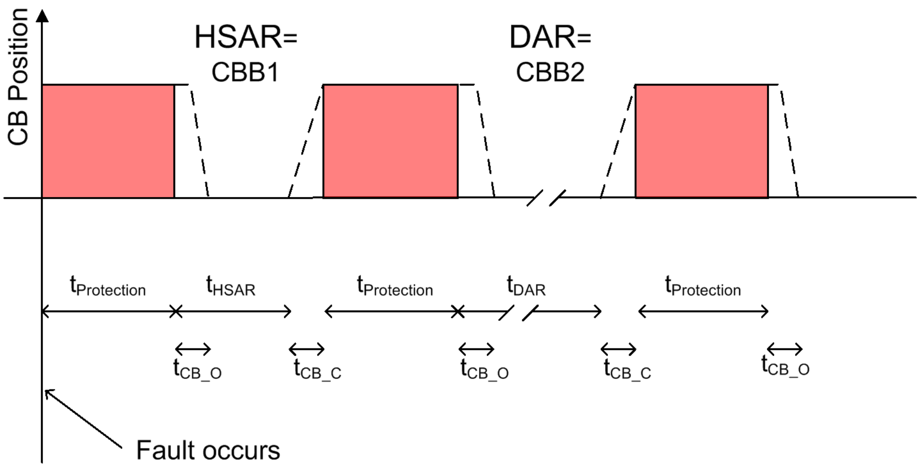



*Figure 240: Auto-reclose sequence with two shots*

| | |
|---|---|
| $t_{HSAR}$ | Time delay of high-speed auto-reclosing, here: *First reclose time* |
| $t_{DAR}$ | Time delay of delayed auto-reclosing, here: *Second reclose time* |
| $t_{Protection}$ | Operating time for the protection stage to clear the fault |
| $t_{CB\_O}$ | Operating time for opening the circuit breaker |
| $t_{CB\_C}$ | Operating time for closing the circuit breaker |

In this case, the sequence needs two CBBs. The reclosing times for shot 1 and shot 2 are different, but each protection function initiates the same sequence. The CBB sequence is as follows:

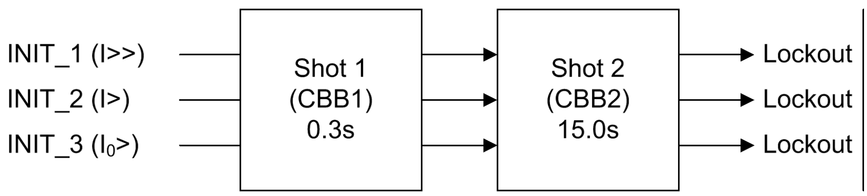



*Figure 241: Two shots with three initiation lines*

*Table 390: 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 auto-reclosing with a short time delay. Shot 2 is implemented with CBB2 and meant to be the first shot of the auto-reclose sequence initiated by the low stage of the overcurrent protection (I>) and the low stage of the non-directional earth-fault protection ($I_o$>). It has the same reclose time in both situations. It is set as a high-speed auto-reclosing for corresponding faults. The third shot, which is the second shot in the auto-reclose sequence initiated by I> or $I_o$>, is set as a delayed auto-reclosing and executed after an unsuccessful high-speed auto-reclosing of a corresponding sequence.

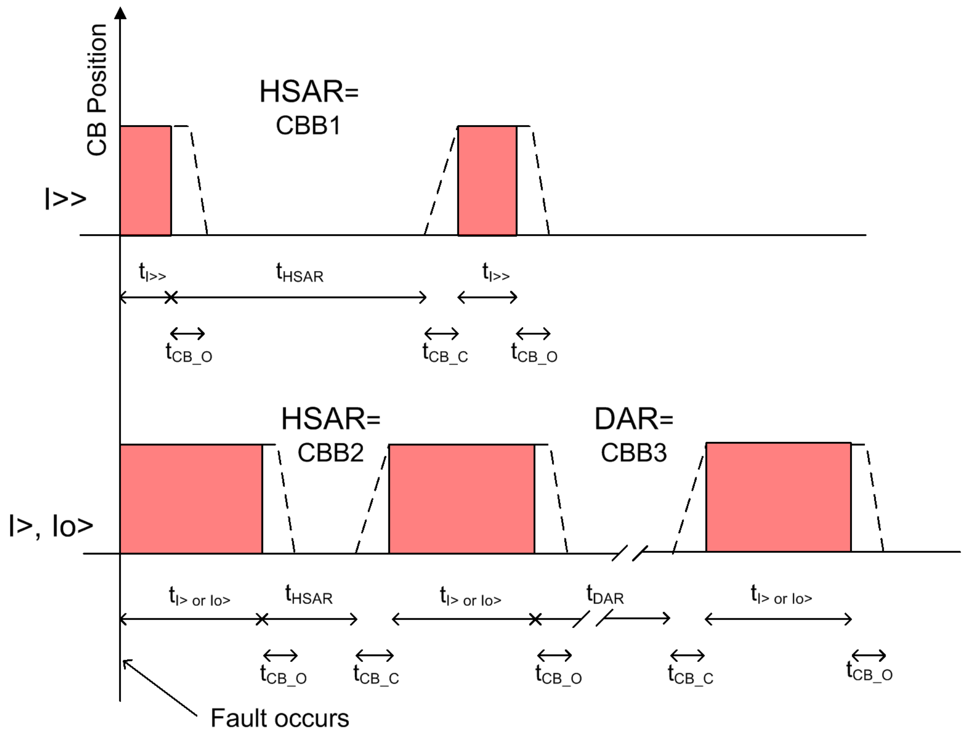



*Figure 242: Auto-reclose sequence with two shots with different shot settings according to initiation signal*

| | |
|---|---|
| $t_{HSAR}$ | Time delay of high-speed auto-reclosing, here: *First reclose time* |
| $t_{DAR}$ | Time delay of delayed auto-reclosing, here: *Second reclose time* |
| $t_{I>>}$ | Operating time for the I>> protection stage to clear the fault |
| $t_{I>}$ or $_{Io>}$ | Operating time for the I> or $I_0$> protection stage to clear the fault |
| $t_{CB\_O}$ | Operating time for opening the circuit breaker |
| $t_{CB\_C}$ | Operating time for closing the circuit breaker |

In this case, the number of needed CBBs is three, that is, the first shot's reclosing time depends on the initiation signal. The CBB sequence is as follows:

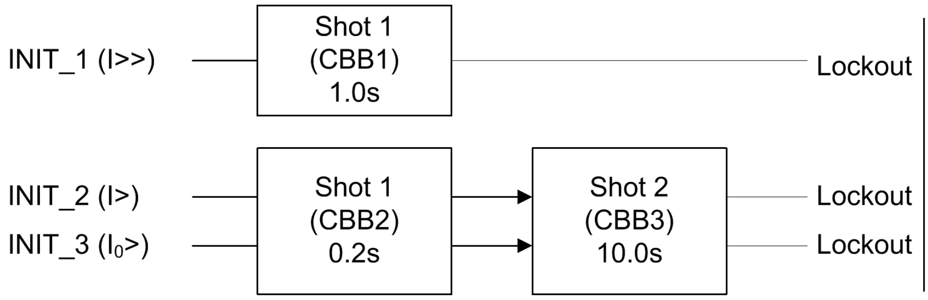



*Figure 243: Three shots with three initiation lines*

If the sequence is initiated from the `INIT_1` line, that is, the overcurrent protection high stage, the sequence is one shot long. On the other hand, if the sequence is initiated from the `INIT_2` or `INIT_3` lines, the sequence is two shots long.

*Table 391: 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 |

### 9.3.6.4 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.

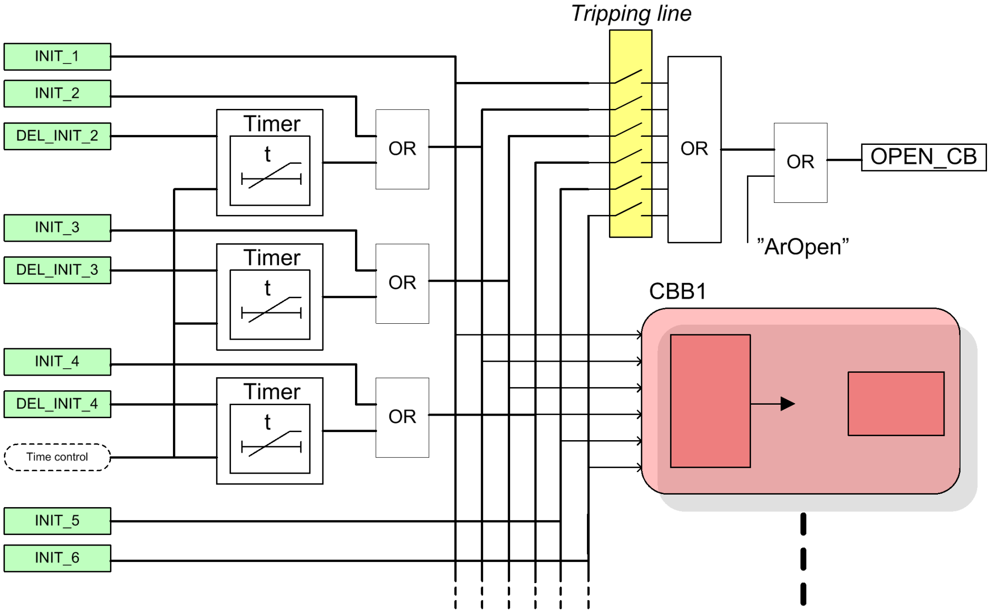



*Figure 244: Simplified logic diagram of initiation lines*

Each delayed initiation line has four different time settings:

*Table 392: 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. |

### 9.3.6.5 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.

### 9.3.6.6 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.

## 9.3.7 Signals

*Table 393: 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 394: DARREC Output signals*

| Name | Type | Description |
|---|---|---|
| OPEN_CB | BOOLEAN | Open command for circuit breaker |
| CLOSE_CB | BOOLEAN | Close (reclose) command for circuit breaker |
| CMD_WAIT | BOOLEAN | Wait for master command |
| INPRO | BOOLEAN | Reclosing shot in progress, activated during dead time |
| LOCKED | BOOLEAN | Signal indicating that AR is locked out |
| PROT_CRD | BOOLEAN | A signal for coordination between the AR and the protection |
| 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 |

## 9.3.8 Settings

*Table 395: DARREC Non group settings*

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Operation | 1=on<br>5=off | | | 1=on | Operation Off/On |
| Reclosing operation | 1=Off<br>2=External Ctl<br>3=On | | | 1=Off | Reclosing operation (Off, External Ctl / On) |
| Manual close mode | 0=False<br>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 haltDeadTime release |
| Max trip time | 100...10000 | ms | 100 | 10000 | Maximum wait time for deactivation of protection signals |
| Close pulse time | 10...10000 | ms | 10 | 200 | CB close pulse time |
| 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 |
| Reclaim time | 100...1800000 | ms | 100 | 10000 | Reclaim time |
| 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 reclosing |
| 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 |
| Terminal priority | 1=None<br>2=Low (follower)<br>3=High (master) | | | 1=None | Terminal priority |
| Synchronisation set | 0...127 | | | 0 | Selection for synchronizing requirement for reclosing |
| Table continues on next page | | | | | |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Auto wait time | 0...60000 | ms | 10 | 2000 | Wait time for reclosing condition fullfilling |
| Auto lockout reset | 0=False<br>1=True | | | 1=True | Automatic lockout reset |
| Protection crd limit | 1...5 | | | 1 | Protection coordination shot limit |
| Protection crd mode | 1=No condition<br>2=AR inoperative<br>3=CB close manual<br>4=AR inop, CB man<br>5=Always | | | 4=AR inop, CB man | Protection coordination mode |
| Auto initiation cnd | 1=Not allowed<br>2=When sync fails<br>3=CB doesn't close<br>4=Both | | | 2=When sync fails | Auto initiation condition |
| Tripping line | 0...63 | | | 0 | Tripping line, defines INIT inputs which cause OPEN_CB activation |
| Control line | 0...63 | | | 63 | Control line, defines INIT inputs which are protection signals |
| Enable shot jump | 0=False<br>1=True | | | 1=True | Enable shot jumping |
| CB closed Pos status | 0=False<br>1=True | | | 1=True | Circuit breaker closed position status |
| Fourth delay in SOTF | 0=False<br>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 |
| Init signals CBB1 | 0...63 | | | 0 | Initiation lines for CBB1 |
| Init signals CBB2 | 0...63 | | | 0 | Initiation lines for CBB2 |
| Init signals CBB3 | 0...63 | | | 0 | Initiation lines for CBB3 |
| Init signals CBB4 | 0...63 | | | 0 | Initiation lines for CBB4 |
| Init signals CBB5 | 0...63 | | | 0 | Initiation lines for CBB5 |
| Init signals CBB6 | 0...63 | | | 0 | Initiation lines for CBB6 |
| Init signals CBB7 | 0...63 | | | 0 | Initiation lines for CBB7 |
| Blk signals CBB1 | 0...63 | | | 0 | Blocking lines for CBB1 |
| Blk signals CBB2 | 0...63 | | | 0 | Blocking lines for CBB2 |
| Blk signals CBB3 | 0...63 | | | 0 | Blocking lines for CBB3 |
| Blk signals CBB4 | 0...63 | | | 0 | Blocking lines for CBB4 |
| Blk signals CBB5 | 0...63 | | | 0 | Blocking lines for CBB5 |
| Blk signals CBB6 | 0...63 | | | 0 | Blocking lines for CBB6 |
| Blk signals CBB7 | 0...63 | | | 0 | Blocking lines for CBB7 |

Table continues on next page

| Parameter | Values (Range) | Unit | Step | Default | Description |
|---|---|---|---|---|---|
| Shot number CBB1 | 0...5 | | | 0 | Shot number for CBB1 |
| Shot number CBB2 | 0...5 | | | 0 | Shot number for CBB2 |
| Shot number CBB3 | 0...5 | | | 0 | Shot number for CBB3 |
| Shot number CBB4 | 0...5 | | | 0 | Shot number for CBB4 |
| Shot number CBB5 | 0...5 | | | 0 | Shot number for CBB5 |
| Shot number CBB6 | 0...5 | | | 0 | Shot number for CBB6 |
| Shot number CBB7 | 0...5 | | | 0 | Shot number 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 |
| 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 |
| Frq Op counter limit | 0...250 | | | 0 | Frequent operation counter lockout limit |
| Frq Op counter time | 1...250 | min | | 1 | Frequent operation counter time |
| Frq Op recovery time | 1...250 | min | | 1 | Frequent operation counter recovery time |
| Auto init | 0...63 | | | 0 | Defines INIT lines that are activated at auto initiation |

## 9.3.9 Monitored data

*Table 396: DARREC Monitored data*

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| DISA_COUNT | BOOLEAN | 0=False<br>1=True | | Signal for counter disabling |
| FRQ_OPR_CNT | INT32 | 0...2147483647 | | Frequent operation counter |
| FRQ_OPR_AL | BOOLEAN | 0=False<br>1=True | | Frequent operation counter alarm |
| STATUS | Enum | -2=Unsuccessful<br>-1=Not defined<br>1=Ready<br>2=In progress<br>3=Successful | | AR status signal for IEC61850 |
| ACTIVE | BOOLEAN | 0=False<br>1=True | | Reclosing sequence is in progress |

Table continues on next page

| Name | Type | Values (Range) | Unit | Description |
|---|---|---|---|---|
| INPRO_1 | BOOLEAN | 0=False<br>1=True | | Reclosing shot in progress, shot 1 |
| INPRO_2 | BOOLEAN | 0=False<br>1=True | | Reclosing shot in progress, shot 2 |
| INPRO_3 | BOOLEAN | 0=False<br>1=True | | Reclosing shot in progress, shot 3 |
| INPRO_4 | BOOLEAN | 0=False<br>1=True | | Reclosing shot in progress, shot 4 |
| INPRO_5 | BOOLEAN | 0=False<br>1=True | | Reclosing shot in progress, shot 5 |
| DISCR_INPRO | BOOLEAN | 0=False<br>1=True | | Signal indicating that discrimination time is in progress |
| CUTOUT_INPRO | BOOLEAN | 0=False<br>1=True | | Signal indicating that cut-out time is in progress |
| SUC_RECL | BOOLEAN | 0=False<br>1=True | | Indicates a successful reclosing sequence |
| UNSUC_CB | BOOLEAN | 0=False<br>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 | 0...6 | | Shot pointer value |
| MAN_CB_CL | BOOLEAN | 0=False<br>1=True | | Indicates CB manual closing during reclosing sequence |
| SOTF | BOOLEAN | 0=False<br>1=True | | Switch-onto-fault |
| DARREC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off | | Status |

## 9.3.10 Technical data

*Table 397: DARREC Technical data*

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

## 9.3.11 Technical revision history

*Table 398: Technical revision history*

| Technical revision | Change |
|---|---|
| B | PROT_DISA output removed and removed the related settings |

# Section 10 General function block features

## 10.1 Definite time characteristics

### 10.1.1 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.

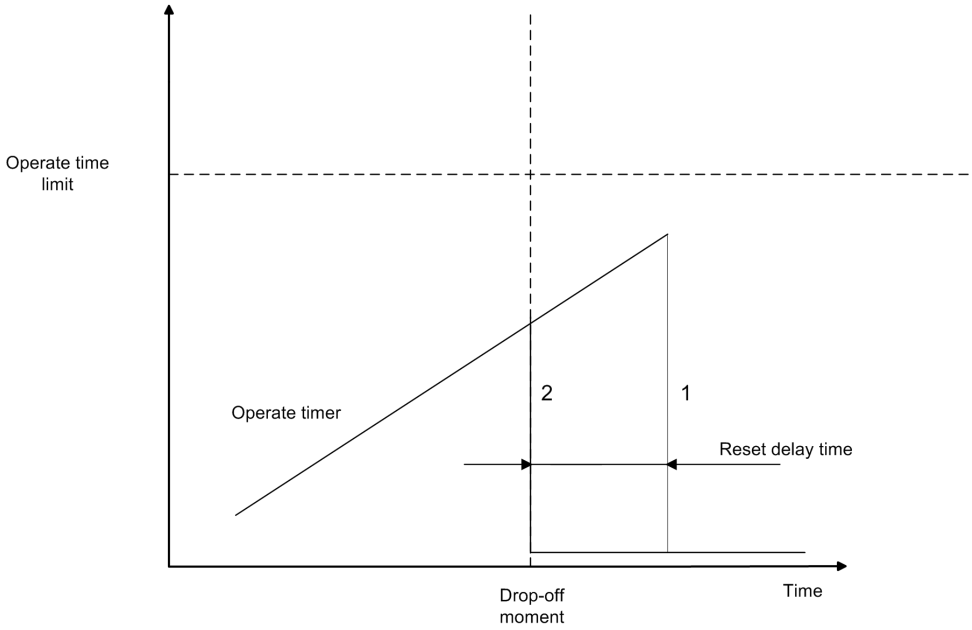



*Figure 245: Operation of the counter in drop-off*

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.

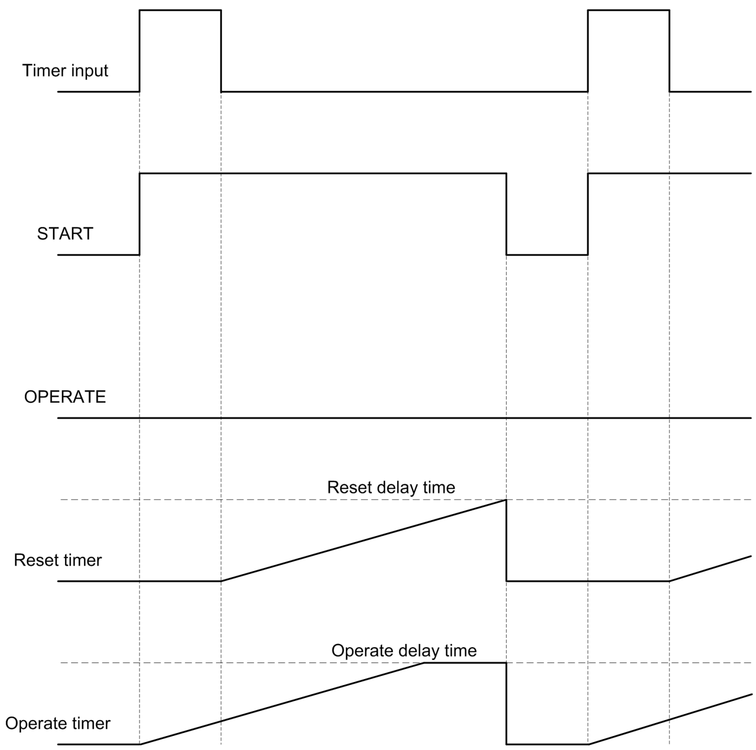



*Figure 246: Drop-off period is longer than the set Reset delay time*

When the drop-off period is longer than the set *Reset delay time*, as described in Figure 246, 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.

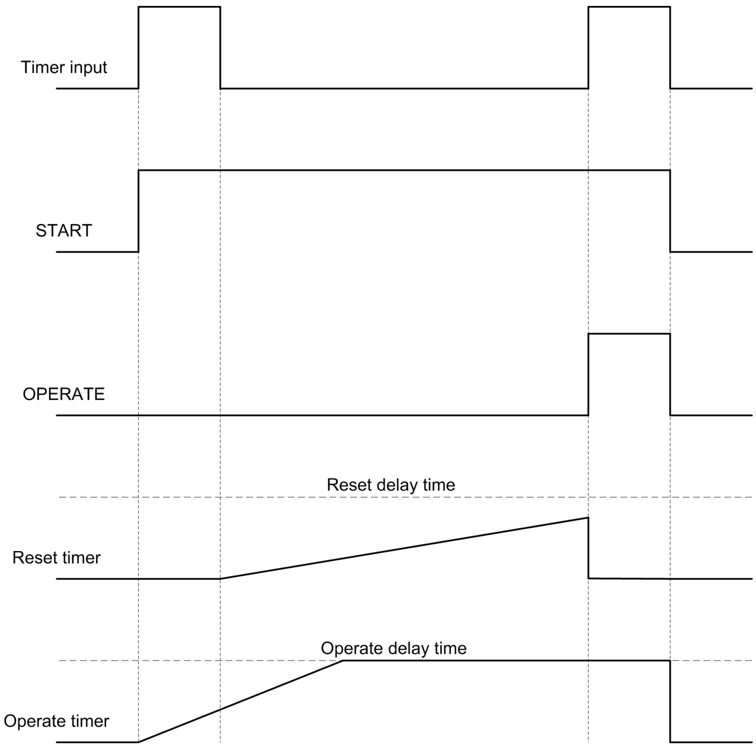



*Figure 247: Drop-off period is shorter than the set Reset delay time*

When the drop-off period is shorter than the set *Reset delay time*, as described in Figure 247, 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.

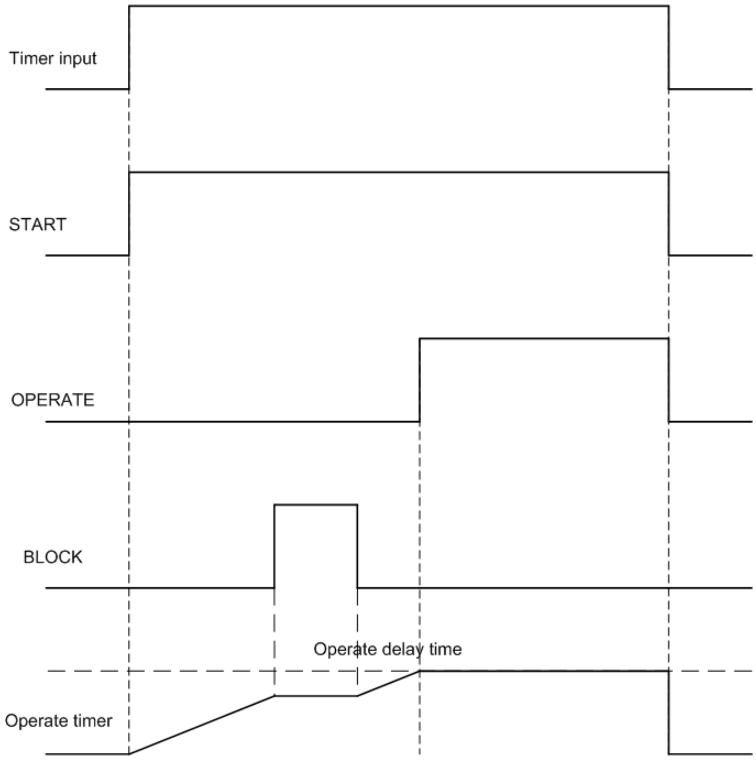



*Figure 248: Operating effect of the* `BLOCK` *input when the selected blocking mode is "Freeze timer"*

If the `BLOCK` input is activated when the operate timer is running, as described in Figure 248, 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 246, regardless of the `BLOCK` input .

The selected blocking mode is "Freeze timer".

## 10.2 Current based inverse definite minimum time characteristics

### 10.2.1 IDMT curves for overcurrent protection

In inverse-time modes, the operate time depends on the momentary value of the current: the higher the current, the faster 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 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:

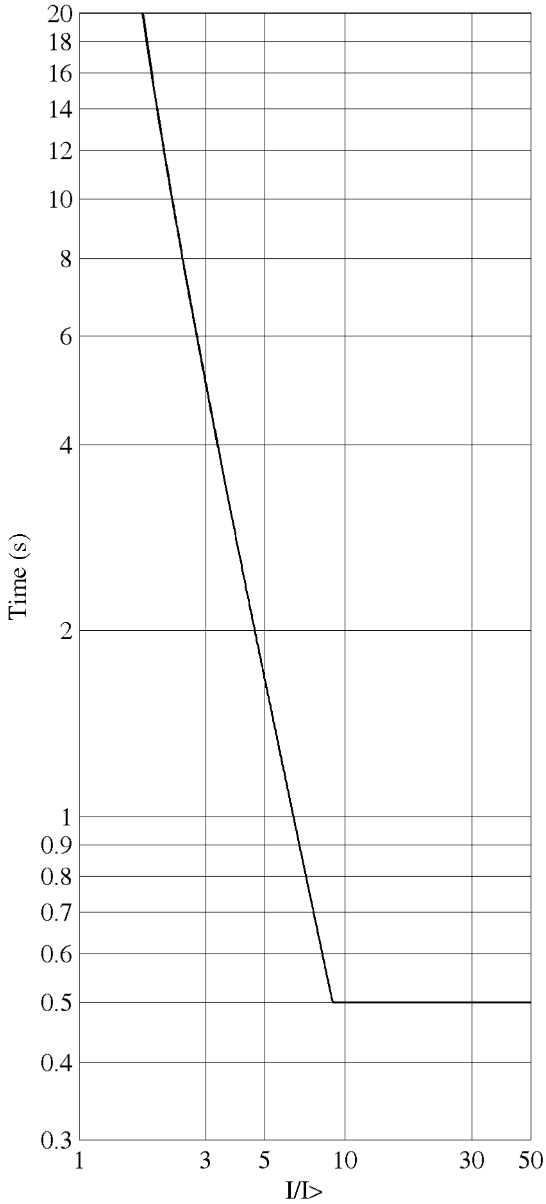



*Figure 249: Operate time curves based on IDMT characteristic with the value of the Minimum operate time setting = 0.5 second*

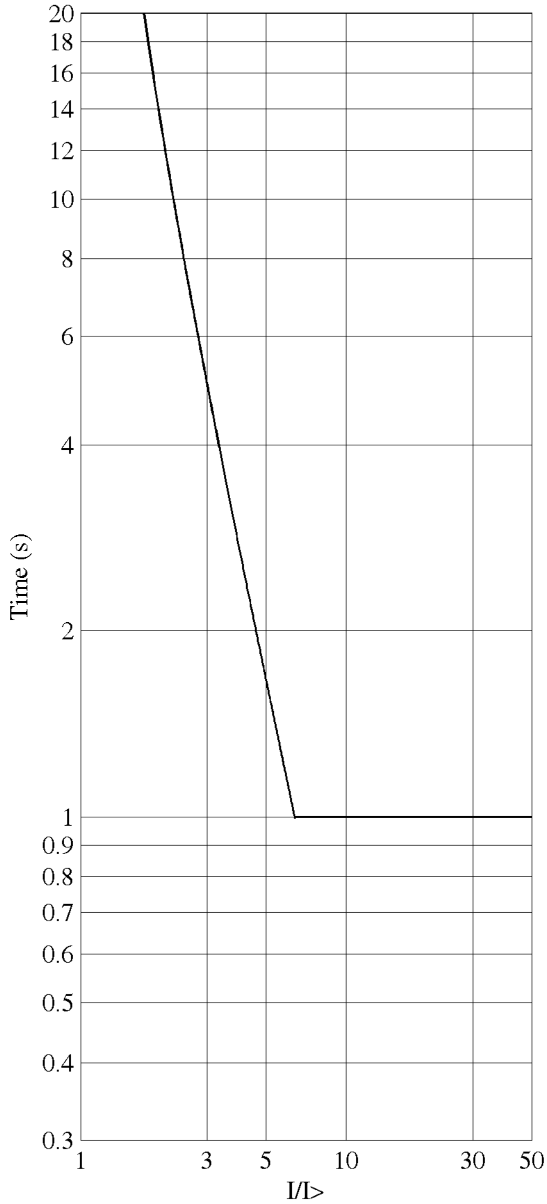



*Figure 250: Operate time curves based on IDMT characteristic with the value of the Minimum operate time setting = 1 second*

### 10.2.1.1 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 67)

t[s] Operate time in seconds

I measured current

I> set *Start value*

k set *Time multiplier*

*Table 399: Curve parameters for ANSI and IEC IDMT curves*

| Curve name | A | B | C |
|---|---|---|---|
| (1) ANSI Extremely Inverse | 28.2 | 0.1217 | 2.0 |
| (2) ANSI Very Inverse | 19.61 | 0.491 | 2.0 |
| (3) ANSI Normal Inverse | 0.0086 | 0.0185 | 0.02 |
| (4) ANSI Moderately Inverse | 0.0515 | 0.1140 | 0.02 |
| (6) Long Time Extremely Inverse | 64.07 | 0.250 | 2.0 |
| (7) Long Time Very Inverse | 28.55 | 0.712 | 2.0 |
| (8) Long Time Inverse | 0.086 | 0.185 | 0.02 |
| (9) IEC Normal Inverse | 0.14 | 0.0 | 0.02 |
| (10) IEC Very Inverse | 13.5 | 0.0 | 1.0 |
| (11) IEC Inverse | 0.14 | 0.0 | 0.02 |
| (12) IEC Extremely Inverse | 80.0 | 0.0 | 2.0 |
| (13) IEC Short Time Inverse | 0.05 | 0.0 | 0.04 |
| (14) IEC Long Time Inverse | 120 | 0.0 | 1.0 |

The maximum guaranteed measured current is 50 x In for the current protection. When the set *Start value* exceeds 1.00 x In, the turn point where the theoretical IDMT characteristics are levelling out to the definite time can be calculated with a formula:

$$Turn\ point = \frac{50 \times In}{Start\ value}$$

(Equation 68)

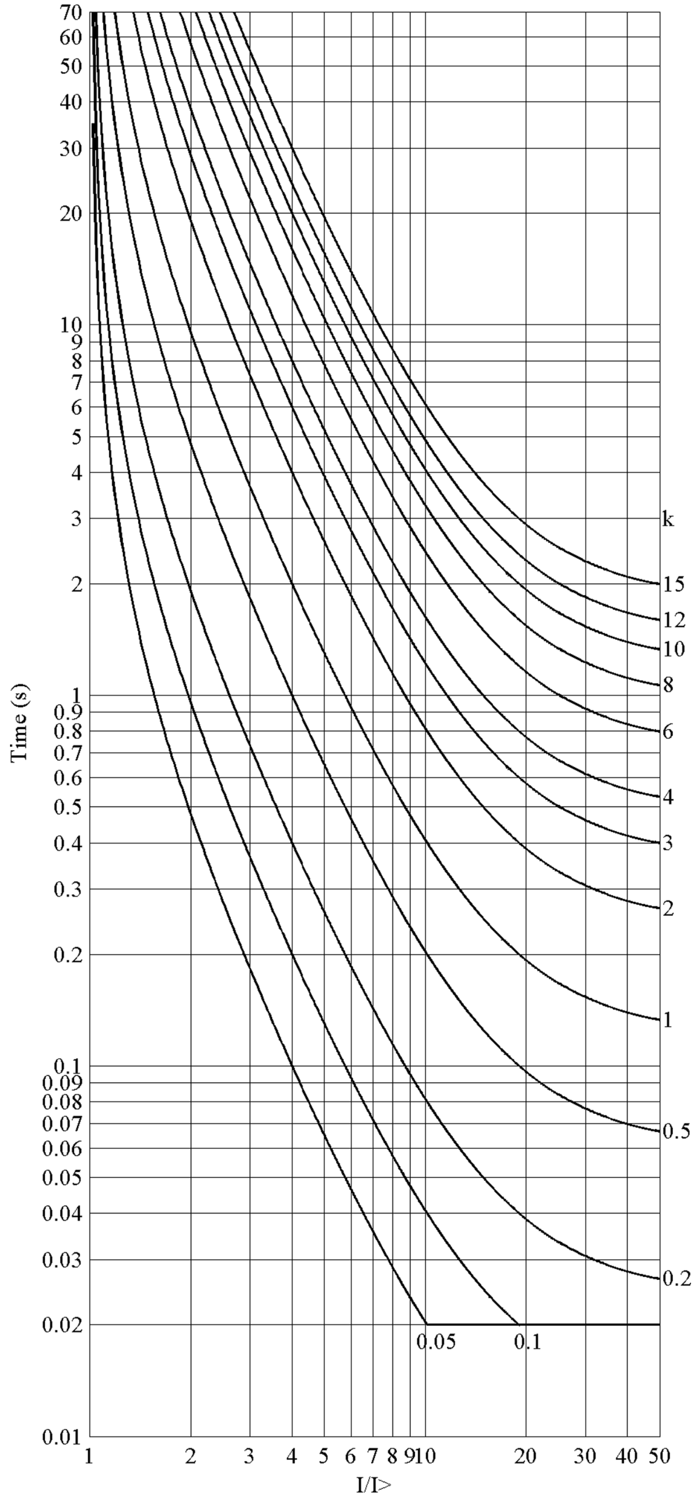



*Figure 251: ANSI extremely inverse-time characteristics*

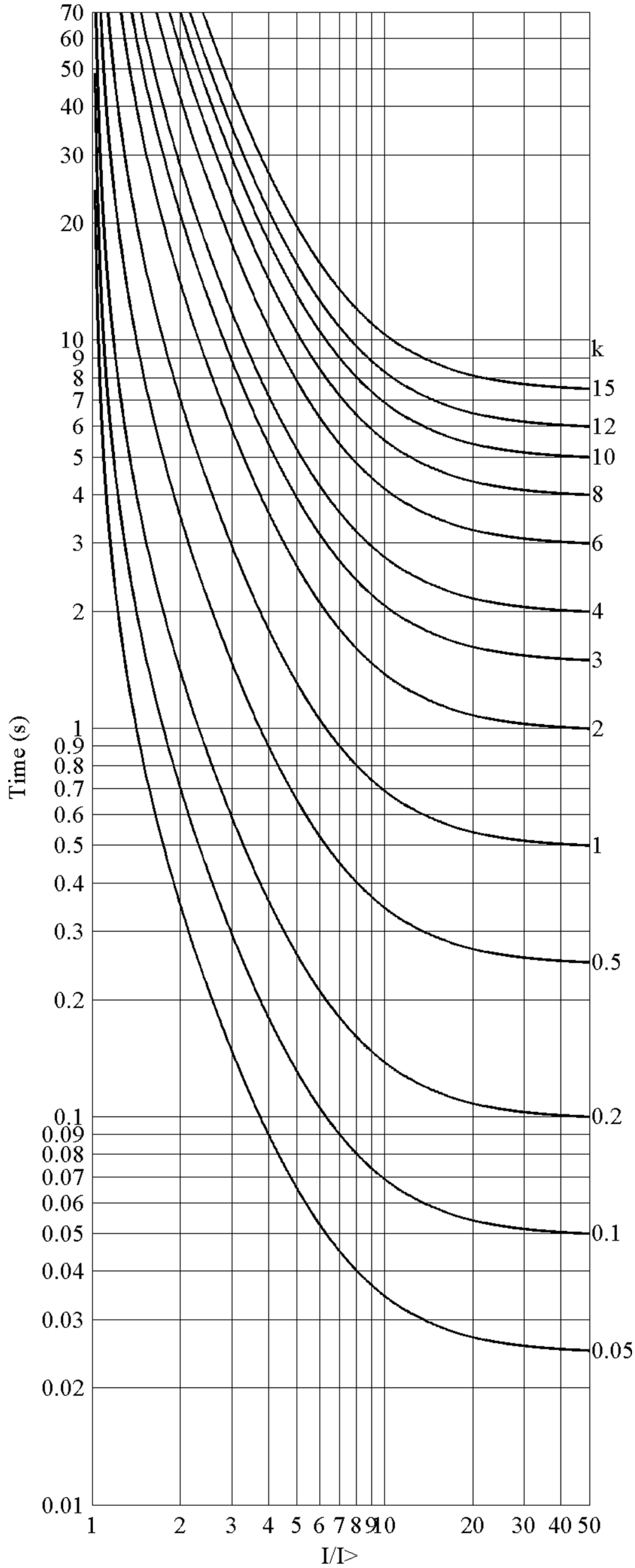



*Figure 252: ANSI very inverse-time characteristics*

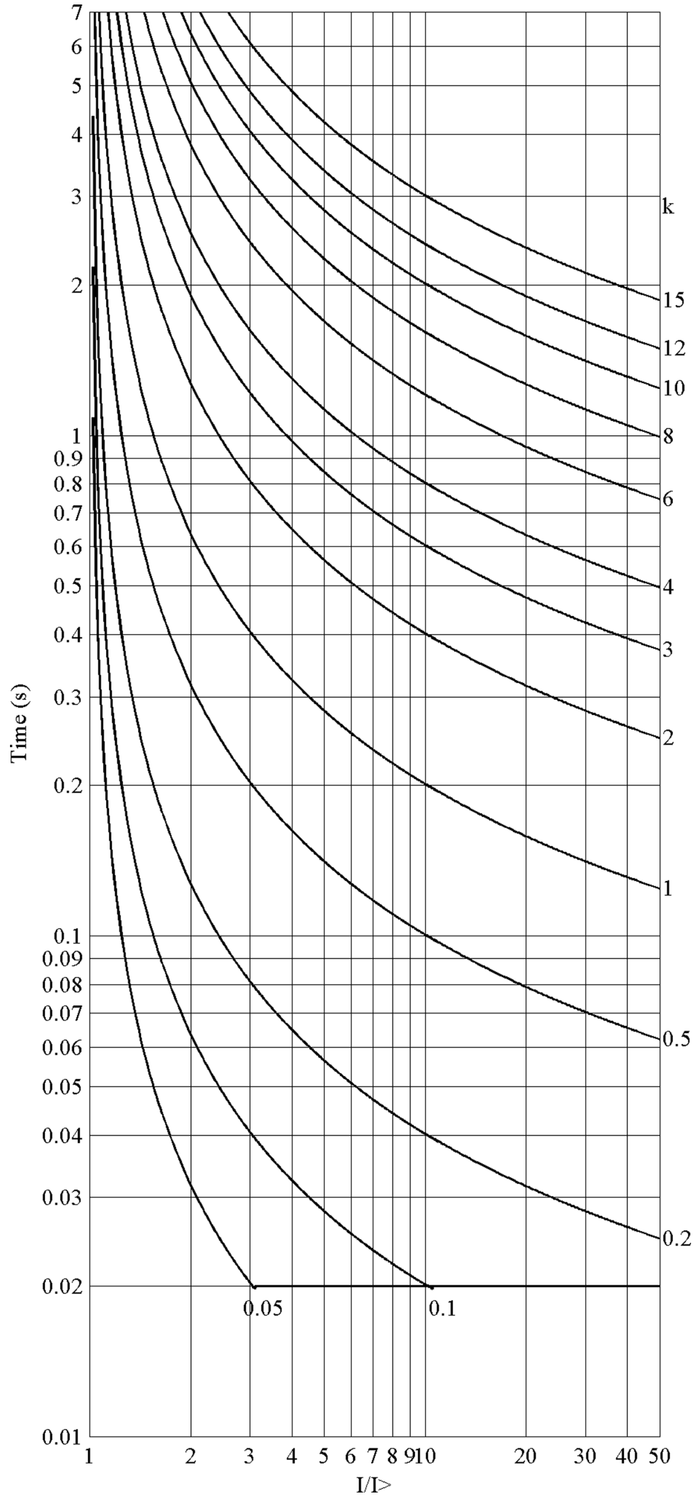



*Figure 253: ANSI normal inverse-time characteristics*

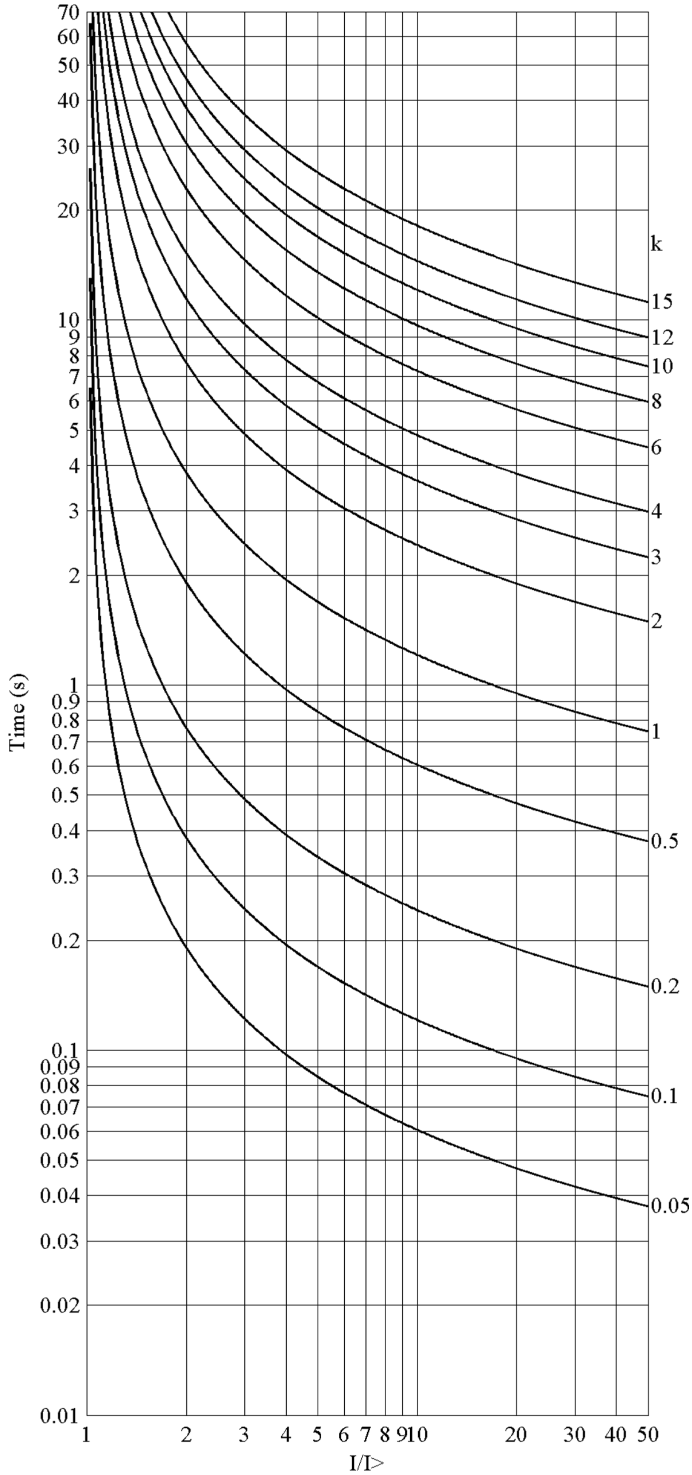



*Figure 254: ANSI moderately inverse-time characteristics*

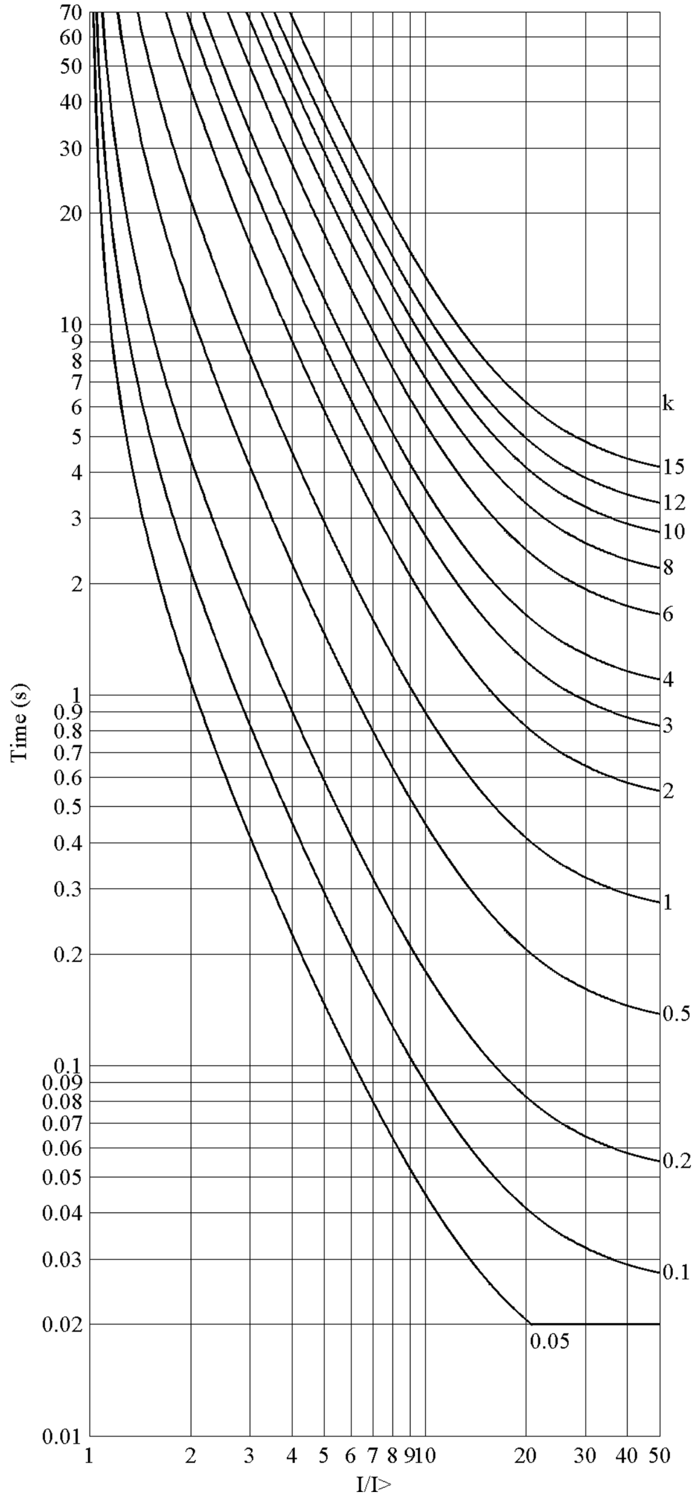



*Figure 255: ANSI long-time extremely inverse-time characteristics*

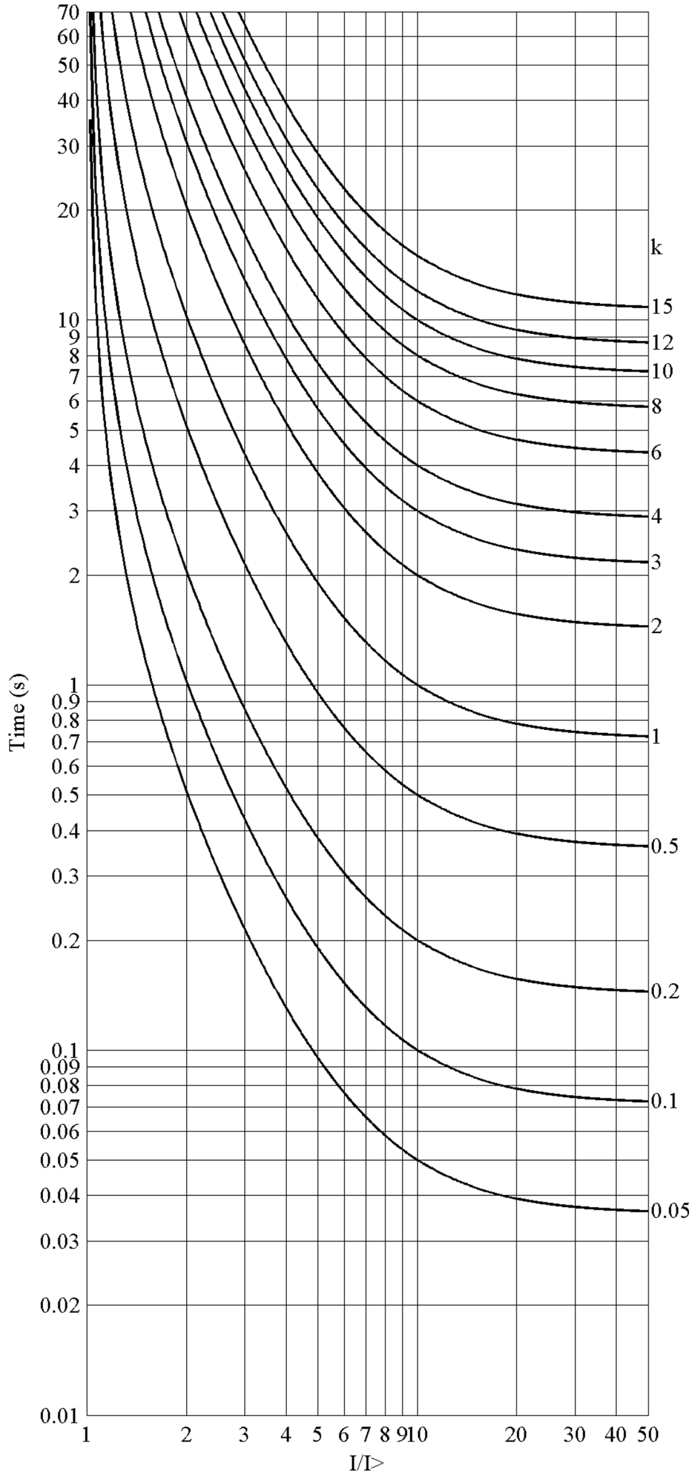



*Figure 256: ANSI long-time very inverse-time characteristics*

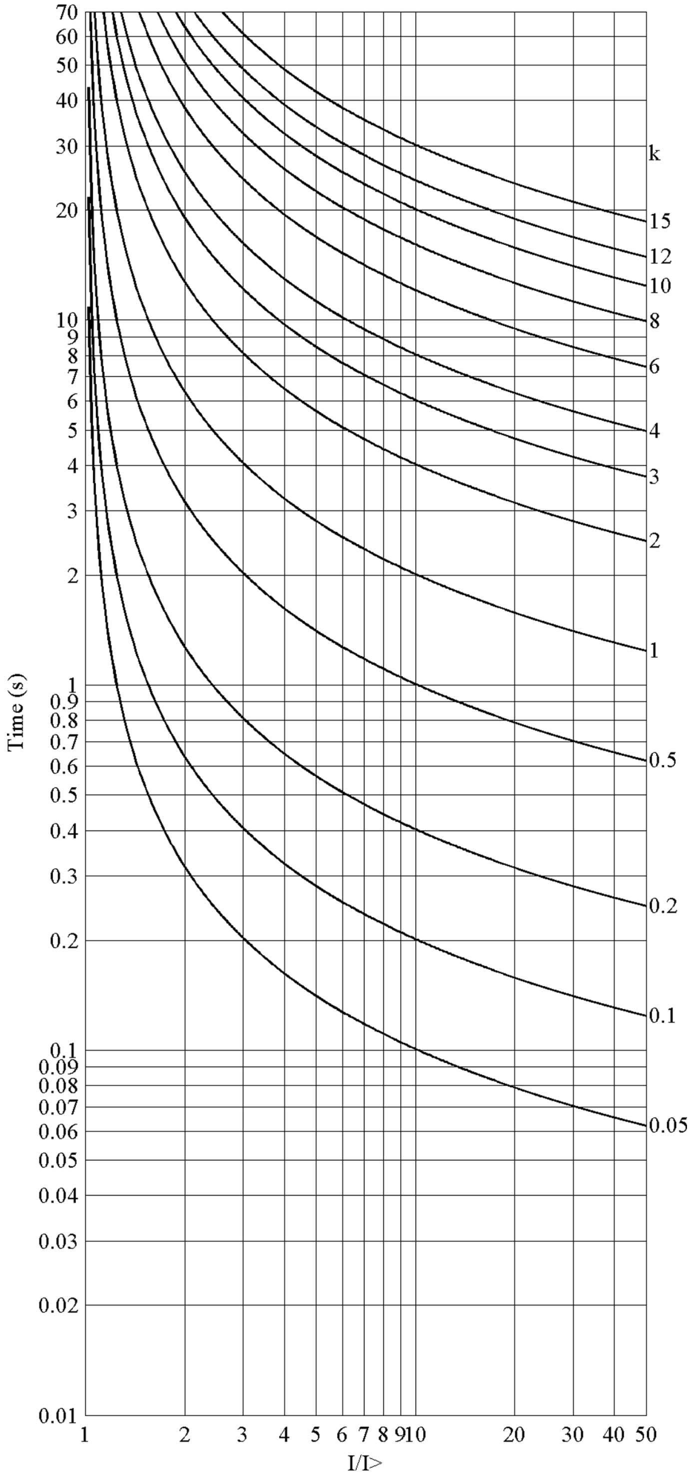



*Figure 257: ANSI long-time inverse-time characteristics*

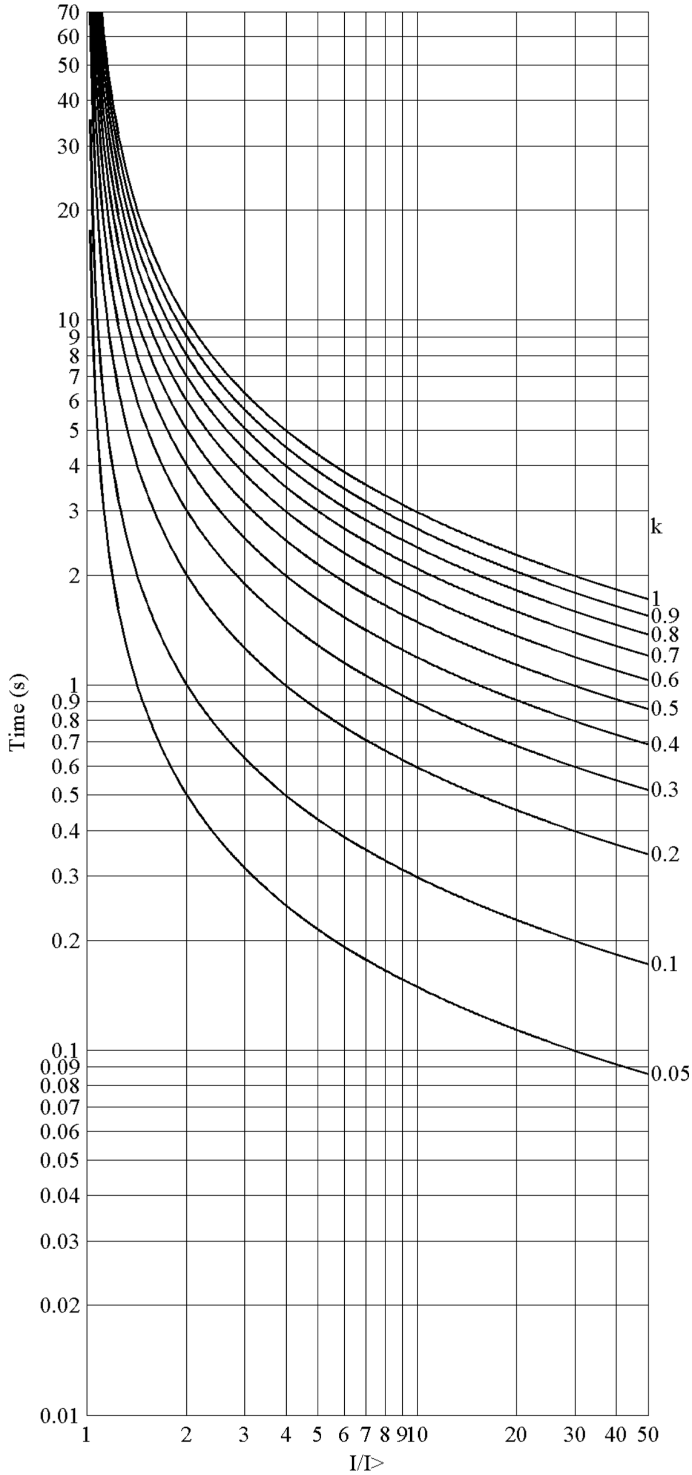



*Figure 258: IEC normal inverse-time characteristics*

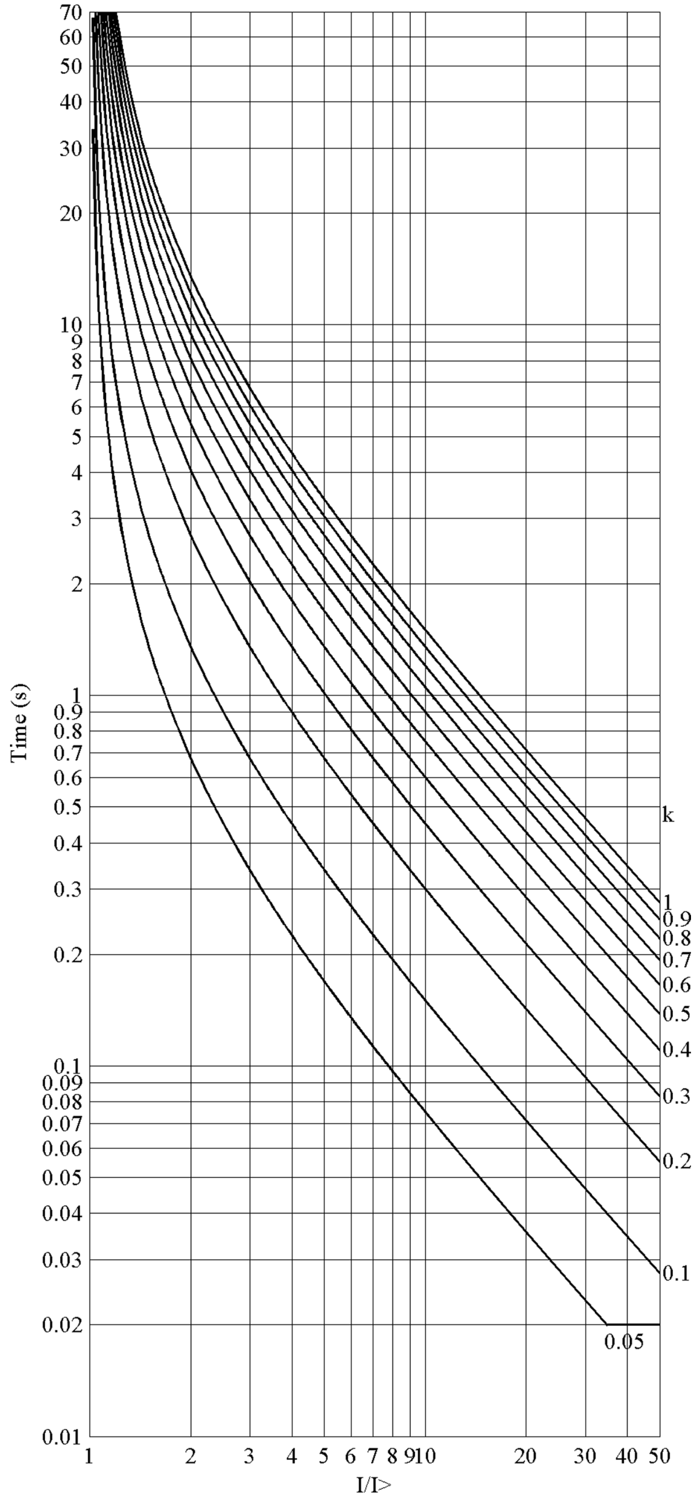



*Figure 259: IEC very inverse-time characteristics*

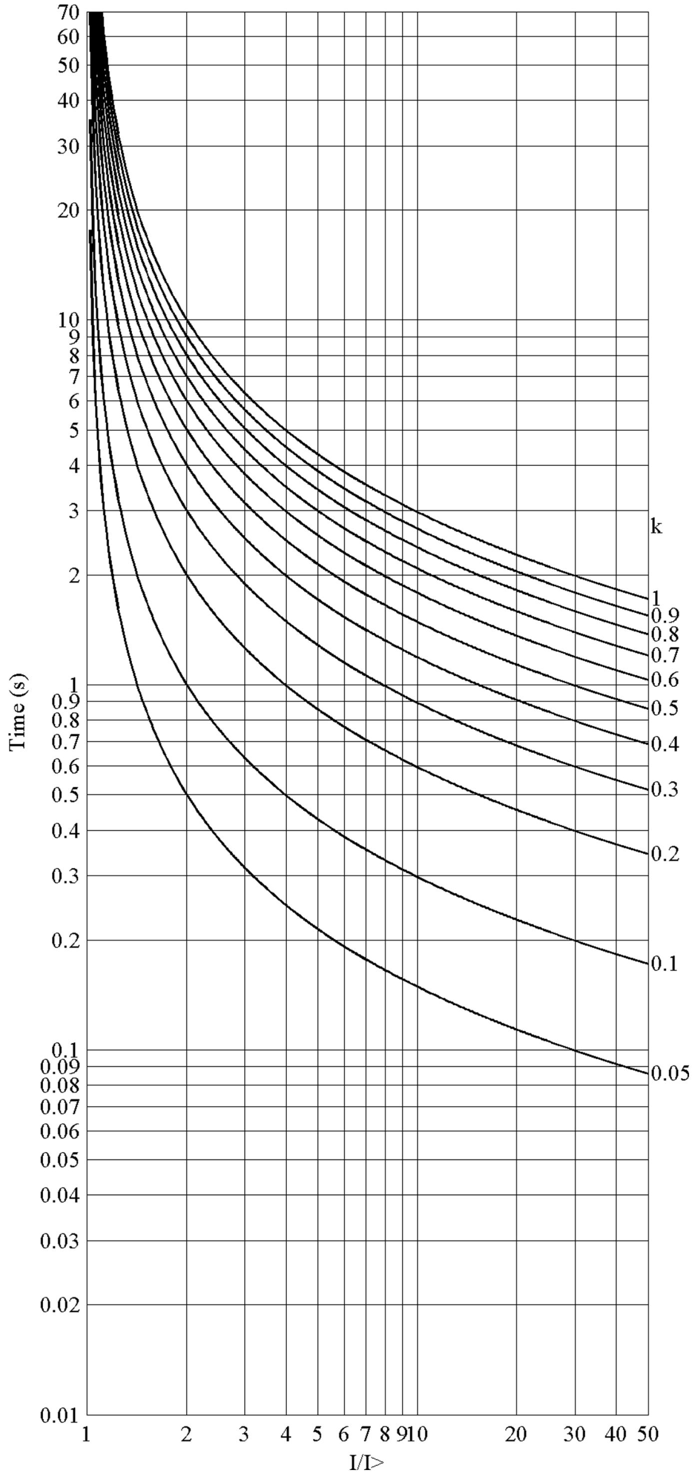



*Figure 260: IEC inverse-time characteristics*

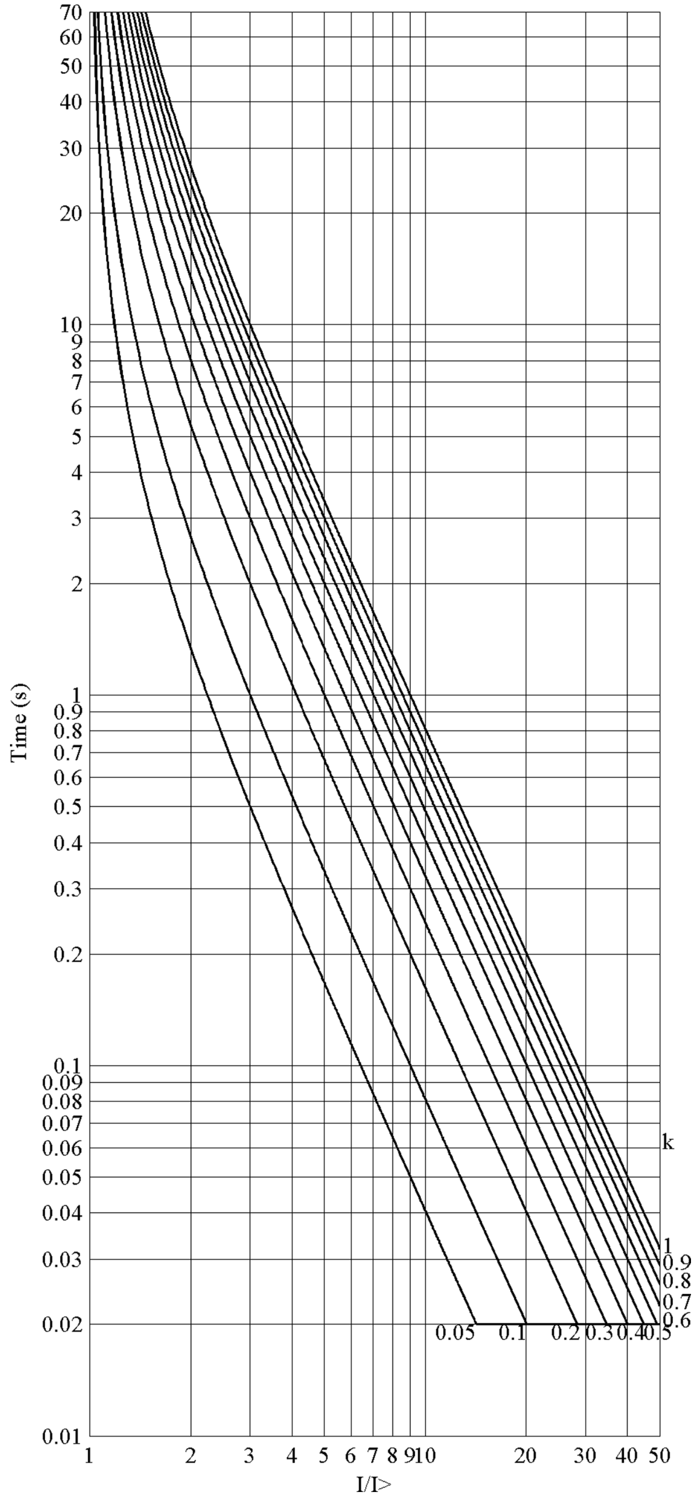



*Figure 261: IEC extremely inverse-time characteristics*

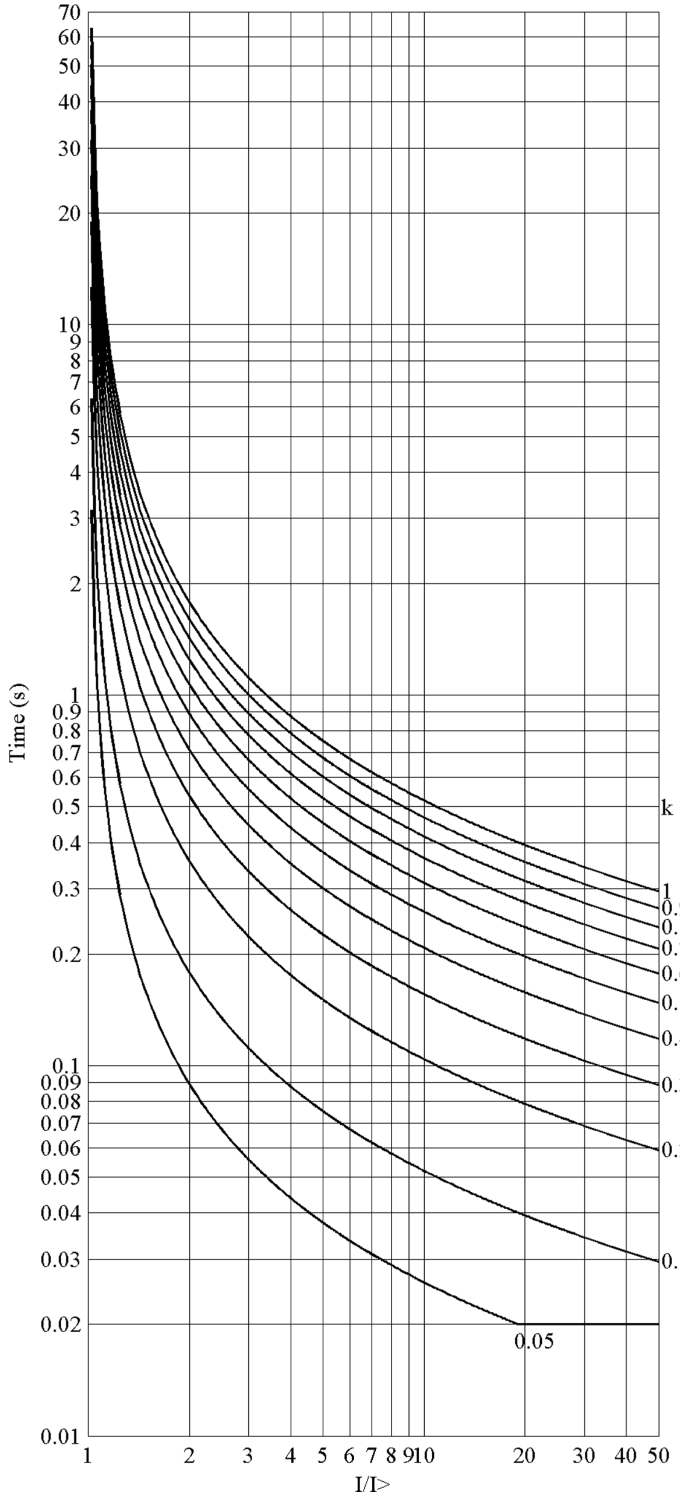



*Figure 262: IEC short-time inverse-time characteristics*

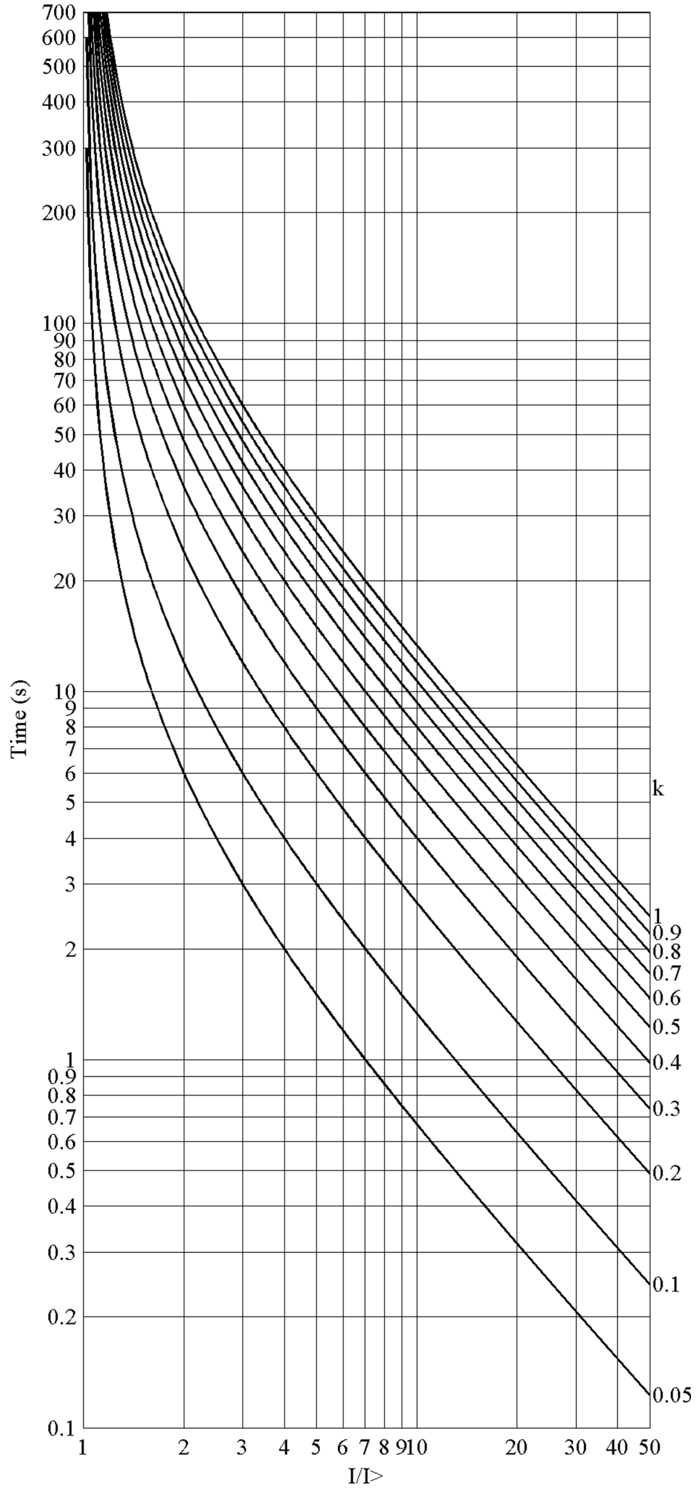



*Figure 263: IEC long-time inverse-time characteristics*

### 10.2.1.2 User-programmable inverse-time characteristics

The user can define curves by entering parameters into the following standard formula:

$$t[s] = \left( \frac{A}{\left( \frac{I}{I>} \right)^{c} - E} + B \right) * k$$

(Equation 69)

| | |
|---|---|
| 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* |

### 10.2.1.3 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 70)

The RD-type is calculated using the formula

$$t[s] = 5.8 - 1.35 \times \text{In}\left( \frac{I}{k \times I>} \right)$$

(Equation 71)

| | |
|---|---|
| t[s] | Operate time (in seconds) |
| k | set *Time multiplier* |
| I | Measured current |
| I> | set *Start value* |

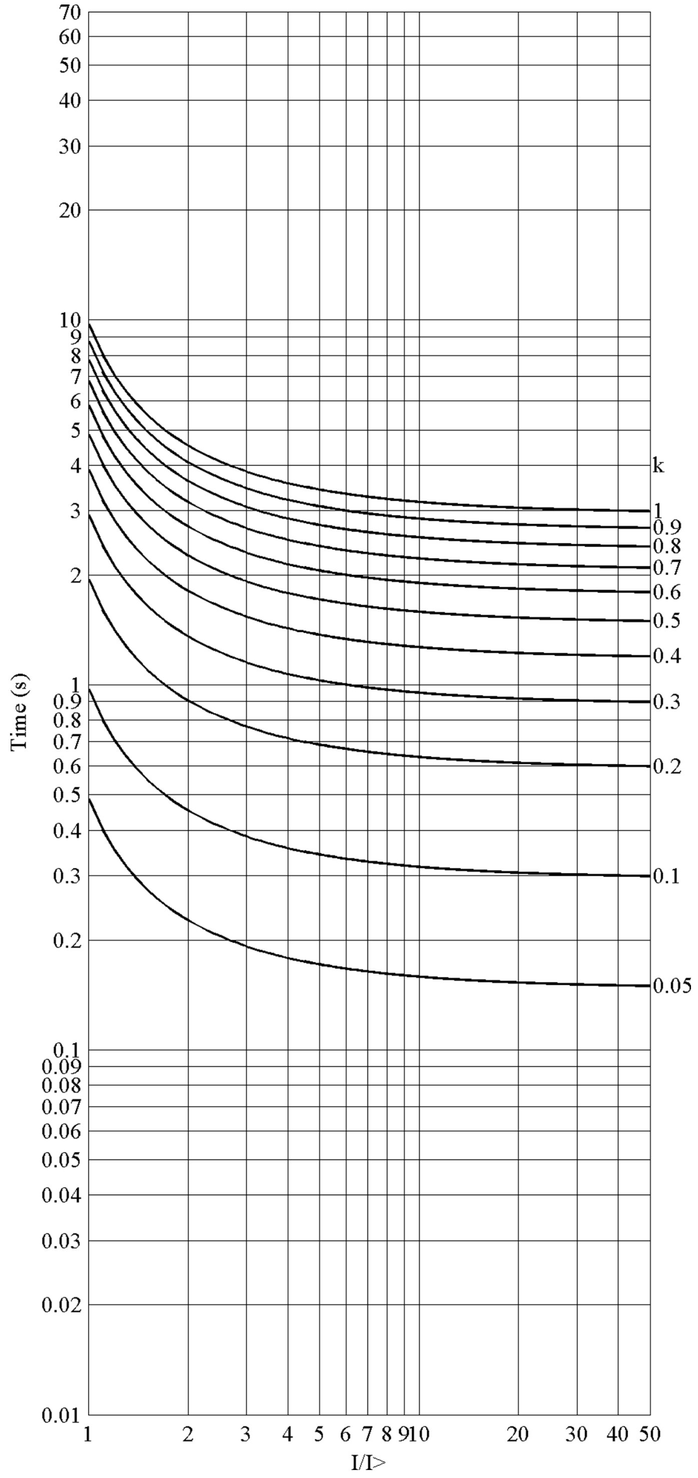



*Figure 264: RI-type inverse-time characteristics*

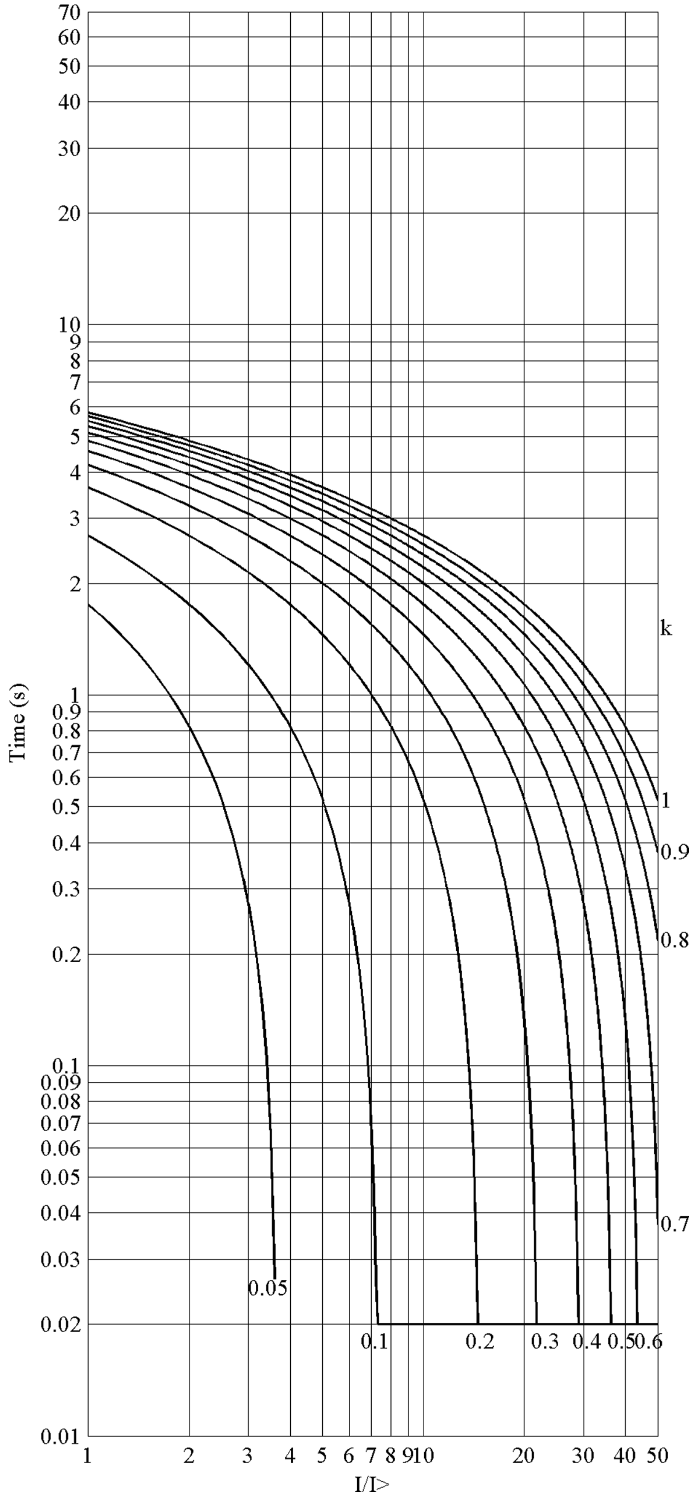



*Figure 265: RD-type inverse-time characteristics*

## 10.2.2 Reset in inverse-time modes

The user can select the reset characteristics by using the *Type of reset curve* setting as follows:

*Table 400: Values for reset mode*

| Setting name | Possible values |
|---|---|
| *Type of reset curve* | 1=Immediate<br>2=Def time reset<br>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 72)

t[s] Reset time (in seconds)

k set *Time multiplier*

I Measured current

I> set *Start value*

*Table 401: 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 |

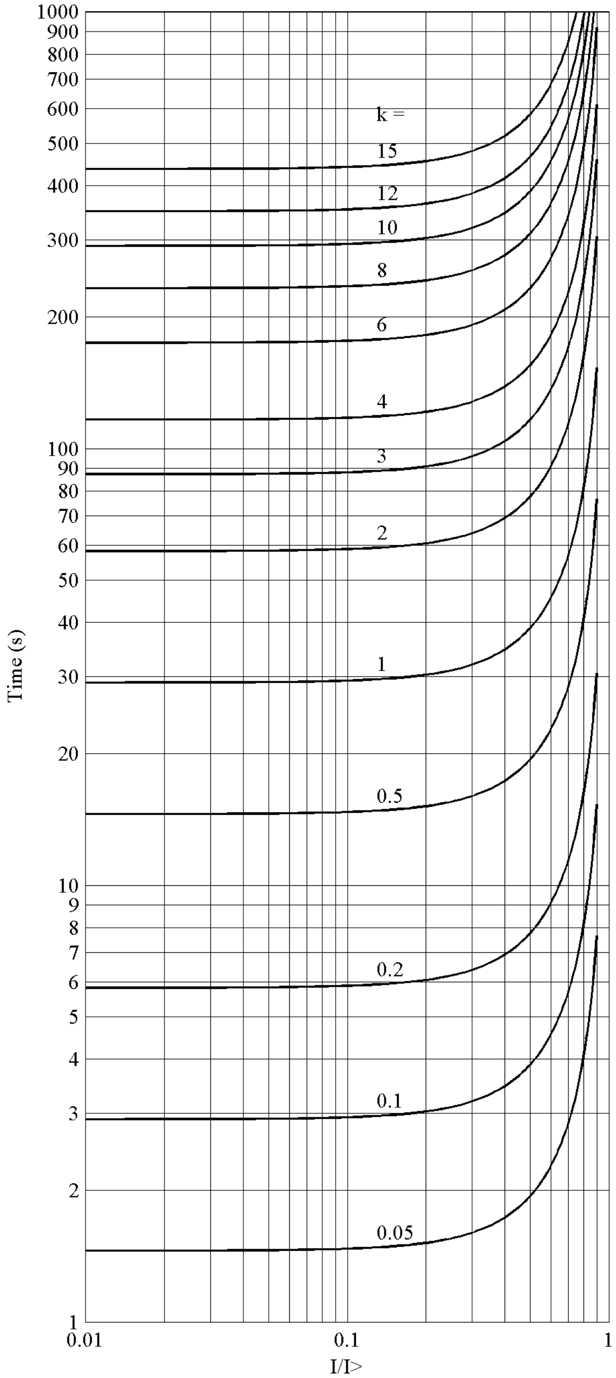



*Figure 266: ANSI extremely inverse reset time characteristics*

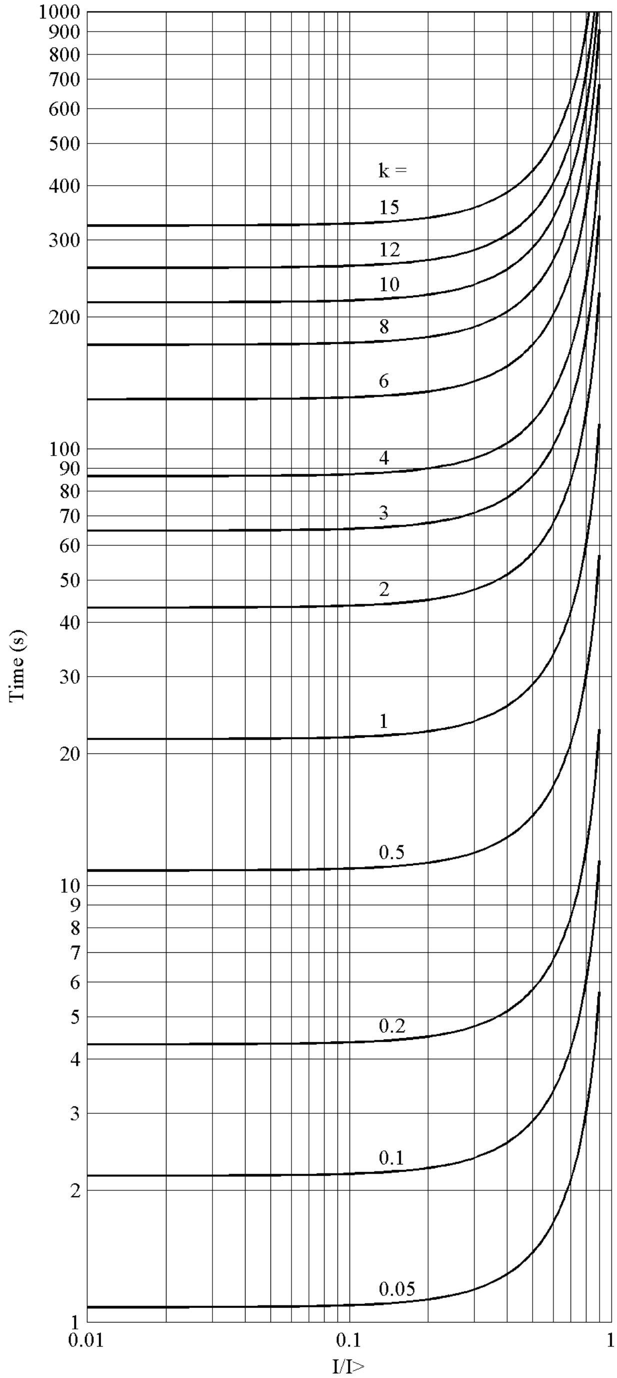



*Figure 267: ANSI very inverse reset time characteristics*

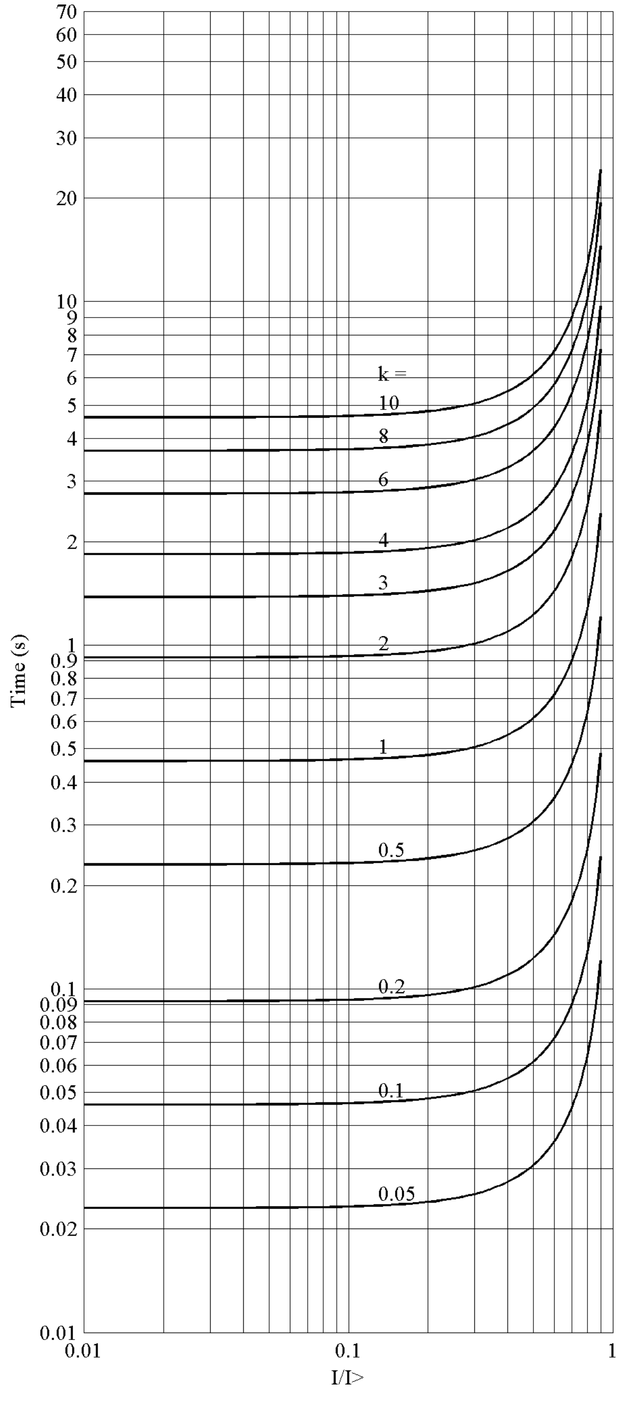



*Figure 268: ANSI normal inverse reset time characteristics*

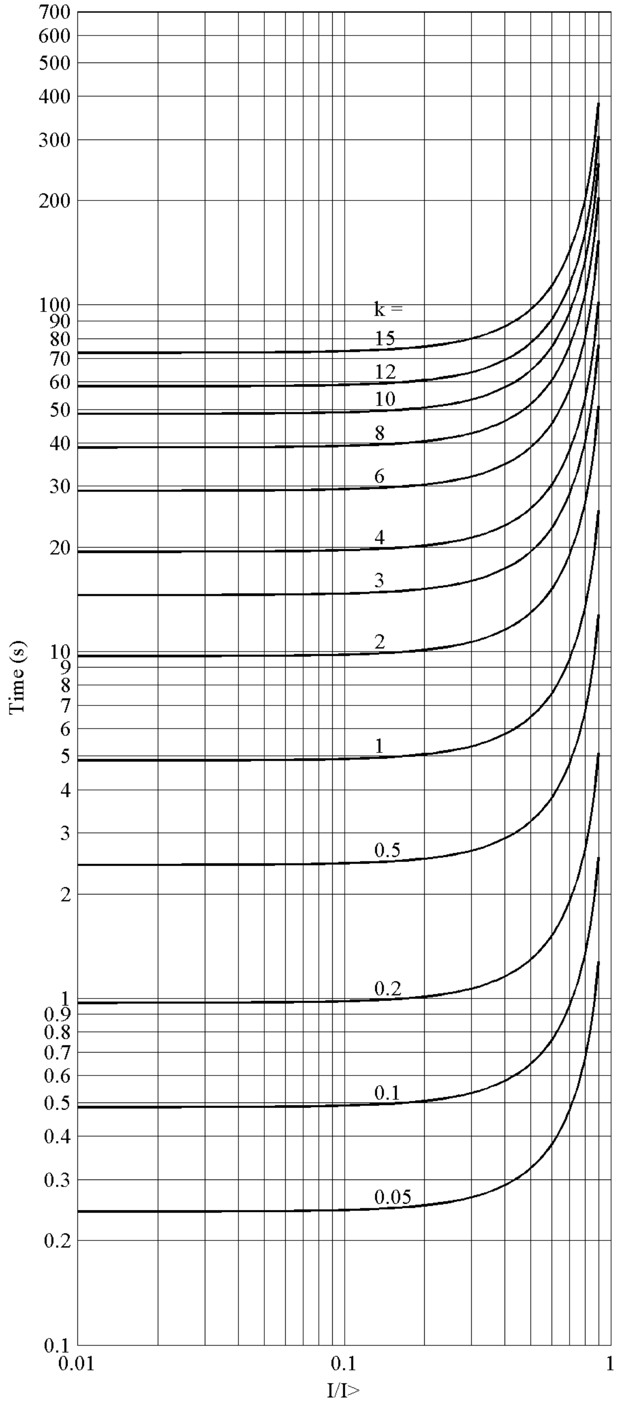



*Figure 269: ANSI moderately inverse reset time characteristics*

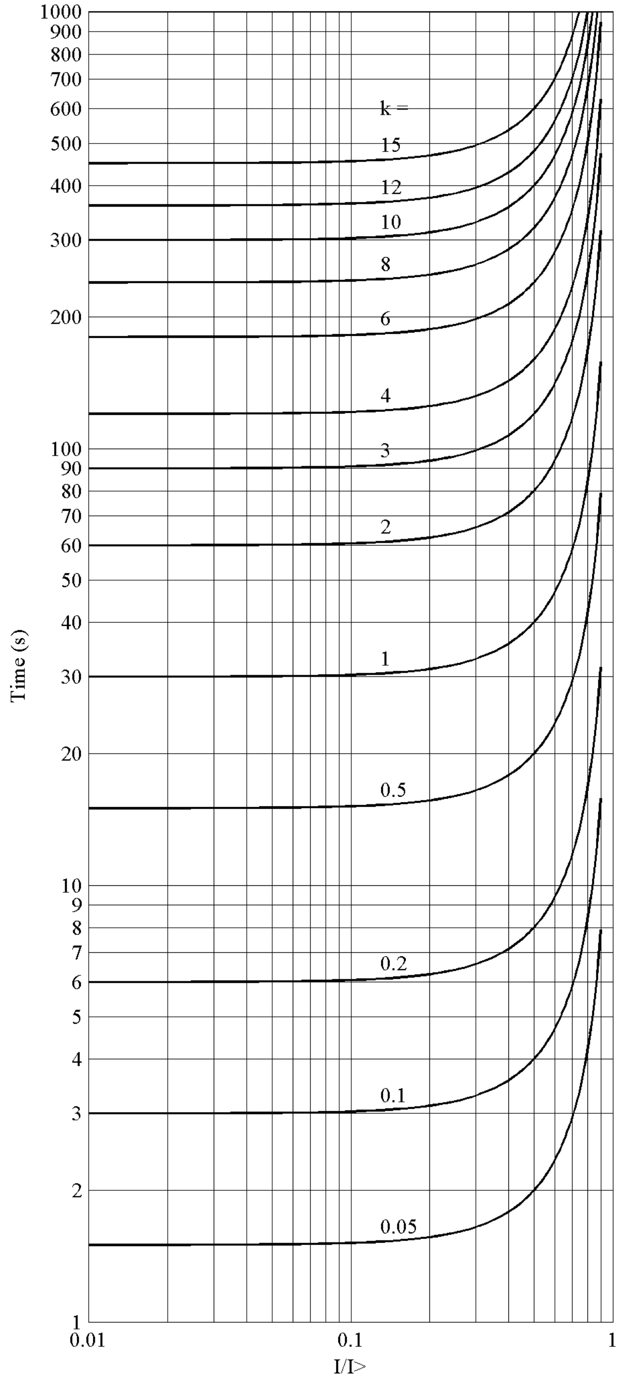



*Figure 270: ANSI long-time extremely inverse reset time characteristics*

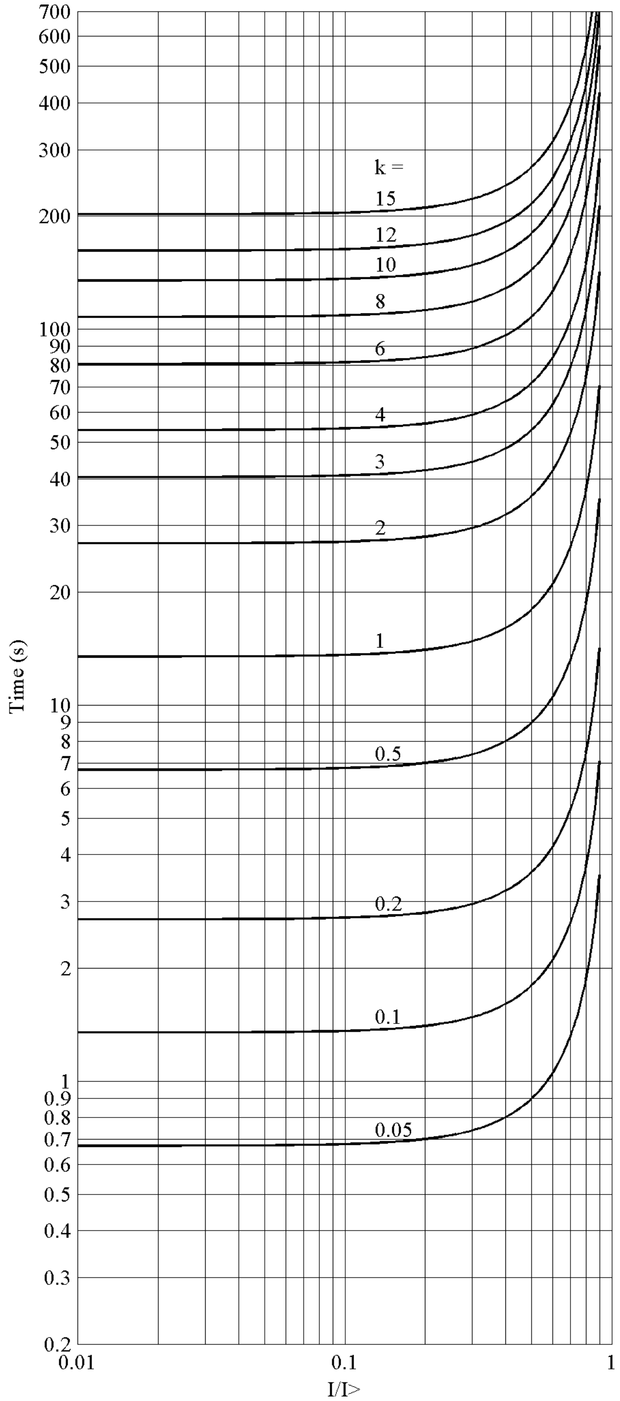



*Figure 271: ANSI long-time very inverse reset time characteristics*

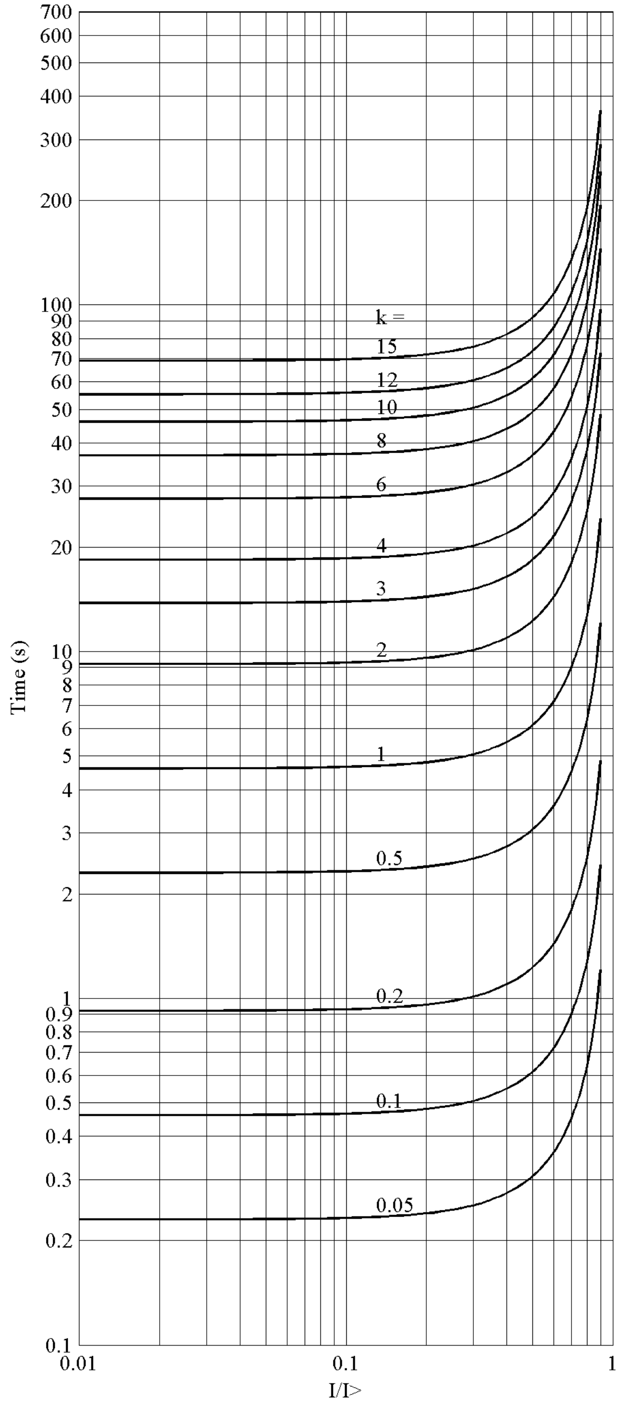



*Figure 272: ANSI long-time inverse reset time characteristics*

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 73)

| | |
|---|---|
| t[s] | Reset time (in seconds) |
| k | set *Time multiplier* |
| D | set *Curve parameter D* |
| I | Measured current |
| I> | set *Start value* |

## 10.2.3 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 an IED needs to be blocked to enable the definite-time operation of another IED 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.

# 10.3 Voltage based inverse definite minimum time characteristics

## 10.3.1 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:

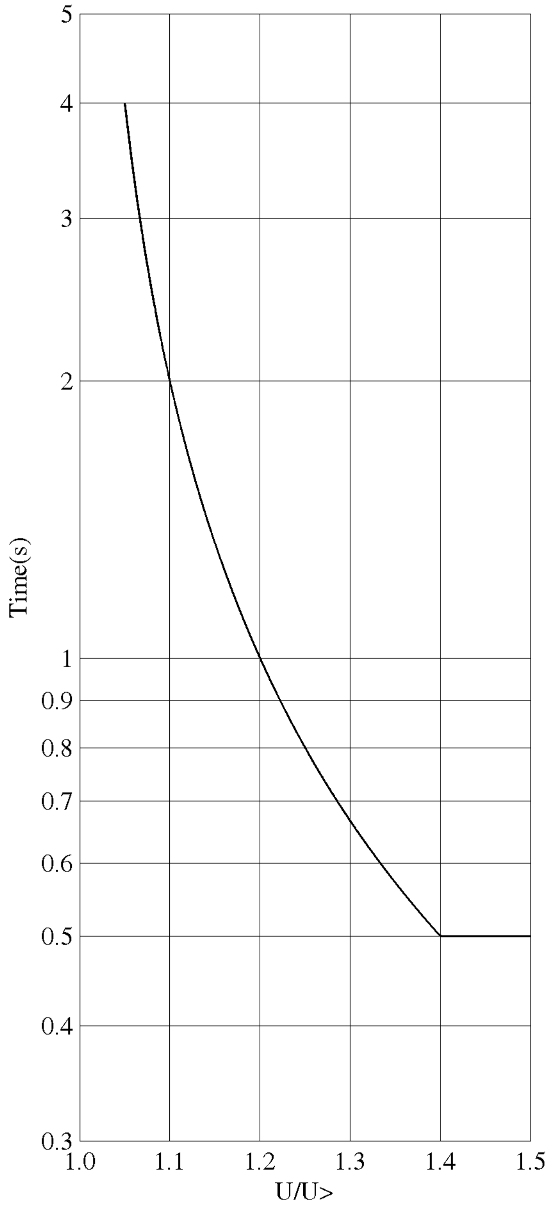



*Figure 273: Operate time curve based on IDMT characteristic with Minimum operate time set to 0.5 second*

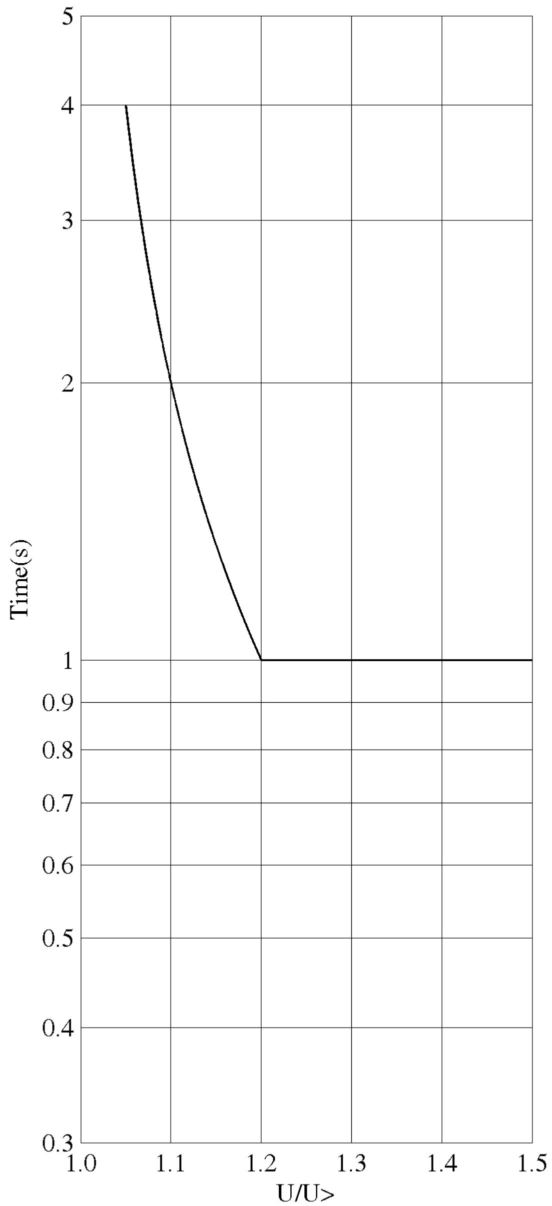



*Figure 274: Operate time curve based on IDMT characteristic with Minimum operate time set to 1 second*

### 10.3.1.1 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 74)

t [s] operate time in seconds

U measured voltage

U> the set value of *Start value*

k the set value of *Time multiplier*

*Table 402: Curve coefficients for 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 |

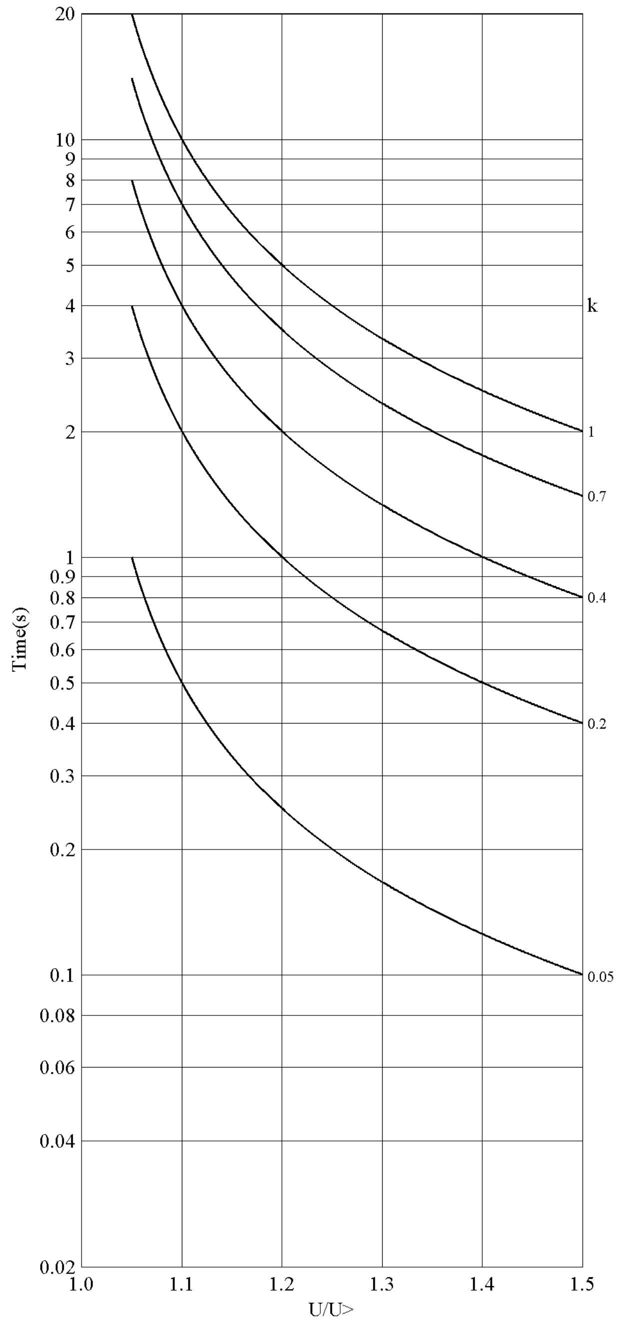



*Figure 275: Inverse curve A characteristic of overvoltage protection*

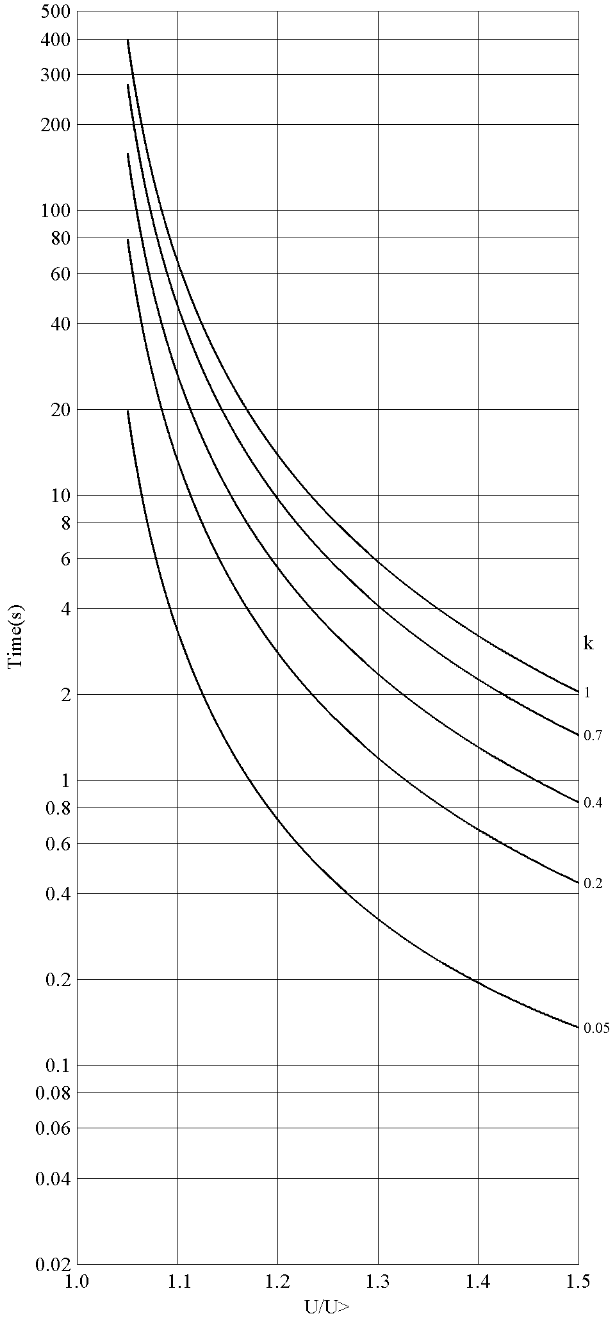



*Figure 276: Inverse curve B characteristic of overvoltage protection*

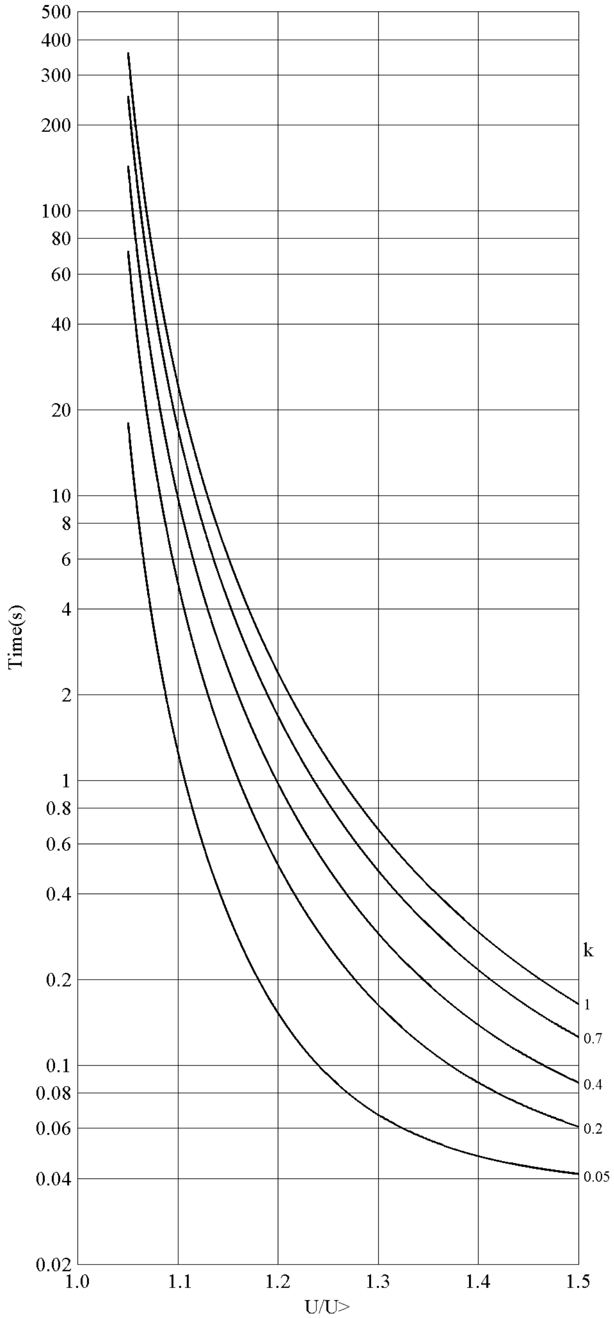



*Figure 277: Inverse curve C characteristic of overvoltage protection*

## 10.3.1.2 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 75)

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*

#### 10.3.1.3 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.

### 10.3.2 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.

### 10.3.2.1 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 76)

| | |
|---|---|
| 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 403: 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 |

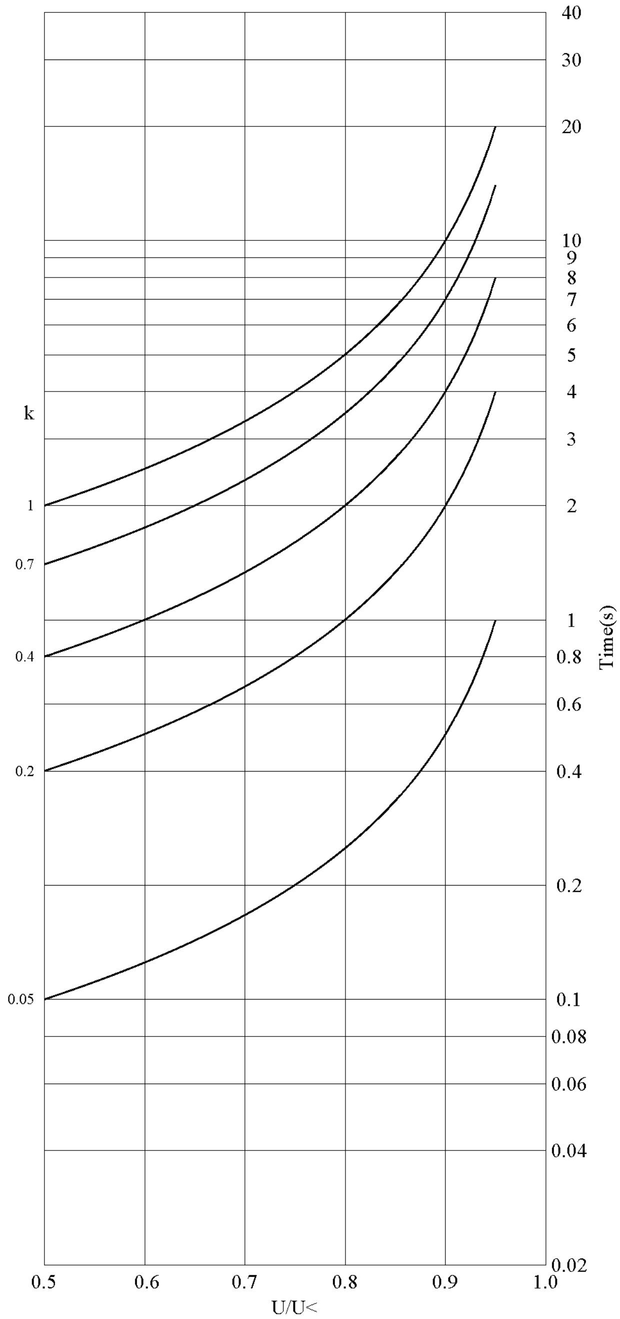



*Figure 278: : Inverse curve A characteristic of undervoltage protection*

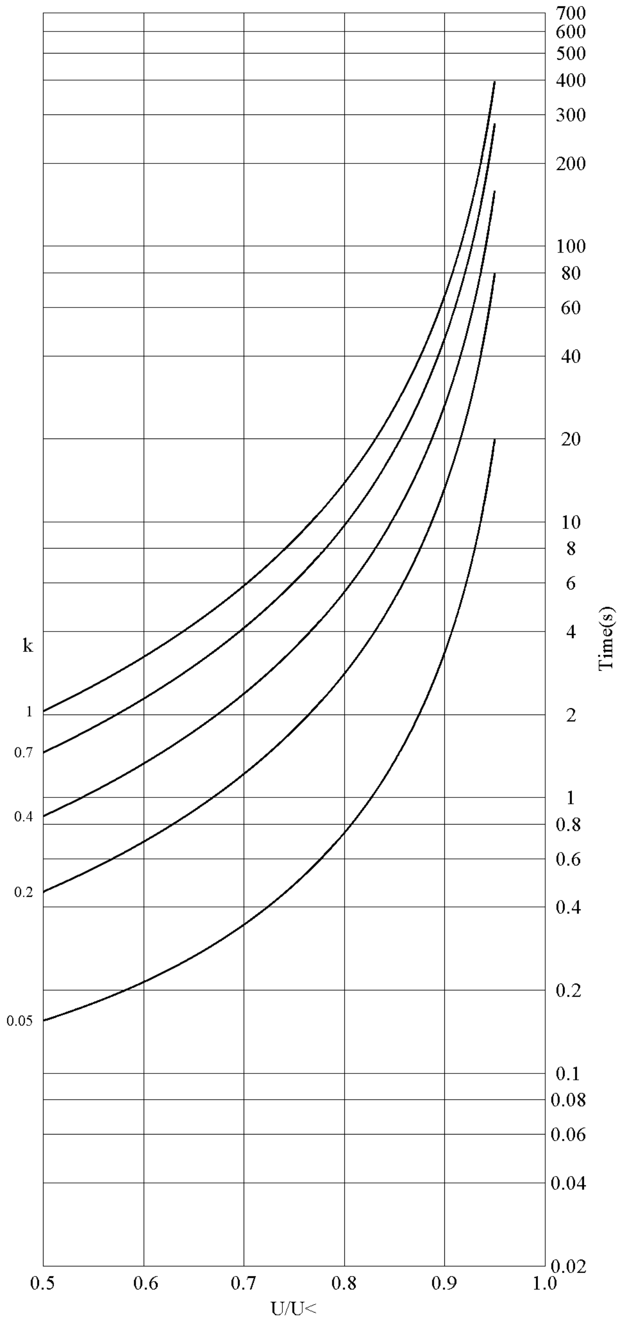



*Figure 279: Inverse curve B characteristic of undervoltage protection*

## 10.3.2.2 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 77)

| | |
|---|---|
| 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* |

### 10.3.2.3 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.

## 10.4 Measurement modes

In many current or voltage dependent function blocks, there are four 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 78)

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 IED 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.

# Section 11 Requirements for measurement transformers

## 11.1 Current transformers

### 11.1.1 Current transformer requirements for non-directional 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 relay settings should be defined in accordance with the CT performance as well as other factors.

#### 11.1.1.1 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 404: 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 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 |

## 11.1.1.2 Non-directional overcurrent protection

### The current transformer selection

Non-directional overcurrent protection does not set high requirements on the accuracy class or on the actual accuracy limit factor ($F_a$) of the CTs. It is, however, recommended to select a CT with $F_a$ of at least 20.

The nominal primary current $I_{1n}$ should be chosen in such a way that the thermal and dynamic strength of the current measuring input of the 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 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 of the relay is to operate, then the start current should be set using the formula:

*Current start value* < 0.7 x ($I_{kmin} / I_{1n}$)

$I_{1n}$ 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 O/C protection is defined. The operate time delay caused by the CT saturation is typically small enough when the relay 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 relay operation. To ensure the time selectivity, the delay must be taken into account when setting the operate times of successive relays.

With definite time mode of operation, the saturation of CT may cause a delay that is as long as the time the 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.

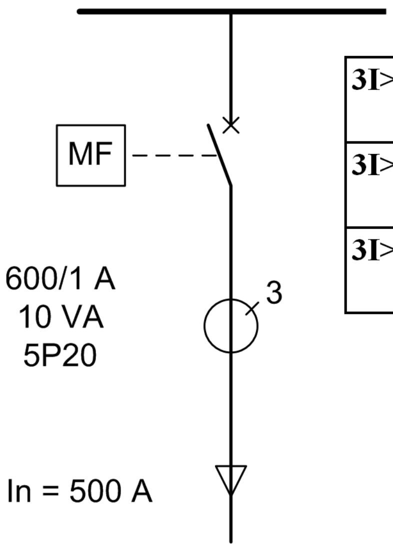
With inverse time mode of operation and when the high-set stages are not used, the AC component of the fault current should not saturate the CT less than 20 times the starting current. Otherwise, the inverse operation time can be further prolonged. Therefore, the accuracy limit factor $F_a$ should be chosen using the formula:

$F_a$ > 20**Current start value* / $I_{1n}$

The *Current start value* is the primary pickup current setting of the relay.

### 11.1.1.3 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**<br>**0.75 s** | **2.00 x $I_{2n}$**<br>**0.75 s** |
| **3I>>** | **1800A**<br>**0.50 s** | **3.00 x $I_{2n}$**<br>**0.50 s** |
| **3I>>>** | **3500 A**<br>**0.20 s** | **5.83 x $I_{2n}$**<br>**0.20 s** |

*Figure 280: 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 relay (not visible in the figure above). 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 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 the figure above.

For the application point of view, the suitable setting for instantaneous stage (I>>>) in this example is 3 500 A (5.83 x $I_{2n}$). For the CT characteristics point of view, the criteria given by the current transformer selection formula is fulfilled and also the relay setting is considerably below the $F_a$. In this application, the CT rated burden could have been selected much lower than 10 VA for economical reasons.

# Section 12 IED physical connections

All external circuits are connected to the terminals on the rear panel of the IED.

- Connect each signal connector (X100, X110 and X130) terminal with one 0.5...2.5 mm$^2$ wire or with two 0.5...1.0 mm$^2$ wires.
- Connect each ring-lug terminal for signal connector X120 with one of maximum 2.5 mm$^2$ wire.
- Connect each compression type terminal for CTs/VTs with one 0.5...6.0 mm$^2$ wire or with two of maximum 2.5 mm$^2$ wires.
- Connect terminals on the optional communication modules for connector X5 with one 0.08...1.5 mm$^2$ wire or with two of maximum 0.75 mm$^2$ wires.

## 12.1 Protective earth connections

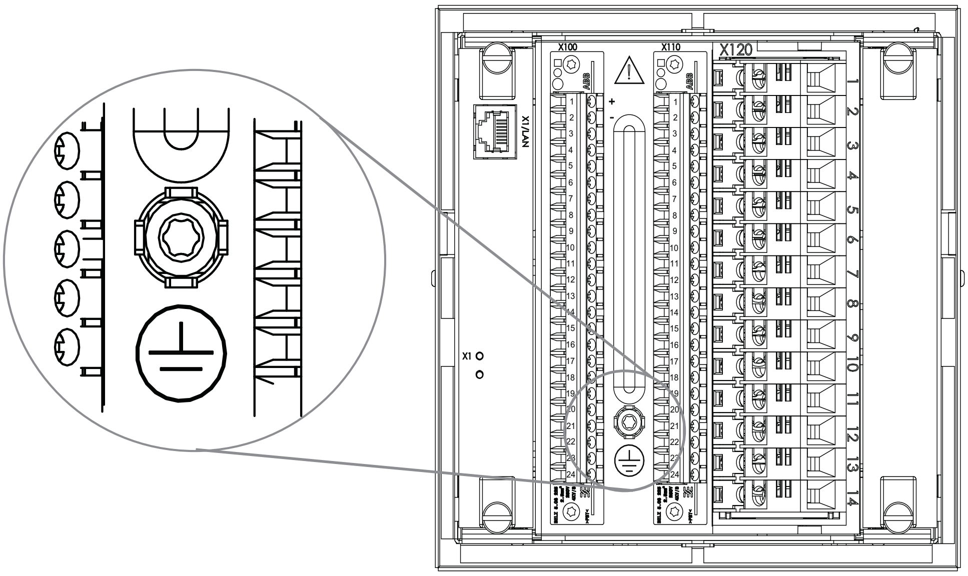



*Figure 281: The protective earth screw is located between connectors X100 and X110*

The earth lead must be at least 4.0 mm$^2$ and as short as possible.

# 12.2 Communication connections

The front communication connection is an RJ-45 type connector used mainly for configuration and setting.

For RED615, the rear communication module is mandatory due to the connection needed for the line-differential protection communication. If station communication is needed for REF615, REM615 or RET615, an optional rear communication module is required. Several optional communication connections are available.

- Galvanic RJ-45 Ethernet connection
- Optical LC Ethernet connection
- ST-type glass fibre serial connection
- EIA-485 serial connection
- EIA-232 serial connection

## 12.2.1 Ethernet RJ-45 front connection

The IED is provided with an RJ-45 connector on the LHMI. The connector is mainly for configuration and setting purposes. The interface on the PC side has to be configured in a way that it obtains the IP address automatically. There is a DHCP server inside IED for the front interface only.

The events and setting values and all input data such as memorized values and disturbance records can be read via the front communication port.

Only one of the possible clients can be used for parametrization at a time.

- PCM600
- LHMI
- WHMI

The default IP address of the IED through this port is 192.168.0.254.

The front port supports TCP/IP protocol. A standard Ethernet CAT 5 crossover cable is used with the front port.

The speed of the front connector interface is limited to 10 Mbps.

## 12.2.2 Ethernet rear connections

The Ethernet communication module is provided with either galvanic RJ-45 connection or optical multimode LC type connection depending on the product variant and selected communication interface option. A shielded twisted-pair cable CAT 5e is used with RJ-45, and an optical cable ( ≤2 km) with LC type connections.

Additionally, line-differential communication modules [1] enable daisy-chaining of the Ethernet devices through connectors X1 and X2. These variants include an internal switch which manages the Ethernet traffic between an IED and a station bus.

The IED's default IP address through this port is 192.168.2.10 with the TCP/IP protocol. The data transfer rate is 100 Mbps.

### 12.2.3 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.

### 12.2.4 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 IED is used is 32, and the maximum length of the bus is 1200 meters.

### 12.2.5 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.

### 12.2.6 Communication interfaces and protocols

The communication protocols supported depend on the optional rear communication module.

*Table 405: Supported station communication interfaces and protocols*

| Interfaces/ Protocols | Ethernet | | Serial | |
|---|---|---|---|---|
| | 100BASE-TX RJ-45 | 100BASE-FX LC1) | EIA-232/EIA-485 | Fibre-optic ST |
| IEC 61850 | ● | ● | - | - |
| MODBUS RTU/ ASCII | - | - | ● | ● |
| MODBUS TCP/IP | ● | ● | - | - |

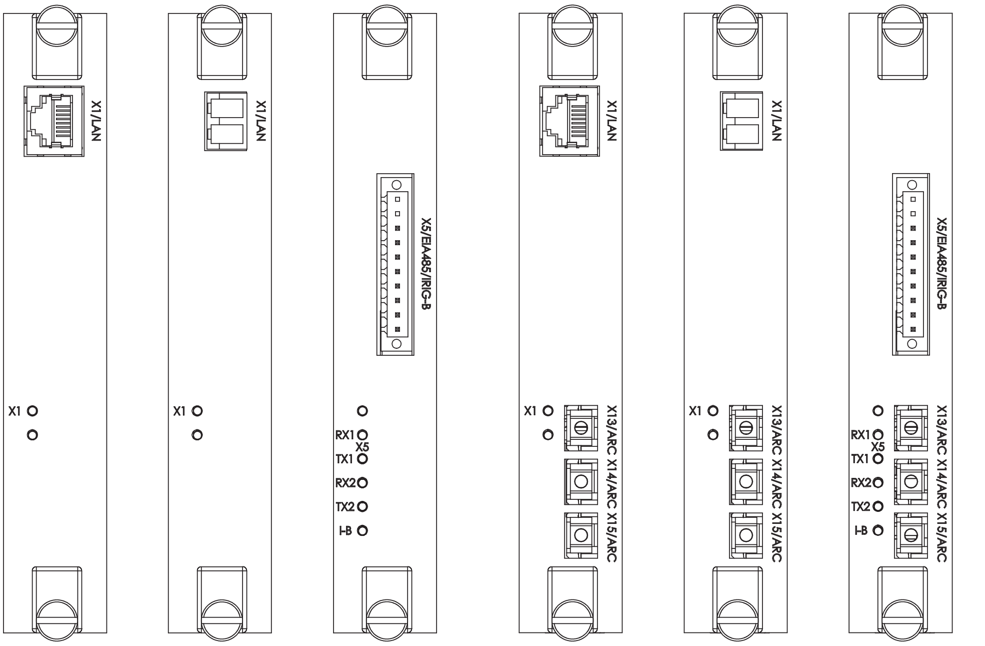
Table continues on next page

[1] Available only for RED615

| Interfaces/ Protocols | Ethernet | | Serial | |
|---|---|---|---|---|
| | 100BASE-TX RJ-45 | 100BASE-FX LC1) | EIA-232/EIA-485 | Fibre-optic ST |
| DNP3 (serial) | - | - | ● | ● |
| DNP3 TCP/IP | ● | ● | - | - |
| IEC 60870-5-103 | - | - | ● | ● |
| ● = Supported | | | | |

1) Not available for RED615

## 12.2.7 Rear communication modules




COM0001
RJ-45

COM0002
LC

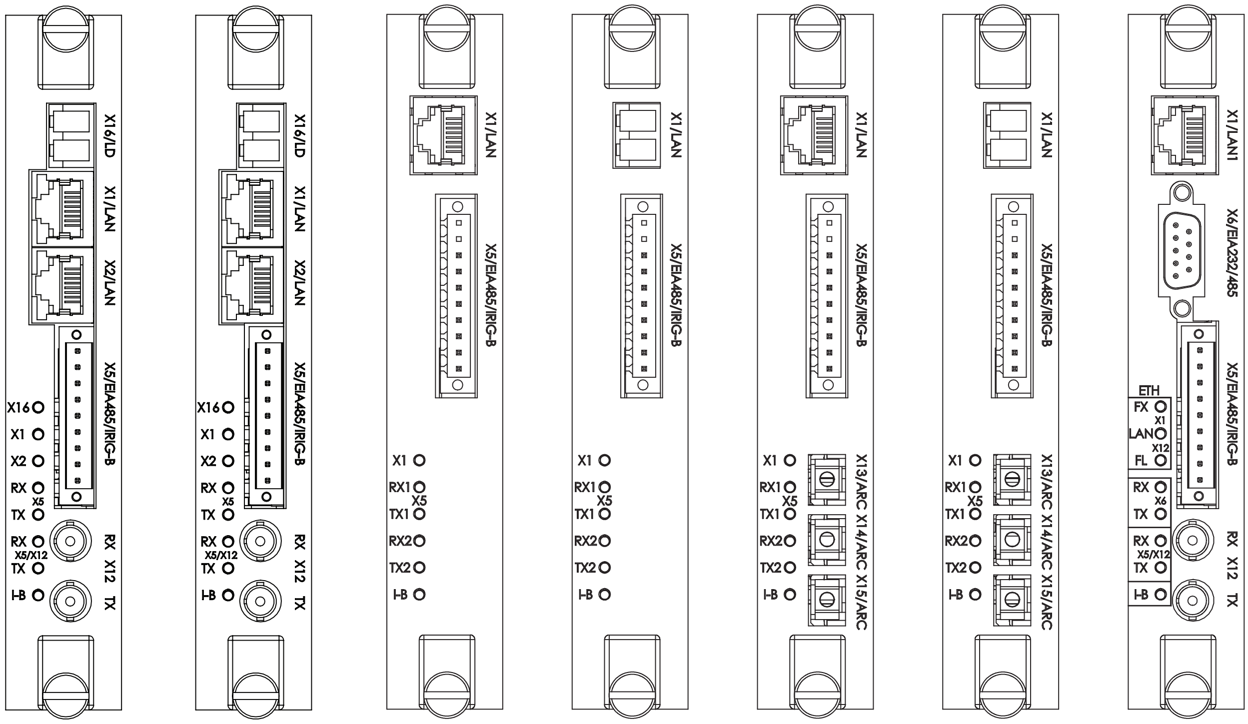
COM0003
RS485+IRIG-B

COM0005
RJ-45+ARC

COM0006
LC+ARC

COM0007
RS485+IRIG-B+
ARC

*Figure 282: Communication module options*




| COM0008 | COM0010 | COM0011 RJ-45+RS485+ IRIG-B | COM0012 LC+RS485+ IRIG-B | COM0013 RJ-45+RS485+ IRIG-B+ARC | COM0014 LC+RS485+ IRIG-B+ARC | COM0023 RJ-45+RS232/485+ RS485+ST+ IRIG-B |
|---|---|---|---|---|---|---|

*Figure 283: Communication module options*

*Table 406: Communication interfaces included in communication modules*

| Module ID | RJ-45 | LC | EIA-485 | EIA-232 | ST |
|---|---|---|---|---|---|
| COM0001 | ● | - | - | - | - |
| COM0002 | - | ● | - | - | - |
| COM0003 | - | - | ● | - | - |
| COM0005 | ● | - | - | - | - |
| COM0006 | - | ● | - | - | - |
| COM0007 | - | - | ● | - | - |
| COM0008[1)] | ● | - | ● | - | ● |
| COM0010[1)] | ● | - | ● | - | ● |
| COM0011 | ● | - | ● | - | - |
| COM0012 | - | ● | ● | - | - |
| COM0013 | ● | - | ● | - | - |
| COM0014 | - | ● | ● | - | - |
| COM0023 | ● | - | ● | ● | ● |

1) Available only for RED615

*Table 407: LED descriptions for COM0001-COM0014*

| LED | Connector | Description[1)] |
|---|---|---|
| LAN | X1 | LAN link status and activity (RJ-45 and LC) |
| RX1 | X5 | COM2 2-wire/4-wire receive activity |
| TX1 | X5 | COM2 2-wire/4-wire transmit activity |
| RX2 | X5 | COM1 2-wire receive activity |
| TX2 | X5 | COM1 2-wire transmit activity |
| I-B | X5 | IRIG-B signal activity |

1) Depending on the COM module and jumper configuration

*Table 408: LED descriptions for COM0008 and COM0010*

| LED | Description[1)] |
|---|---|
| X16 | X16/LD link status and activity |
| X1 | X1/LAN link status and activity |
| X2 | X2/LAN link status and activity |
| RX (X5) | COM1 2-wire receive activity/COM2 4-wire receive activity |
| TX (X5) | COM1 2-wire transmit activity/COM2 4-wire transmit activity |
| RX (X5/X12) | COM2 2-wire receive activity/COM2 4-wire receive activity |
| TX (X5/X12) | COM2 2-wire transmit activity/COM2 4-wire transmit activity |
| I-B | IRIG-B signal activity |

1) Depending on the jumper configuration

*Table 409: LED descriptions for COM0023*

| LED | Connector | Description[1)] |
|---|---|---|
| FX | X12 | Not used by COM0023 |
| LAN | X1 | LAN Link status and activity (RJ-45 and LC) |
| FL | X12 | Not used by COM0023 |
| RX | X6 | COM1 2-wire / 4-wire receive activity |
| TX | X6 | COM1 2-wire / 4-wire transmit activity |
| RX | X5 / X12 | COM2 2-wire / 4-wire or fiber-optic receive activity |
| TX | X5 / X12 | COM2 2-wire / 4-wire or fiber-optic transmit activity |
| I-B | X5 | IRIG-B Signal activity |

1) Depending on the jumper configuration

### 12.2.7.1 COM0001-COM0014 jumper locations and connections

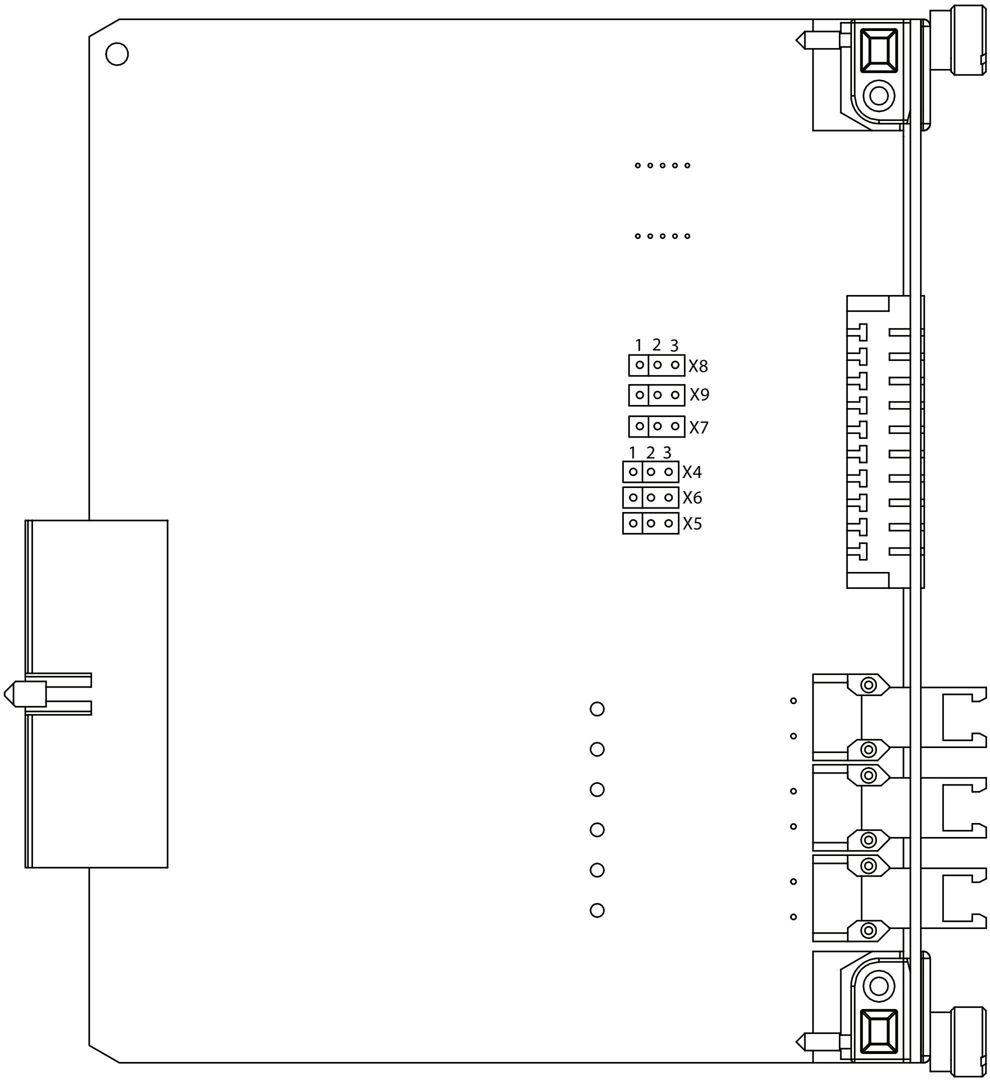



*Figure 284: Jumper connectors on communication module*

*Table 410: 2-wire EIA-485 jumper connectors*

| Group | Jumper connection | Description | Notes |
|---|---|---|---|
| X4 | 1-2 | A+ bias enabled | COM2<br>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 next page | | | |

| Group | Jumper connection | Description | Notes |
|---|---|---|---|
| X7 | 1-2 | B- bias enabled | COM1<br>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 411: 4-wire EIA-485 jumper connectors for COM2*

| Group | Jumper connection | Description | Notes |
|---|---|---|---|
| X4 | 1-2 | A+ bias enabled | COM2<br>4-wire TX channel |
| | 2-3 | A+ bias disabled [1)] | |
| 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<br>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)] | |

1) Default setting

It is recommended to enable biasing only at one end of the bus.

Termination is enabled at each end of the bus.

It is recommended to ground the signal directly to earth from one node and through capacitor from other nodes.

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 fibre-optic ST connection uses the COM1 port.

*Table 412: 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) | | | |

## 12.2.7.2 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 calIed. COM1 and COM2. Alternatively, if only one 4-wire-port is configured, the port is called COM2. The fibre-optic ST connection uses the COM1 port.

*Table 413: 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) |

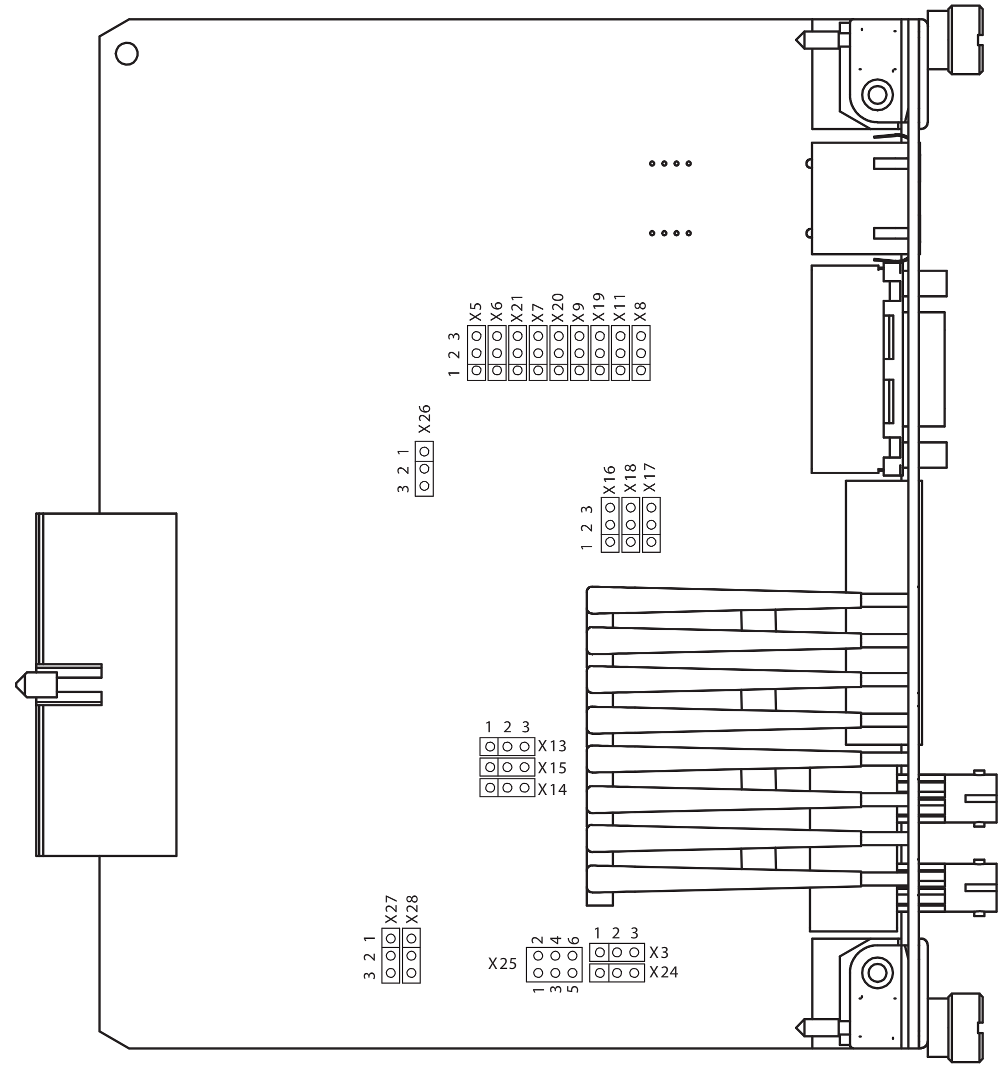



*Figure 285:* *Jumper connections on communication module COM0023*

COM1 port connection type can be either EIA-232 or EIA-485. Type is selected by setting jumpers X19, X20, X21, X26.

The jumpers are set to EIA-232 by default.

*Table 414:* *EIA-232 and EIA-485 jumper connectors for COM1*

| Group | Jumper connection | Description |
|---|---|---|
| X19 | 1-2<br>2-3 | EIA-485<br>EIA-232 |
| X20 | 1-2<br>2-3 | EIA-485<br>EIA-232 |
| X21 | 1-2<br>2-3 | EIA-485<br>EIA-232 |
| X26 | 1-2<br>2-3 | EIA-485<br>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, X9 to enabled position. The bus termination is selected by setting jumpers X7, X11 to enabled position.

The jumpers have been set to no termination and no biasing as default.

*Table 415: 2-wire EIA-485 jumper connectors for COM1*

| Group | Jumper connection | Description | Notes |
|---|---|---|---|
| X5 | 1-2<br>2-3 | A+ bias enabled<br>A+ bias disabled[1] | COM1<br>Rear connector X6<br>2-wire connection |
| X6 | 1-2<br>2-3 | B- bias enabled<br>B- bias disabled[1] | |
| X7 | 1-2<br>2-3 | Bus termination enabled<br>Bus termination disabled[1] | |

1) Default setting

*Table 416: 4–wire EIA-485 jumper connectors for COM1*

| Group | Jumper connection | Description | Notes |
|---|---|---|---|
| X5 | 1-2<br>2-3 | A+ bias enabled<br>A+ bias disabled[1] | COM1<br>Rear connector X6<br>4-wire TX channel |
| X6 | 1-2<br>2-3 | B- bias enabled<br>B- bias disabled[1] | |
| X7 | 1-2<br>2-3 | Bus termination enabled<br>Bus termination disabled[1] | |
| X9 | 1-2<br>2-3 | A+ bias enabled<br>A+ bias disabled[1] | 4-wire RX channel |
| X8 | 1-2<br>2-3 | B- bias enabled<br>B- bias disabled[1] | |
| X11 | 1-2<br>2-3 | Bus termination enabled<br>Bus termination disabled[1] | |

1) Default setting

COM2 port connection can be either EIA-485 or optical ST. Connection type is selected by setting jumpers X27 and X28.

*Table 417: COM2 serial connection X5 EIA-485/ X12 Optical ST*

| Group | Jumper connection | Description |
|---|---|---|
| X27 | 1-2<br>2-3 | EIA-485<br>Optical ST |
| X28 | 1-2<br>2-3 | EIA-485<br>Optical ST |

*Table 418: 2-wire EIA-485 jumper connectors for COM2*

| Group | Jumper connection | Description |
|---|---|---|
| X13 | 1-2<br>2-3 | A+ bias enabled<br>A+ bias disabled |
| X14 | 1-2<br>2-3 | B- bias enabled<br>B- bias disabled |
| X15 | 1-2<br>2-3 | Bus termination enabled<br>Bus termination disabled |

*Table 419: 2-wire EIA-485 jumper connectors for COM2*

<table>
<tr><th>Group</th><th>Jumper connection</th><th>Description</th><th>Notes</th></tr>
<tr><td>X13</td><td>1-2<br>2-3</td><td>A+ bias enabled<br>A+ bias disabled</td><td rowspan="3">COM2<br>4-wire TX channel</td></tr>
<tr><td>X14</td><td>1-2<br>2-3</td><td>B- bias enabled<br>B- bias disabled</td></tr>
<tr><td>X15</td><td>1-2<br>2-3</td><td>Bus termination enabled<br>Bus termination disabled</td></tr>
<tr><td>X17</td><td>1-2<br>2-3</td><td>A+ bias enabled<br>A+ bias disabled</td><td rowspan="3">4-wire RX channel</td></tr>
<tr><td>X18</td><td>1-2<br>2-3</td><td>B- bias enabled<br>B- bias disabled</td></tr>
<tr><td>X19</td><td>1-2<br>2-3</td><td>Bus termination enabled<br>Bus termination disabled</td></tr>
</table>

*Table 420: X12 Optical ST connection*

| Group | Jumper connection | Description |
|---|---|---|
| X3 | 1-2<br>2-3 | Star topology<br>Loop topology |
| X24 | 1-2<br>2-3 | Idle state = Light on<br>Idle state = Light off |

*Table 421: 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 422: EIA-485 connections for COM0023 (X6)*

| Pin | 2-wire mode | 4-wire mode |
|---|---|---|
| 1 | - | Rx/+ |
| 6 | - | Rx/- |
| 7 | B/- | Tx/- |
| 8 | A/+ | Tx/+ |

*Table 423: 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) | |

### 12.2.7.3 COM0008 and COM0010 jumper locations and connections

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 or 4-wire, half-duplex, multi-point communication. Serial communication can be also used through optical connection which is used either in loop or star topology.

Two parallel 2-wire serial communication channels can be used at the same time. Also optical serial connector can be used in parallel with one 2-wire or 4-wire serial channel.

The maximum number of devices (nodes) connected to the bus where the IED is being used is 32, and the maximum length of the bus is 1200 meters.

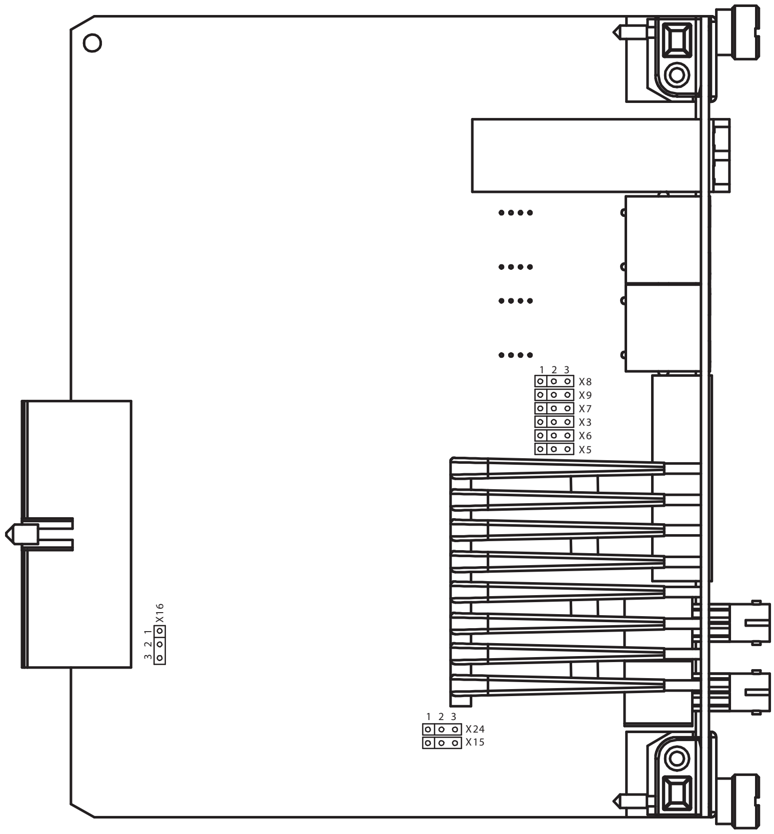



*Figure 286: Jumper connectors on communication module*

*Table 424: 2-wire EIA-485 jumper connectors*

| Group | Jumper connection | Description | Notes |
|---|---|---|---|
| X3 | 1-2 | A+ Bias enabled | COM1<br>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 | |
| X7 | 1-2 | B- Bias enabled | COM2<br>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 X3, 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 425: 4-wire EIA-485 jumper connectors for COM2*

| Group | Jumper connection | Description | Notes |
|---|---|---|---|
| X3 | 1-2 | A+ Bias enabled | COM2<br>4-wire TX channel |
| | 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 | |
| X7 | 1-2 | B- Bias enabled | COM2<br>4-wire RX channel |
| | 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 | |

*Table 426: Jumper connectors for COM1 serial connection type*

| Group | Jumper connection | Description |
|---|---|---|
| X16 | 1-2 | EIA-485 selected for COM1 |
| | 2-3 | FO_UART selected for COM1 |
| X15 | 1-2 | Star topology selected for FO_UART |
| | 2-3 | Loop topology selected for FO_UART |
| X24 | 1-2 | FO_UART channel idle state: Light on |
| | 2-3 | FO_UART channel idle state: Light off |

It is recommended to enable biasing only at one end of the bus.

Termination is enabled at each end of the bus

It is recommended to ground the signal directly to earth from one node and through capacitor from other nodes.

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 as COM1 and COM2. Alternatively, if there is only one 4-wire port configured, the port is called COM2. The fibre-optic ST connection uses the COM1 port.

*Table 427: EIA-485 connections for COM0008 and COM0010*

| Pin | 2-wire mode | | 4-wire mode | |
|---|---|---|---|---|
| 9 | COM1 | A/+ | COM2 | Rx/+ |
| 8 | | B/- | | Rx/- |
| 7 | COM2 | A/+ | | Tx/+ |
| 6 | | B/- | | Tx/- |
| 5 | AGND (isolated ground) | | | |
| 4 | IRIG-B + | | | |
| 3 | IRIG-B - | | | |
| 2 | GNDC (case via capasitor) | | | |
| 1 | GND (case) | | | |

## 12.2.8 Recommended industrial Ethernet switches

ABB recommends three third-party industrial Ethernet switches.

- RuggedComRS900
- RuggedCom RS1600
- RuggedCom RSG2100

# Section 13 Technical data

*Table 428: Dimensions*

| Description | Value | |
|---|---|---|
| Width | frame | 179.8 mm |
| | case | 164 mm |
| Height | frame | 177 mm (4U) |
| | case | 160 mm |
| Depth | | 194 mm (153 + 41 mm) |
| Weight | IED | 3.5 kg |
| | spare unit | 1.8 kg |

*Table 429: Power supply*

| Description | Type 1 | Type 2[1)] |
|---|---|---|
| $U_{aux}$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 | |
| $U_{aux}$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 < 9.0 W (nominal)/< 15.1 W (max)<br>AC< 10.7 W (nominal)/< 16.7 W (max) | DC < 6.9 W (nominal)/< 13.3 W (max) |
| Table continues on next page | | |

| Description | Type 1 | Type 2[1)] |
|---|---|---|
| Ripple in the DC auxiliary voltage | Max 12% of the DC value (at frequency of 100 Hz) | |
| Maximum interruption time in the auxiliary DC voltage without resetting the IED | RED615:<br>• 110 V DC: 84 ms<br>• 110 V AC: 124 ms<br><br>REF615:<br>• 110 V DC: 84 ms<br>• 110 V AC: 116 ms<br><br>REM615:<br>• 110 V DC: 86 ms<br>• 110 V AC: 118 ms<br><br>RET615:<br>• 110 V DC: 106 ms<br>• 110 V AC: 166 ms | REF615: 48 V DC: 68 ms<br>REM615: 48 V DC: 64 ms<br>RET615: 48 V DC: 74 ms |
| Fuse type | T4A/250 V | |

1) Not available for RED615

*Table 430: Energizing inputs*

| Description | | Value | |
|---|---|---|---|
| Rated frequency | | 50/60 Hz ± 5 Hz | |
| Current inputs | Rated current, $I_n$ | 0.2/1 A[1)2)] | 1/5 A[3)] |
| | Thermal withstand capability:<br>• Continuously<br>• For 1 s | <br>4 A<br>100 A | <br>20 A<br>500 A |
| | Dynamic current withstand:<br>• Half-wave value | <br>250 A | <br>1250 A |
| | Input impedance | <100 mΩ | <20 mΩ |
| Voltage inputs[4)] | Rated voltage | 100 V AC/ 110 V AC/ 115 V AC/ 120 V AC (Parametrization) | |
| | Voltage withstand:<br>• Continuous<br>• For 10 s | <br>2 x $U_n$ (240 V AC)<br>3 x $U_n$ (360 V AC) | |
| | Burden at rated voltage | <0.05 VA | |

1) Ordering option for residual current input
2) Not available for RET625
3) Residual current and/or phase current
4) Not available for RED615 and RET615

*Table 431: 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 | 18...176 V DC |
| Reaction time | 3 ms |

*Table 432: Signal outputs and IRF output*

| Description | Value |
|---|---|
| Rated voltage | 250 V AC/DC |
| Continuous contact carry | 5 A |
| Make and carry for 3.0 s | 10 A |
| Make and carry 0.5 s | 15 A |
| Breaking capacity when the control-circuit time constant L/R<40 ms, at 48/110/220 V DC | 1 A/0.25 A/0.15 A |
| Minimum contact load | 100 mA at 24 V AC/DC |

*Table 433: Double-pole power output relays with TCS function*

| Description | Value |
|---|---|
| Rated voltage | 250 V AC/DC |
| Continuous contact carry | 8 A |
| Make and carry for 3.0 s | 15 A |
| Make and carry for 0.5 s | 30 A |
| Breaking capacity when the control-circuit time constant L/R<40 ms, at 48/110/220 V DC (two contacts connected in series) | 5 A/3 A/1 A |
| Minimum contact load | 100 mA at 24 V AC/DC |
| Trip-circuit supervision (TCS): | |
| • Control voltage range | 20...250 V AC/DC |
| • Current drain through the supervision circuit | ~1.5 mA |
| • Minimum voltage over the TCS contact | 20 V AC/DC (15...20 V) |

*Table 434: Single-pole power output relays*

| 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, at 48/110/220 V DC | 5 A/3 A/1 A |
| Minimum contact load | 100 mA at 24 V AC/DC |

*Table 435: 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 fibre-optic cable with LC connector | 100 MBits/s |

*Table 436: Serial rear interface*

| Type | Counter connector |
|---|---|
| Serial port (X5) | 10-pin counter connector Weidmüller BL 3.5/10/180F AU OR BEDR<br>or<br>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) Depending on the optional communication module

*Table 437: Fibre-optic communication link*

| Connector | Fibre type | Wave length | Max. distance | Permitted path attenuation[1)] |
|---|---|---|---|---|
| LC | MM 62.5/125 μm glass fibre core | 1300 nm | 2 km | <8 dB |
| ST | MM 62.5/125 μm glass fibre core | 820-900 nm | 1 km | <11 dB |

1) Maximum allowed attenuation caused by connectors and cable together

*Table 438: Lens sensor and optical fibre for arc protection*

| Description | Value |
|---|---|
| Fibre-optic cable including lens | 1.5 m, 3.0 m or 5.0 m |
| Normal service temperature range of the lens | -40...+100 °C |
| Maximum service temperature range of the lens, max 1 h | +140°C |
| Minimum permissible bending radius of the connection fibre | 100 mm |

*Table 439: Degree of protection of flush-mounted IED*

| Description | Value |
|---|---|
| Front side | IP 54 |
| Rear side, connection terminals | IP 20 |

*Table 440: Environmental conditions*

| Description | Value |
|---|---|
| Operating temperature range | -25...+55ºC (continuous) |
| Short-time service temperature range | • REF615, REM615 and RET615: -40...+85ºC (<16 h)1)2)<br>• RED615: -40...+70ºC (<16 h)1)2) |
| Relative humidity | <93%, non-condensing |
| Atmospheric pressure | 86...106 kPa |
| Altitude | Up to 2000 m |
| Transport and storage temperature range | -40...+85ºC |

1) Degradation in MTBF and HMI performance outside the temperature range of -25...+55 ºC
2) For IEDs with an LC communication interface the maximum operating temperature is +70 ºC

*Table 441: Environmental tests*

| Description | Type test value | Reference |
|---|---|---|
| Dry heat test (humidity <50%) | • 96 h at +55ºC<br>• 16 h at +85ºC1) | IEC 60068-2-2 |
| Dry cold test | • 96 h at -25ºC<br>• 16 h at -40ºC | IEC 60068-2-1 |
| Damp heat test, cyclic | • 6 cycles (12 h + 12 h) at +25°C…+55°C, humidity >93% | IEC 60068-2-30 |
| Storage test | • 96 h at -40ºC<br>• 96 h at +85ºC | IEC 60068-2-48 |

1) For IEDs with an LC communication interface the maximum operating temperature is +70ºC

# Section 14 IED and functionality tests

*Table 442: Electromagnetic compatibility tests*

| Description | Type test value | Reference |
|---|---|---|
| 1 MHz burst disturbance test: | | IEC 61000-4-18 and IEC 60255-22-1, level 3 |
| • Common mode | 2.5 kV | |
| • Differential mode | 1.0 kV | |
| Electrostatic discharge test: | | IEC 61000-4-2, IEC 60255-22-2 and IEEE C37.90.3.2001 |
| • Contact discharge | 8 kV | |
| • Air discharge | 15 kV | |
| Radio frequency interference tests: | | IEC 61000-4-6 and IEC 60255-22-6, level 3 |
| • Conducted, common mode | 10 V (rms), f=150 kHz...80 MHz | |
| • Radiated, amplitude-modulated | 10 V/m (rms), f=80...2700 MHz | IEC 61000-4-3 and IEC 60255-22-3, level 3 |
| • Radiated, pulse-modulated | 10 V/m, f=900 MHz | ENV 50204 and IEC 60255-22-3, level 3 |
| Fast transient disturbance tests: | | IEC 61000-4-4 and IEC 60255-22-4, class A |
| • All ports | 4kV | |
| Surge immunity test: | | IEC 61000-4-5 and IEC 60255-22-5, level 4/3 |
| • Binary inputs | 4 kV, line-to-earth<br>2 kV, line-to-line | |
| • Communication | 1 kV, line-to-earth | |
| • Other ports | 4 kV, line-to-earth<br>2 kV, line-to-line | |
| Power frequency (50 Hz) magnetic field: | | IEC 61000-4-8, level 5 |
| • Continuous | 300 A/m | |
| Table continues on next page | | |

| Description | Type test value | Reference |
|---|---|---|
| Power frequency immunity test:<br>• Common mode<br>• Differential mode | Binary inputs only<br>300 V rms<br>150 V rms | IEC 61000-4-16 and IEC 60255-22-7, class A |
| Voltage dips and short interruptions | 30%/10 ms<br>60%/100 ms<br>60%/1000 ms<br>>95%/5000 ms | IEC 61000-4-11 |
| Electromagnetic emission tests:<br>• Conducted, RF-emission (mains terminal)<br>0.15...0.50 MHz<br>0.5...30 MHz<br>• Radiated RF -emission<br>30...230 MHz<br>230...1000 MHz | <br><br>< 79 dB(µV) quasi peak<br>< 66 dB(µV) average<br>< 73 dB(µV) quasi peak<br>< 60 dB(µV) average<br><br>< 40 dB(µV/m) quasi peak, measured at 10 m distance<br>< 47 dB(µV/m) quasi peak, measured at 10 m distance | EN 55011, class A and IEC 60255-25 |

*Table 443: Insulation tests*

| Description | Type test value | Reference |
|---|---|---|
| Dielectric tests:<br>• Test voltage | 2 kV, 50 Hz, 1 min<br>500 V, 50 Hz, 1min, communication | IEC 60255-5 |
| Impulse voltage test:<br>• Test voltage | 5 kV, unipolar impulses, waveform 1.2/50 µs, source energy 0.5 J<br>1 kV, unipolar impulses, waveform 1.2/50 µs, source energy 0.5 J, communication | IEC 60255-5 |
| Insulation resistance measurements<br>• Isolation resistance | >100 MΩ, 500 V DC | IEC 60255-5 |
| Protective bonding resistance<br>• Resistance | <0.1 Ω, 4 A, 60 s | IEC 60255-27 |

*Table 444: Mechanical tests*

| Description | Reference | Requirement |
|---|---|---|
| Vibration tests (sinusoidal) | IEC 60068-2-6 (test Fc)<br>IEC 60255-21-1 | Class 2 |
| Shock and bump test | IEC 60068-2-27 (test Ea Shock)<br>IEC 60068-2-29 (test Eb Bump)<br>IEC 60255-21-2 | Class 2 |

*Table 445: Product safety*

| Description | Reference |
|---|---|
| LV directive | 2006/95/EC |
| Standard | EN 60255-27 (2005)<br>EN 60255-6 (1994) |

## 14.1 EMC compliance

*Table 446: EMC compliance*

| Description | Reference |
|---|---|
| EMC directive | 2004/108/EC |
| Standard | EN 50263 (2000)<br>EN 60255-26 (2007) |

# Section 15 Applicable standards and regulations

EN 50263

EN 60255-26

EN 60255-27

EMC council directive 2004/108/EC

EU directive 2002/96/EC/175

IEC 60255

Low-voltage directive 2006/95/EC

# Section 16 Glossary

| | |
|---|---|
| 100BASE-TX | A physical media 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 |
| AIM | Analog input module |
| CAT 5 | A twisted pair cable type designed for high signal integrity |
| CAT 5e | An enhanced version of CAT 5 that adds specifications for far end crosstalk |
| CB | Circuit breaker |
| CBB | Cycle building block |
| CPU | Central processing unit |
| CT | Current transformer |
| CTS | Clear to send |
| DFT | Discrete Fourier transform |
| DHCP | Dynamic Host Configuration Protocol |
| DNP3 | A distributed network protocol originally developed by Westronic. The DNP3 Users Group has the ownership of the protocol and assumes responsibility for its evolution. |
| DSR | Data set ready |
| DT | Definite time |
| DTR | Data terminal ready |
| 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 |
| FPGA | Field programmable gate array |
| GOOSE | Generic Object Oriented Substation Event |
| GPS | Global Positioning System |
| HMI | Human-machine interface |
| IDMT | Inverse definite minimum time |

| | |
|---|---|
| IEC | International Electrotechnical Commission |
| IEC 60870-5-103 | Communication standard for protective equipment; A serial master/slave protocol for point-to-point communication |
| IEC 61850 | International standard for substation communication and modelling |
| IED | Intelligent electronic device |
| 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. |
| IRIG-B | Inter-Range Instrumentation Group's time code format B |
| LAN | Local area network |
| LC | Connector type for glass fibre cable |
| LCD | Liquid crystal display |
| LED | Light-emitting diode |
| LHMI | Local human-machine interface |
| Modbus | A serial communication protocol developed by the Modicon company in 1979. Originally used for communication in PLCs and RTU devices. |
| MV | Medium voltage |
| NPS | Negative phase sequence |
| PC | Personal computer; Polycarbonate |
| PCM600 | Protection and Control IED Manager |
| Peak-to-peak | The amplitude of a waveform between its maximum positive value and its maximum negative value; 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 |
| RAM | Random access memory |
| RCA | Also known as MTA or base angle. Characteristic angle. |
| RED615 | Line differential protection and control IED |

| | |
|---|---|
| RET615 | Transformer protection and control IED |
| RJ-45 | Galvanic connector type |
| RMS | Root-mean-square (value) |
| ROM | Read-only memory |
| RTC | Real-time clock |
| RTS | Ready to send |
| SBO | Select-before-operate |
| SCL | Substation configuration language |
| SMT | Signal Matrix Tool in PCM600 |
| SNTP | Simple Network Time Protocol |
| SOTF | Switch on to fault |
| SW | Software |
| TCP/IP | Transmission Control Protocol/Internet Protocol |
| TCS | Trip-circuit supervision |
| UTC | Coordinated universal time |
| WAN | Wide area network |
| WHMI | Web human-machine interface |

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