

Application Manual

Feeder Protection Relay

REF615





Document ID: 1MRS756378
Issued: 02.07.2008
Revision: C
Product version: 1.1

© Copyright 2008 - ABB. All rights reserved

Copyright

This document and parts thereof must not be reproduced or copied without written permission from ABB, and the contents thereof must not be imparted to a third party, nor used for any unauthorized purpose.

The software or hardware described in this document is furnished under a license and may be used, copied, or disclosed only in accordance with the terms of such license.

Trademarks

ABB is a registered trademark of ABB Group. All other brand or product names mentioned in this document may be trademarks or registered trademarks of their respective holders.

Guarantee

Please inquire about the terms of guarantee from your nearest ABB representative.

ABB Oy
Distribution Automation
P.O. Box 699
FI-65101 Vaasa, Finland
Telephone: +358 10 2211
Facsimile: +358 10 22 41094
<http://www.abb.com/substationautomation>

Disclaimer

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

This document has been carefully checked by ABB but deviations cannot be completely ruled out. In case any errors are detected, the reader is kindly requested to notify the manufacturer. Other than under explicit contractual commitments, in no event shall ABB be responsible or liable for any loss or damage resulting from the use of this manual or the application of the equipment.

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 Council 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 a test conducted by ABB in accordance with Article 10 of the directive in agreement 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.....	7
	This manual.....	7
	Intended audience.....	7
	Product documentation.....	8
	Product documentation set.....	8
	Document revision history.....	9
	Related documentation.....	10
	Document symbols and conventions.....	10
	Safety indication symbols.....	10
	Document conventions.....	11
	Functions, codes and symbols.....	11
Section 2	REF615 overview.....	13
	Overview.....	13
	Product version history.....	13
	PCM600 and IED connectivity package version.....	14
	Operation functionality.....	14
	Standard configurations.....	14
	Optional functions.....	16
	Physical hardware.....	16
	LHMI.....	17
	LCD.....	18
	LEDs.....	18
	Keypad.....	19
	WHMI.....	19
	Authorization.....	20
	Communication.....	21
Section 3	REF615 variants.....	23
	REF615 variant list.....	23
	Presentation of standard configurations.....	23
	Standard configurations.....	24
	Connection diagrams.....	26
	Standard configuration A including directional earth-fault protection.....	28
	Applications.....	28
	Functions.....	28
	Default I/O connections.....	29
	Functional diagrams.....	30
	Functional diagrams for protection.....	30

Functional diagrams for disturbance recorder and trip circuit supervision.....	35
Functional diagrams for control and interlocking.....	36
Standard configuration B including directional earth-fault protection and CB condition monitoring.....	38
Applications.....	38
Functions.....	38
Default I/O connections.....	39
Functional diagrams.....	40
Functional diagrams for protection.....	41
Functional diagram for disturbance recorder and trip circuit supervision.....	46
Functional diagrams for control and interlocking.....	47
Standard configuration C including non-directional earth-fault protection.....	51
Applications.....	51
Functions.....	51
Default I/O connections.....	52
Functional diagrams.....	53
Functional diagrams for protection.....	53
Functional diagram for disturbance recorder and trip circuit supervision.....	58
Functional diagrams for control and interlocking.....	59
Standard configuration D including non-directional earth-fault protection and CB condition monitoring.....	61
Applications.....	61
Functions.....	61
Default I/O connections.....	62
Functional diagrams.....	63
Functional diagrams for protection.....	63
Functional diagram for disturbance recorder and trip circuit supervision.....	68
Functional diagrams for control and interlocking.....	69
Section 4 Basic functions.....	73
General parameters.....	73
Self-supervision.....	83
Internal faults.....	83
Warnings.....	85
Time synchronization.....	86
Parameter setting groups.....	87
Section 5 Protection functions.....	89
Three-phase current protection.....	89

Three-phase non-directional overcurrent protection PHxPTOC.....	89
Identification.....	89
Functionality.....	89
Application.....	89
Three-phase thermal overload protection for overhead lines and cables T1PTTR.....	96
Identification.....	96
Functionality.....	96
Application.....	97
Earth-fault protection.....	97
Non-directional earth-fault protection EfxPTOC.....	97
Identification.....	97
Functionality.....	98
Application.....	98
Directional earth-fault protection DEFxPDEF.....	98
Identification.....	98
Functionality.....	99
Directional earth-fault principles.....	99
Application.....	102
Transient/intermittent earth-fault protection INTRPTEF.....	104
Identification.....	104
Functionality.....	104
Application.....	105
Unbalance protection.....	108
Negative phase-sequence current protection NSPTOC.....	108
Identification.....	108
Functionality.....	108
Application.....	108
Phase discontinuity PDNSPTOC.....	109
Identification.....	109
Functionality.....	109
Application.....	109
Arc protection ARCSARC.....	111
Identification.....	111
Functionality.....	111
Application.....	112
Section 6 Protection related functions.....	117
Three-phase inrush detector INRPHAR.....	117
Identification.....	117
Functionality.....	117
Application.....	117
Circuit breaker failure protection CCBRBRF.....	118

	Identification.....	118
	Functionality.....	118
	Application.....	119
	Protection trip conditioning TRPPTRC.....	120
	Identification.....	120
	Functionality.....	120
	Application.....	121
Section 7	Supervision functions.....	123
	Trip circuit supervision TCSSCBR.....	123
	Identification.....	123
	Functionality.....	123
	Application.....	123
Section 8	Condition monitoring functions.....	133
	Circuit breaker condition monitoring SSCBR.....	133
	Identification.....	133
	Functionality.....	133
	Application.....	133
Section 9	Measurement functions.....	137
	Basic measurements.....	137
	Three-phase current CMMXU.....	137
	Identification.....	137
	Neutral current RESCMMXU.....	137
	Identification.....	137
	Sequence current CSMSQI.....	137
	Identification.....	137
	Residual voltage RESVMMXU.....	137
	Identification.....	137
	Functions.....	138
	Measurement function applications.....	138
	Disturbance recorder.....	139
	Functionality.....	139
	Application.....	139
Section 10	Control functions.....	141
	Circuit breaker control CBXCBR.....	141
	Identification.....	141
	Functionality.....	141
	Application.....	141
	Disconnecter control DCSXSWI and earthing switch control ESSXSWI.....	142
	Identification.....	142
	Functionality.....	142

Application.....	143
Interaction between control modules.....	143
Auto recloser DARREC.....	145
Identification.....	145
Functionality.....	145
Application.....	145
Shot initiation.....	146
Sequence.....	148
Configuration examples.....	149
Delayed initiation lines.....	152
Shot initiation from protection start signal.....	154
Fast trip in Switch on to fault.....	154
Section 11 Requirements for measurement transformers.....	157
Current transformers.....	157
Current transformer requirements for non-directional overcurrent protection.....	157
Current transformer accuracy class and accuracy limit factor.....	157
Non-directional overcurrent protection.....	158
Example for non-directional overcurrent protection.....	159
Section 12 Glossary.....	161

Section 1 Introduction

1.1 This manual

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.

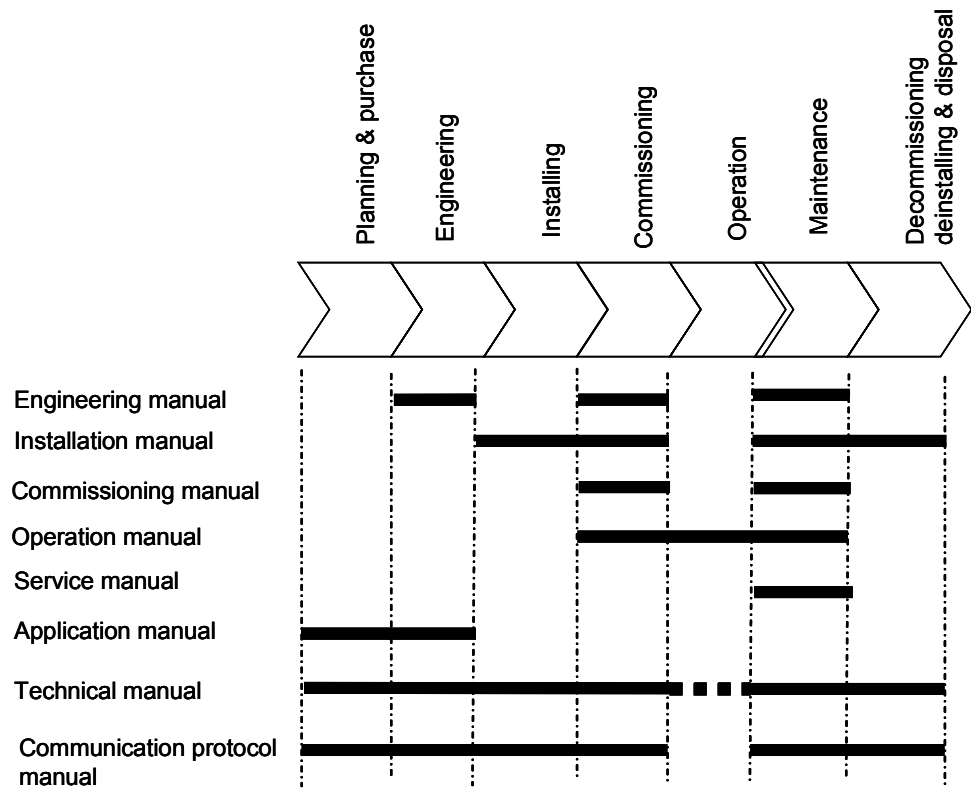
1.2 Intended audience

This manual addresses the protection and control engineer responsible for planning, pre-engineering and engineering.

The protection and control engineer must be experienced in electrical power engineering and have knowledge of related technology, such as communication and protocols.

1.3 Product documentation

1.3.1 Product documentation set



en07000220.vsd

Engineering Manual contains instructions on how to engineer the IED products. 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 IED products 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 the chronological order in which the protection 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 the chronological order in which the IED should be commissioned.

Operation Manual contains instructions on how to operate the IED during normal service once it has been commissioned. The manual can be used to find out how to handle disturbances or how to view calculated and measured network data in order 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.

The Communication Protocol manuals describe the different communication protocols supported by the IED. The manuals concentrate on vendor-specific implementations.

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



All manuals are not available yet.

1.3.2

Document revision history

Document revision/date	Product version	History
A/20.12.2007	1.0	First release
B/08.02.2008	1.0	Content updated
C/02.07.2008	1.1	Content updated to correspond to the product version



The latest revision of the document can be downloaded from the ABB web site <http://www.abb.com/substationautomation>

1.3.3 Related documentation

Name of the document	Document ID
Modbus Communication Protocol Manual	1MRS756468
Installation Manual	1MRS756375
Operation Manual	1MRS756376
Technical Manual	1MRS756377

1.4 Document symbols and conventions

1.4.1 Safety indication symbols

This publication includes the following 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 relevant 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

The following conventions are used for the presentation of material:

- Abbreviations in this manual are spelled out in the section "Glossary". In addition, the section contains descriptions on several terms.
- Push button navigation in the HMI menu structure is presented by using the push button icons, for example:
To navigate between the options, use  and .
- HMI menu paths are presented as follows:
Select **Main menu/Configuration/HMI**.
- Menu names are shown in bold in WHMI, for example:
Click **Information** in the WHMI menu structure.
- HMI 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

Table 1: Functions included in the REF615 standard configuration

Function	IEC 61850	IEC 61617	IEC-ANSI
Three-phase non-directional overcurrent protection, low stage	PHLPTOC1	3I>	51P-1
Three-phase non-directional overcurrent protection, high stage, instance 1	PHHPTOC1	3I>> (1)	51P-2 (1)
Three-phase non-directional overcurrent protection, high stage, instance 2	PHHPTOC2	3I>> (2)	51P-2 (2)
Three-phase non-directional overcurrent protection, instantaneous stage	PHIPTOC1	3I>>>	50P/51P
Arc protection	ARCSARC1 ARCSARC2 ARCSARC3	ARC (1) ARC (2) ARC (3)	50L/50NL (1) 50L/50NL (2) 50L/50NL (3)
Non-directional earth-fault protection, low stage	EFLPTOC1	I ₀ > (1)	51N-1 (1)
Non-directional earth-fault protection, low stage	EFLPTOC2	I ₀ > (2)	51N-1 (2)
Non-directional earth-fault protection, high stage	EFHPTOC1	I ₀ >>	51N-2
Non-directional earth-fault protection, instantaneous stage	EFIPTOC1	I ₀ >>>	50N/51N
Directional earth-fault protection, low stage, instance 1	DEFLPDEF1	I ₀ > → (1)	67N-1 (1)
Table continues on next page			

Function	IEC 61850	IEC 61617	IEC-ANSI
Directional earth-fault protection, low stage, instance 2	DEFLPDEF2	$I_0 > \rightarrow (2)$	67N-1 (2)
Directional earth-fault protection, high stage	DEFHPDEF1	$I_0 >> \rightarrow$	67N-2
Transient/Intermittent earth-fault protection	INTRPTEF1	$I_0 > \rightarrow$ IEF	67NIEF
Non-directional earth-fault protection, high stage (calculated I_0 current)	EFHPTOC1	$I_0 >>$	50N-2
Negative-sequence overcurrent protection, instance 1	NSPTOC1	$I_2 > (1)$	46 (1)
Negative-sequence overcurrent protection, instance 2	NSPTOC2	$I_2 > (2)$	46 (2)
Phase discontinuity	PDNSPTOC1	$I_2/I_1 >$	46PD
Three-phase inrush detector	INRPHAR1	$3I_2 f >$	68
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR1	$3I_{th} >$	49F
Autoreclosure	DARREC1	$O \rightarrow I$	79
Circuit breaker failure protection	CCBRBRF1	$3I > /I_0 > BF$	51BF/51NBF
Master Trip	TRPPTRC1 TRPPTRC2	Master Trip (1) Master Trip (2)	94/86 (1) 94/86 (2)
Trip circuit supervision, instance 1	TCSSCBR1	TCS (1)	TCM (1)
Trip circuit supervision, instance 2	TCSSCBR2	TCS (2)	TCM (2)
Disturbance recorder	RDRE1	-	-
Circuit breaker condition monitoring	SSCBR1	CBCM	CBCM
Three-phase current measurement	CMMXU1	$3I$	$3I$
Sequence current measurement	CSMSQI1	I_1, I_2, I_0	I_1, I_2, I_0
Residual current measurement	RESCMMXU1	I_0	I_n
Residual voltage measurement	RESVMMXU1	U_0	V_n

Section 2 REF615 overview

2.1 Overview

REF615 is a native IEC 61850 feeder protection relay for selective short-circuit, overcurrent and earth-fault protection. It is applicable to all types of radial isolated neutral networks, resistant earthed networks and compensated networks. REF615 is part of a product family that will cover main protection applications for utility and industry customers.

The IED features draw-out-type design, compact size and ease of use. Depending on the IED variant, the protection functions may include:

- Three-phase non-directional overcurrent protection, 4 stages
- Double earth-fault protection (cross-country earth-fault protection)
- Non-directional earth-fault, 3 stages
- Non-directional sensitive earth-fault
- Directional earth-fault protection, 3 stages
- Transient/intermittent earth-fault protection
- Negative-phase-sequence protection, 2 stages
- Phase discontinuity
- Three-phase transformer inrush detector
- Three-phase thermal overload, lines and cables
- Circuit breaker failure protection
- Electrically latched lockout relay

Depending on the IED variant, the optional functions may include:

- Auto-reclose
- Arc protection, three lens sensors for arc detection

2.1.1 Product version history

IED version	Release date	Product history
1.0	20.12.2007	Product released
1.1	02.07.2008	• IRIG-B • Support for parallel protocols added: IEC 61850 and Modbus • X130 BIO added: optional for variants B and D • CB interlocking functionality enhanced • TCS functionality in HW enhanced • Non-volatile memory added

2.1.2 PCM600 and IED connectivity package version

Supported tools:

- Protection and Control IED Manager PCM600 Ver. 2.0 SP1 or later
- REF615 Connectivity Package Ver. 1.2
 - Parameter Setting Tool
 - Disturbance Handling Tool
 - Signal Monitoring Tool
 - Signal Matrix Tool
 - Communication Management Tool



The necessary connectivity packages can be downloaded from the ABB web site <http://www.abb.com/substationautomation>

2.2 Operation functionality

2.2.1 Standard configurations

The IED is available with four alternative standard configurations. The table indicates the functions supported by the different IED configurations.

Standard configuration functionality	Overcurrent and directional earth-fault protection		Overcurrent and non-directional earth-fault protection	
	Std. conf. A (FE01)	Std. conf. B (FE02)	Std. conf. C (FE03)	Std. conf. D (FE04)
Protection				
Three-phase non-directional overcurrent, low-set stage	•	•	•	•
Three-phase non-directional overcurrent, high-set stage, instance 1	•	•	•	•
Three-phase non-directional overcurrent, high-set stage, instance 2	•	•	•	•
Three-phase non-directional overcurrent, instantaneous stage	•	•	•	•
Directional earth-fault, low-set stage, instance 1	•	•	-	-
Directional earth-fault, low-set stage, instance 2	•	•	-	-
Table continues on next page				

Directional earth-fault, high-set stage	•	•	-	-
Double earth-fault protection (cross-country earth-fault)	•	•	-	-
Transient/intermittent earth-fault	•	•	-	-
Non-directional earth-fault, low-set stage	-	-	•	•
Non-directional earth-fault, high-set stage	-	-	•	•
Non-directional earth-fault, instantaneous stage	-	-	•	•
Non-directional sensitive earth-fault	-	-	•	•
Negative-sequence overcurrent, instance 1	•	•	•	•
Negative-sequence overcurrent, instance 2	•	•	•	•
Phase discontinuity	•	•	•	•
Thermal overload	•	•	•	•
Circuit breaker failure protection	•	•	•	•
Three-phase inrush current detection	•	•	•	•
Arc protection with three sensors	○	○	○	○
Control				
Circuit breaker control with basic interlocking ¹⁾	•	•	•	•
Circuit breaker control with extended interlocking ²⁾	-	•	-	•
Auto-reclosing of one circuit breaker	○	○	○	○
Supervision and Monitoring				
Circuit breaker condition monitoring	-	•	-	•
Trip-circuit supervision of two trip circuits	•	•	•	•
Measurement				
Transient disturbance recorder	•	•	•	•
Three-phase current measurement	•	•	•	•
Current sequence components	•	•	•	•
Residual current measurement	•	•	•	•
Residual voltage measurement	•	•	-	-

- 1) **Basic interlocking functionality:** Closing of the circuit breaker can be enabled by a binary input signal. The actual interlocking scheme is implemented outside the relay. The binary input serves as a "master interlocking input" and when energized, it enables circuit breaker closing.
- 2) **Extended interlocking functionality:** The circuit breaker interlocking scheme is implemented in the relay configuration, based on primary equipment position information (via binary inputs) and the logical functions available. The signal matrix tool of PCM600 can be used for modifying the interlocking scheme to suit the application.

● = Included, ○ = Optional at the time of the order

2.2.2 Optional functions

The optional functions available in the IED are:

- Arc protection
- Auto-reclosing
- Modbus TCP/IP or RTU/ASCII

2.3 Physical hardware

The IED consists of two main parts: plug-in unit and case. The plug-in unit content depends on the ordered functionality.

Table 2: *Plug-in unit and case*

Main unit	Content options		
Plug-in unit	HMI		
	CPU module		
	Auxiliary power/ binary output module (slot X100)	48-250V DC / 100-240 V AC; or 24-60 V DC 2 normally-open PO contacts 1 change-over SO contacts 1 normally open SO contact 2 double-pole PO contacts with TCS 1 dedicated internal fault output contact	
	AI module (slot X120) ¹⁾	Option 1:	3 phase current inputs (1/5A) 1 residual current input for non-directional earth-fault protection (1/5A or 0.2/1A ²⁾) 4 BIs
		Option 2:	3 phase current inputs (1/5A) 1 residual current input (1/5A or 0.2/1A) 1 residual voltage input for directional earth-fault protection (100, 110, 115 or 120 V) 3 BIs
BI/O module (slot X110)	7 BIs 3 SO contacts		
Case	Optional BI/O module (slot X130)	6 BIs 3 SO contacts	
	AI module interface connectors Auxiliary power/binary output module interface connectors BI/O module interface connectors Communication module		

1) The analog input module option depends on the selected standard configuration.

2) The 0.2/1A input is normally used in applications requiring sensitive earth-fault protection and featuring core-balance current transformers.

The rated input levels are selected in the IED software for phase current, residual current and residual voltage. The binary input thresholds 18...176 V DC are selected by adjusting the IED's parameter settings.



The additional BI/O module in slot X110 is included in the IED with standard configurations B and D. The optional BI/O module in slot X130 is available for configurations B and D.

The connection diagrams of different hardware modules are presented in this manual.



See the Installation Manual for more information about the case and the plug-in unit.

2.4

LHMI

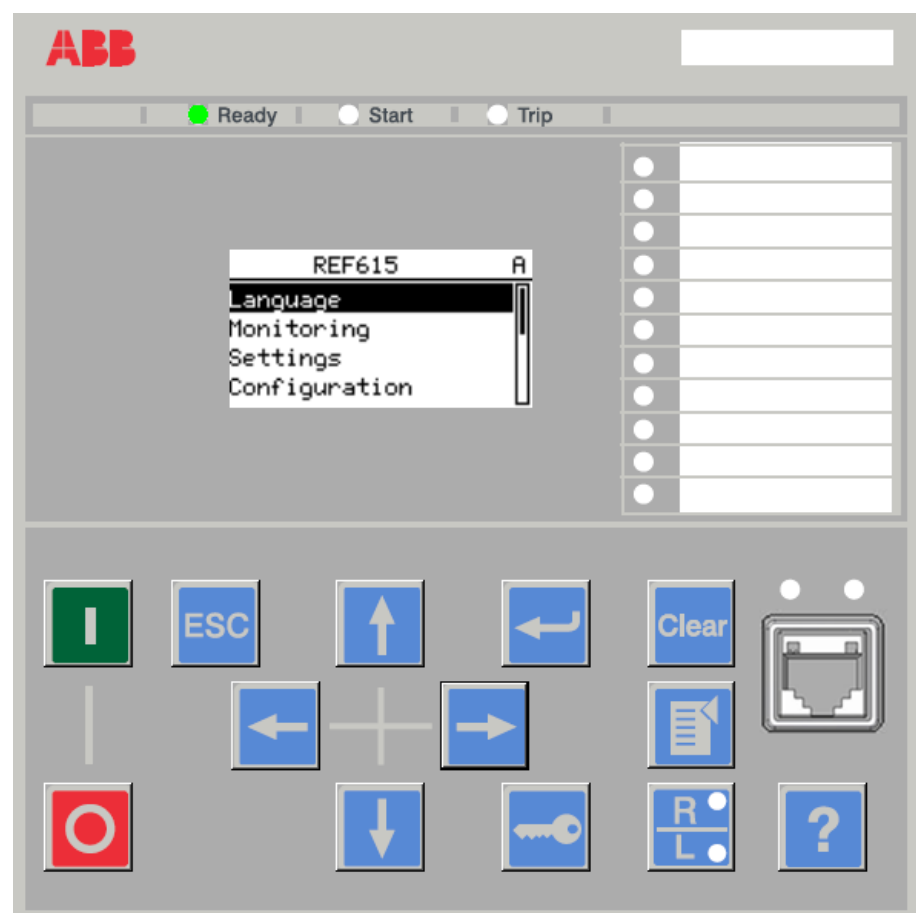


Figure 1: LHMI

The LHMI of the IED contains the following elements:

- Display
- Buttons
- LED indicators
- Communication port

The LHMI is used for setting, monitoring and controlling.

2.4.1

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:

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

The display view is divided into four basic areas:

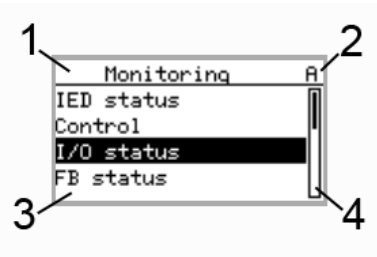


Figure 2: Display layout

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

2.4.2

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.

2.4.3

Keypad

The LHMI keypad consists of push buttons which are used to navigate in different views or menus. With push buttons you can give open or close commands to, for example, circuit breakers, disconnectors and switches. The push buttons are also used to acknowledge alarms, reset indications, provide help and switch between local and remote control mode.

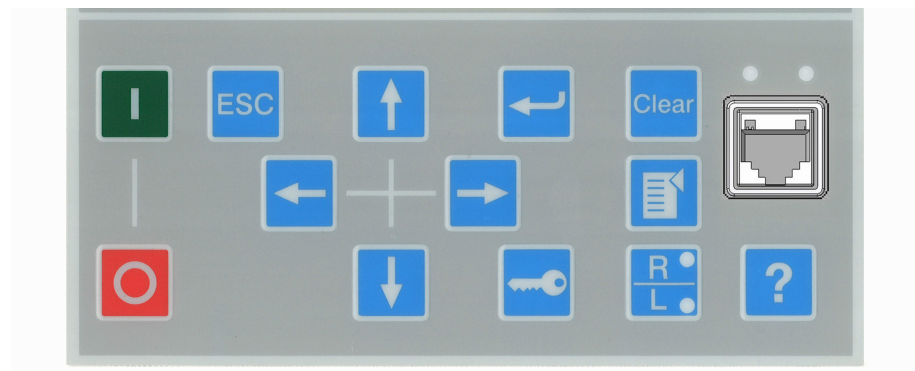


Figure 3: LHMI keypad with object control, navigation and command push buttons and RJ-45 communication port

2.5

WHMI

The WHMI enables the user to access the IED via a web browser.



WHMI is disabled by default.

WHMI offers the following functions:

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

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

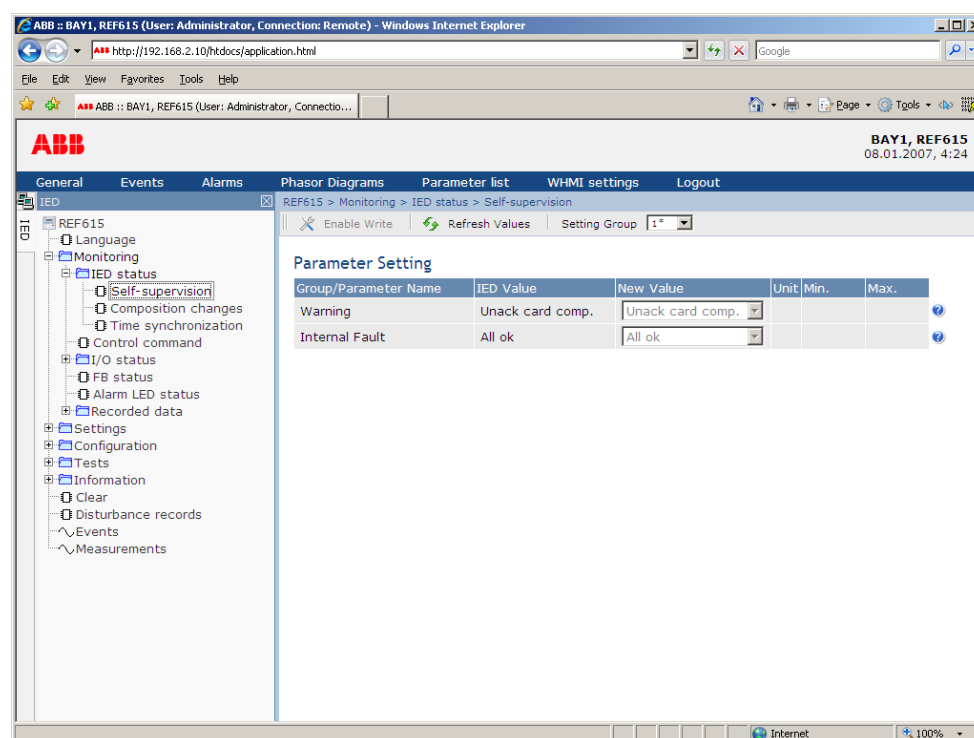


Figure 4: Example view of the WHMI

The WHMI can be accessed:

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

2.6

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.

Table 3: *Predefined user categories*

Username	User rights
VIEWER	Read only access
OPERATOR	• Selecting remote or local state with  (only locally) • Changing setting groups • Controlling • Clearing alarm and indication LEDs and textual indications
ENGINEER	• Changing settings • Clearing event list • Clearing disturbance records • Changing system settings such as IP address, serial baud rate or disturbance recorder settings • Setting the IED to test mode • Selecting language
ADMINISTRATOR	• All listed above • Changing password



For user authorization for PCM600, see PCM600 documentation.

2.7 Communication

The IED supports two different communication protocols: IEC 61850 and Modbus[®]. Operational information and controls are available through these protocols. However, some communication functionality, for example, horizontal communication between the IEDs and parameters setting, is only enabled by the IEC 61850 communication protocol.

The IEC 61850 communication implementation supports all monitoring and control functions. Additionally, parameter setting and disturbance file records can be accessed using the IEC 61850-8-1 protocol. Further, the IED can send and receive binary signals from other IEDs (so called horizontal communication) using the IEC 61850-8-1 GOOSE profile, where the highest performance class with a total transmission time of 3 ms is supported. The IED can simultaneously report to five different IEC 61850-8-1 clients.

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) or the fibre-

optic LC connector (100BASE-FX). If connection to a RS-485 network is required, the 10-pin screw-terminal connector can be used.

Section 3 REF615 variants

3.1 REF615 variant list

The protection and control relay REF615 is mainly intended for MV feeder applications. The product has a number of standard configurations covering a wide range of primary circuit configurations in distribution networks based on different system earthing methods.

Some of the functions included in the IED's standard configurations are optional to the user at the time of placing the order. The description of standard configurations covers the full functionality including options, presenting the functionality, flexibility and external connections of REF615 with a specific configuration as delivered from the factory.

3.2 Presentation of standard configurations

Functional diagrams

The functional diagrams describe the IED's functionality from the protection, measuring, condition monitoring, disturbance recording, control and interlocking perspective. Diagrams show the default functionality with simple symbol logics forming principle diagrams. The external connections to primary devices are also shown, stating the default connections to measuring transformers. The positive measuring direction of directional protection functions is towards the outgoing feeder.

The functional diagrams are divided into sections which each constitute one functional entity. The external connections are also divided into sections. Only the relevant connections for a particular functional entity are presented in each section.

Protection function blocks are part of the functional diagram. They are identified based on their IEC 61850 name but the IEC based symbol and the ANSI function number are also included. Some function blocks, such as PHHPTOC, are used several times in the configuration. To separate the blocks from each other, the IEC 61850 name, IEC symbol and ANSI function number are appended with a running number, that is an instance number, from one upwards. If the block has no suffix after the IEC or ANSI symbol, the function block has been used, that is, instantiated, only once. The IED's internal functionality and the external connections are separated with a dashed line presenting the IED's physical casing.

Signal Matrix Tool

With SMT the user can modify the standard configuration according to the actual needs. The IED is delivered from the factory with default connections described in the functional diagrams for BI's, BO's, function to function connections and alarm LEDs. SMT has a number of different page views, designated as follows:

- Binary input
- Binary output
- Functions.

The functions in different page views are identified by the IEC 61850 names with analogy to the functional diagrams.

3.2.1

Standard configurations

The IED is available with four alternative standard configurations. The table indicates the functions supported by the different IED configurations.

Standard configuration functionality	Overcurrent and directional earth-fault protection		Overcurrent and non-directional earth-fault protection	
	Std. conf. A (FE01)	Std. conf. B (FE02)	Std. conf. C (FE03)	Std. conf. D (FE04)
Protection				
Three-phase non-directional overcurrent, low-set stage	•	•	•	•
Three-phase non-directional overcurrent, high-set stage, instance 1	•	•	•	•
Three-phase non-directional overcurrent, high-set stage, instance 2	•	•	•	•
Three-phase non-directional overcurrent, instantaneous stage	•	•	•	•
Directional earth-fault, low-set stage, instance 1	•	•	-	-
Directional earth-fault, low-set stage, instance 2	•	•	-	-
Directional earth-fault, high-set stage	•	•	-	-
Double earth-fault protection (cross-country earth-fault)	•	•	-	-
Transient/intermittent earth-fault	•	•	-	-
Non-directional earth-fault, low- set stage	-	-	•	•
Table continues on next page				

Non-directional earth-fault, high-set stage	-	-	●	●
Non-directional earth-fault, instantaneous stage	-	-	●	●
Non-directional sensitive earth-fault	-	-	●	●
Negative-sequence overcurrent, instance 1	●	●	●	●
Negative-sequence overcurrent, instance 2	●	●	●	●
Phase discontinuity	●	●	●	●
Thermal overload	●	●	●	●
Circuit breaker failure protection	●	●	●	●
Three-phase inrush current detection	●	●	●	●
Arc protection with three sensors	○	○	○	○
Control				
Circuit breaker control with basic interlocking ¹⁾	●	●	●	●
Circuit breaker control with extended interlocking ²⁾	-	●	-	●
Auto-reclosing of one circuit breaker	○	○	○	○
Supervision and Monitoring				
Circuit breaker condition monitoring	-	●	-	●
Trip-circuit supervision of two trip circuits	●	●	●	●
Measurement				
Transient disturbance recorder	●	●	●	●
Three-phase current measurement	●	●	●	●
Current sequence components	●	●	●	●
Residual current measurement	●	●	●	●
Residual voltage measurement	●	●	-	-

- 1) **Basic interlocking functionality:** Closing of the circuit breaker can be enabled by a binary input signal. The actual interlocking scheme is implemented outside the relay. The binary input serves as a "master interlocking input" and when energized, it enables circuit breaker closing.
- 2) **Extended interlocking functionality:** The circuit breaker interlocking scheme is implemented in the relay configuration, based on primary equipment position information (via binary inputs) and the logical functions available. The signal matrix tool of PCM600 can be used for modifying the interlocking scheme to suit the application.

● = Included, ○ = Optional at the time of the order

3.2.2 Connection diagrams

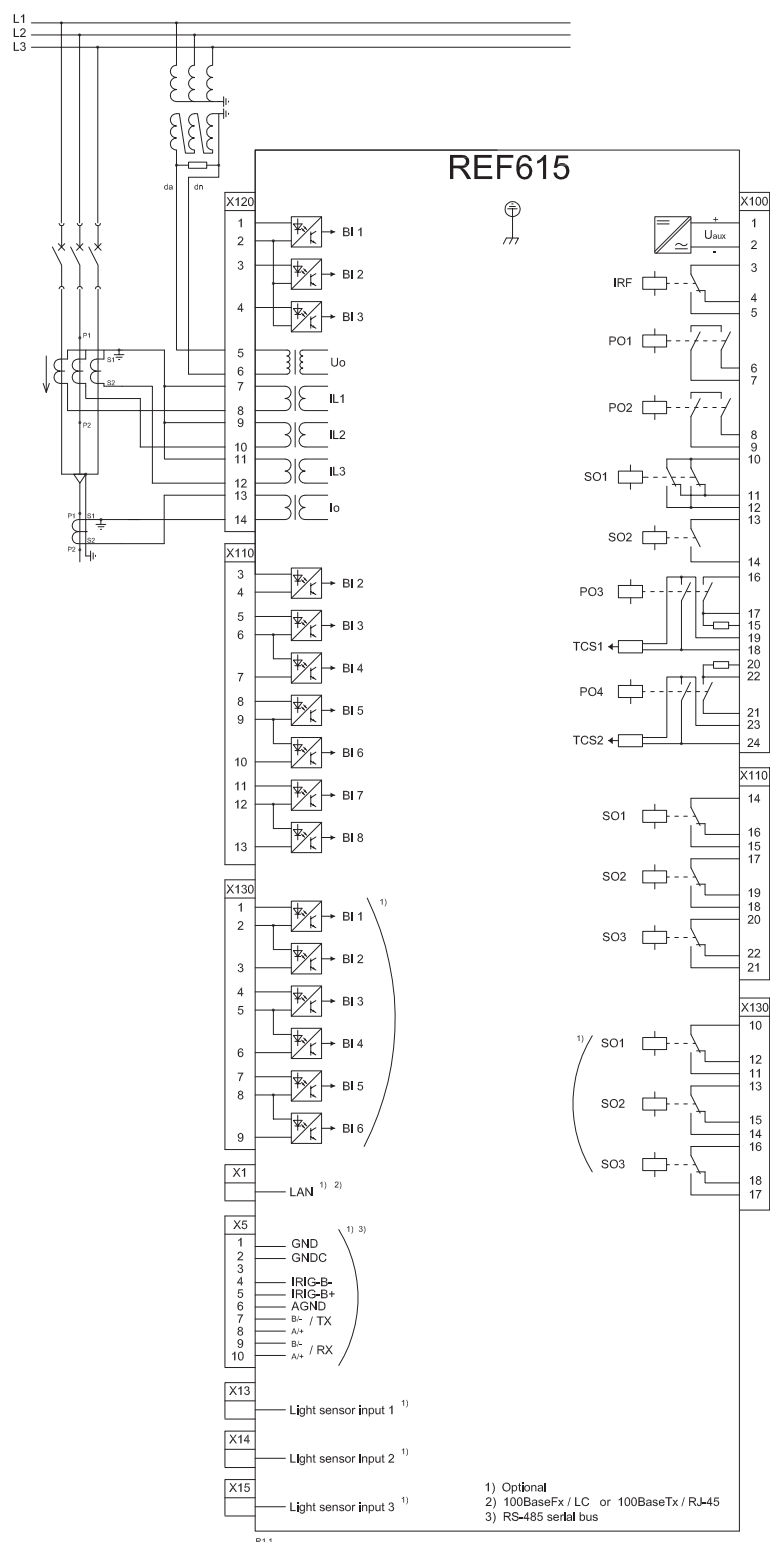


Figure 5: Connection diagram for configurations A and B (overcurrent and directional earth-fault protection)^[1]

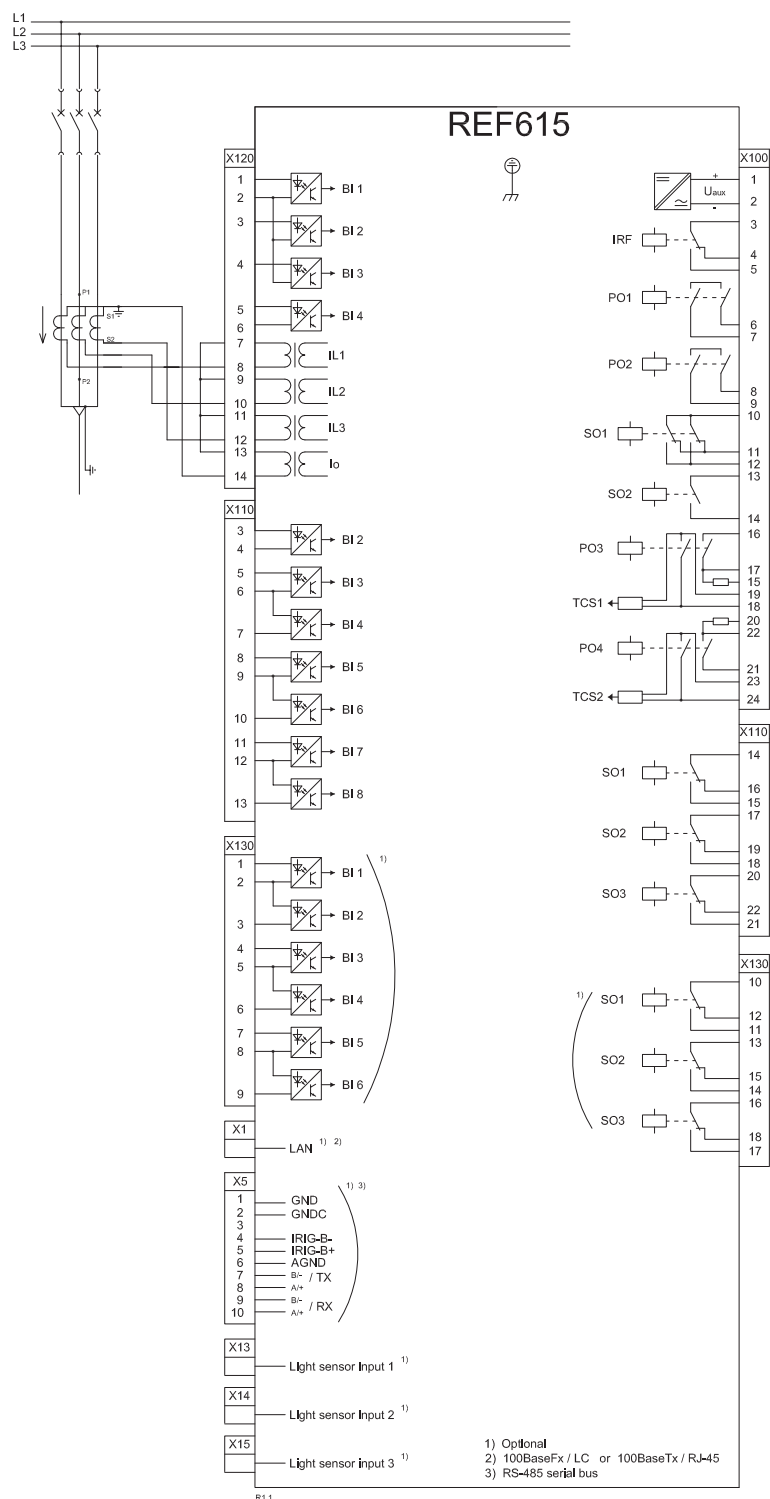


Figure 6: Connection diagram for configurations C and D (overcurrent and non-directional earth-fault protection)^[2]

[1] Additional BIO-module (X110 in the diagram) is included in the IED variant B

[2] Additional BIO-module (X110 in the diagram) is included in the IED variant D

3.3 Standard configuration A including directional earth-fault protection

3.3.1 Applications

The standard configuration for directional earth-fault protection is mainly intended for cable and overhead line feeder applications in isolated and resonant-earthed distribution networks. The IED with this standard configuration is delivered from the factory with default settings and parameters. The end-user flexibility for incoming, outgoing and internal signal designation within the IED enables this configuration to be further adapted to different primary circuit layouts and the related functionality needs by modifying the internal functionality with SMT and PST.

3.3.2 Functions

Table 4: *Functions included in the REF615 standard configuration with directional earth-fault protection*

Function	IEC 61850	IEC	ANSI
Three-phase non-directional overcurrent protection, low stage	PHLPTOC1	3I>	51P-1
Three-phase non-directional overcurrent protection, high stage, instance 1	PHHPTOC1	3I>> (1)	51P-2 (1)
Three-phase non-directional overcurrent protection, high stage, instance 2	PHHPTOC2	3I>> (2)	51P-2 (2)
Three-phase non-directional overcurrent protection, instantaneous stage	PHIPTOC1	3I>>>	50P/51P
Arc protection	ARCSARC1 ARCSARC2 ARCSARC3	ARC (1) ARC (2) ARC (3)	50L/50NL (1) 50L/50NL (2) 50L/50NL (3)
Directional earth-fault protection, low stage, instance 1	DEFLPDEF1	I ₀ > → (1)	67N-1 (1)
Directional earth-fault protection, low stage, instance 2	DEFLPDEF2	I ₀ > → (2)	67N-1 (2)
Directional earth-fault protection, high stage	DEFHPDEF1	I ₀ >> →	67N-2
Transient/intermittent earth-fault protection	INTRPTEF1	I ₀ > → IEF	67NIEF
Non-directional earth-fault protection, high stage, calculated I ₀ current (Double earth-fault protection)	EFHPTOC1	I ₀ >>	51N-2
Negative-sequence overcurrent protection, instance 1	NSPTOC1	I ₂ > (1)	46 (1)
Negative-sequence overcurrent protection, instance 2	NSPTOC2	I ₂ > (2)	46 (2)
Phase discontinuity	PDNSPTOC1	I ₂ /I ₁ >	46PD
Three-phase inrush detector	INRPHAR1	3I2f>	68
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR1	3Ith>	49F
Table continues on next page			

Function	IEC 61850	IEC	ANSI
Autoreclosure	DARREC1	O → I	79
Circuit breaker failure protection	CCBRBRF1	3I>I ₀ >BF	51BF/51NBF
Master Trip	TRPPTRC1 TRPPTRC2	Master Trip (1) Master Trip (2)	94/86 (1) 94/86 (2)
Trip circuit supervision, instance 1	TCSSCBR1	TCS (1)	TCM (1)
Trip circuit supervision, instance 2	TCSSCBR2	TCS (2)	TCM (2)
Disturbance recorder	RDRE1	-	-
Three-phase current measurement	CMMXU1	3I	3I
Sequence current measurement	CSMSQI1	I ₁ , I ₂ , I ₀	I ₁ , I ₂ , I ₀
Residual current measurement	RESCMMXU1	I ₀	I _n
Residual voltage measurement	RESVMMXU1	U ₀	V _n

3.3.2.1

Default I/O connections

Binary Input	Default usage	Connector-Pins
X120-BI1	Blocking of Overcurrent Instantaneous Stage	X120-1,2
X120-BI2	Circuit Breaker Closed position indication	X120-3,2
X120-BI3	Circuit Breaker Open position indication	X120-4,2

Binary Output	Default usage	Connector-Pins
X100-PO1	Close Circuit Breaker	X100-6,7
X100-PO2	Circuit Breaker Failure protection trip to upstream breaker	X100-8,9
X100-PO3	Open Circuit Breaker / trip coil 1	X100-16,17,18,19
X100-PO4	Open Circuit Breaker / trip coil 2	X100-20,21,22,23
X100-SO1	General Start Indication	X100-10,11,12
X100-SO2	General Operate Indication	X100-13,14,15

LED	Default usage
1	Non-Directional Overcurrent Operate
2	Directional/Intermittent Earth fault Operate
3	Double (Cross country) Earth fault Operate
4	Negative Seq. Overcurrent/Phase Discontinuity Operate
5	Thermal Overload Alarm
6	Breaker Failure Operate
7	Disturbance Recorder Triggered
8	Not connected
9	Trip Circuit Supervision Alarm
10	ARC Protection Operate
11	Auto Reclose Sequence in Progress

3.3.3 Functional diagrams

The functional diagrams describe the default input, output, alarm LED and function to function connections. The default connections can be viewed with SMT and changed according to the application requirements, if necessary.

The analog channels, measurements from CTs and VTs, have fixed connections towards the different function blocks inside the IED's standard configuration. Exceptions from this rule are the 12 analog channels available for the disturbance recorder function. These channels are freely selectable and a part of the disturbance recorder's parameter settings, thus not included in the SMT functionality.

The analog channels are assigned to different functions as shown in the functional diagrams. The common signal marked with 3I represents the three phase currents. The signal marked with I_0 represents the measured residual current via a core balance CT. The signal marked with U_0 represents the measured residual voltage via open delta connected VTs.

The EFHPTOC protection function block for double (cross-country) earth-faults uses the calculated residual current originating from the measured phase currents.

3.3.3.1 Functional diagrams for protection

The following functional diagrams describe the IED's protection functionality in detail and according to the factory set default connections in SMT.

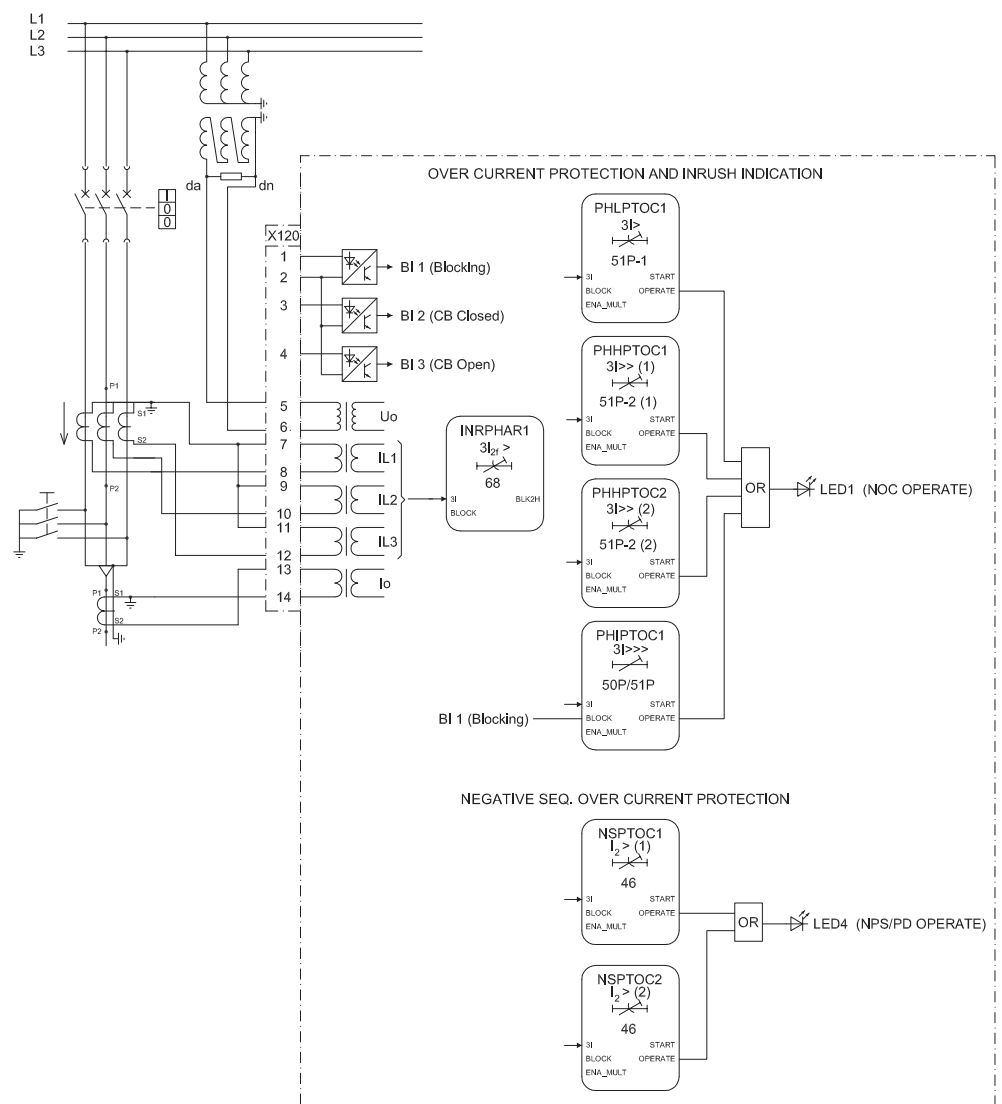


Figure 7: Overcurrent protection

Four overcurrent stages are offered for overcurrent and short-circuit protection. The instantaneous stage (PHIPTOC1) can be blocked by energizing the binary input 1 (X120:1-2). Two negative sequence overcurrent stages (NSPTOC1 and NSPTOC2) are offered for phase unbalance protection. The inrush detection block's (INRPHAR1) output BLK2H caters the possibility to either block the function or multiply the active settings for any of the shown protection function blocks.

All operate signals are connected to the Master Trip and also to the alarm LEDs. LED 1 is used for overcurrent and LED 4 for negative sequence overcurrent protection operate indication. LED 4 is also used for phase discontinuity protection operate indication.

There are four IED variant specific setting groups. Parameters can be set independently for each setting group.

The active setting group (1...4) can be changed with a parameter. The change of an active setting group can also be made via a binary input if the binary input is enabled for this. To enable the change of the active setting group via a binary input, connect a free binary input with SMT to the ActSG input of the SGCB-block.

Table 5: *Binary input states and corresponding active setting groups*

BI State	Active setting group
OFF	1
ON	2

The active setting group defined by a parameter is overridden when a binary input is enabled for changing the active setting group.

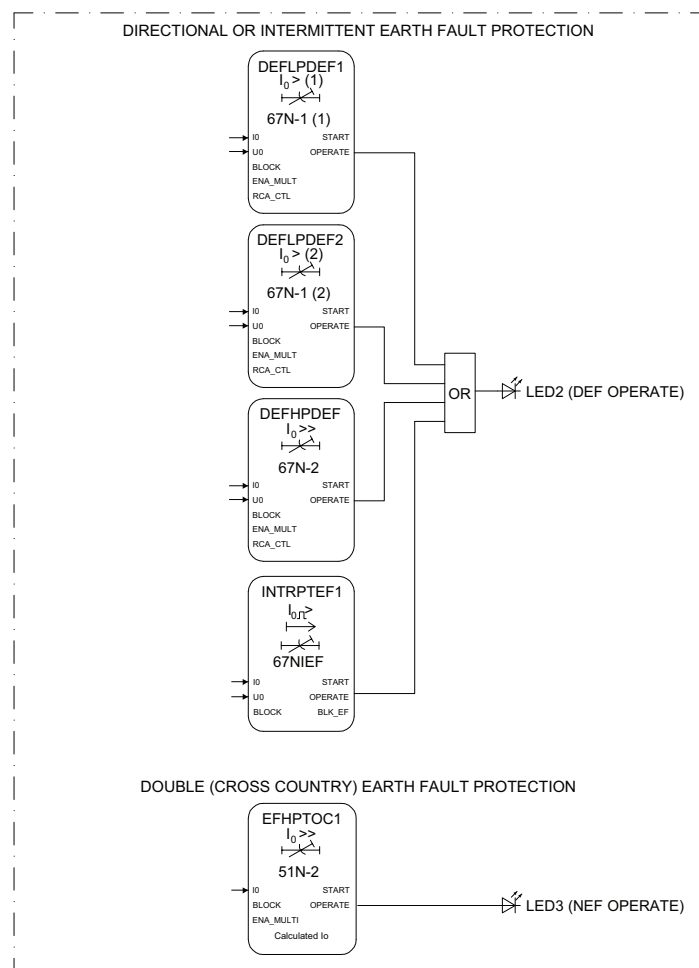


Figure 8: *Directional earth-fault protection*

Three stages are offered for directional earth-fault protection. In addition, there is a dedicated protection stage (INTRPTEF) either for transient based earth-fault protection or for cable intermittent earth-fault protection in compensated networks.

A dedicated non-directional earth-fault protection block (EFHPTOC) is intended for protection against double earth-fault situations in isolated or compensated networks. This protection function uses the calculated residual current originating from the phase currents.

All operate signals are connected to the Master Trip and also to the alarm LEDs. LED 2 is used for directional earth-fault and LED 3 for double earth-fault protection operate indication.

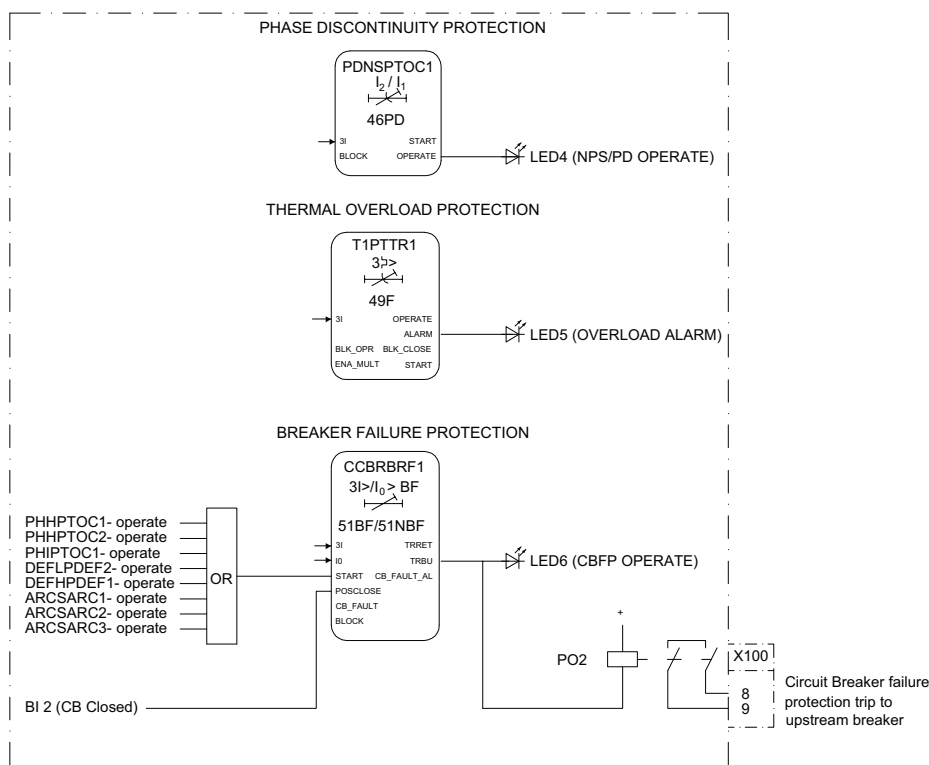


Figure 9: Phase discontinuity, thermal overload and circuit breaker failure protection

The phase discontinuity protection (PDNPSTOC1) provides protection for interruptions in the normal three-phase load supply, for example, in downed conductor situations. The thermal overload protection (T1PTTR1) provides indication on overload situations. The operate signal of the phase discontinuity protection is connected to the Master Trip and also to an alarm LED. LED 4 is used for the phase discontinuity protection operate indication, the same as for negative sequence overcurrent protection operate indication, and LED 5 is used for the thermal overload protection alarm indication.

The breaker failure protection (CCBRBRF1) is initiated via the start input by a number of different protection stages in the IED. The breaker failure protection function offers different operating modes associated with the circuit breaker position and the measured phase and residual currents. The breaker failure protection has two operating outputs: TRRET and TRBU. The TRRET operate output is used for re-tripping its own breaker through the Master Trip 2. The TRBU output is used to give

a back-up trip to the breaker feeding upstream. For this purpose, the TRBU operate output signal is connected to the output PO2 (X100: 8-9). LED 6 is used for back-up (TRBU) operate indication.

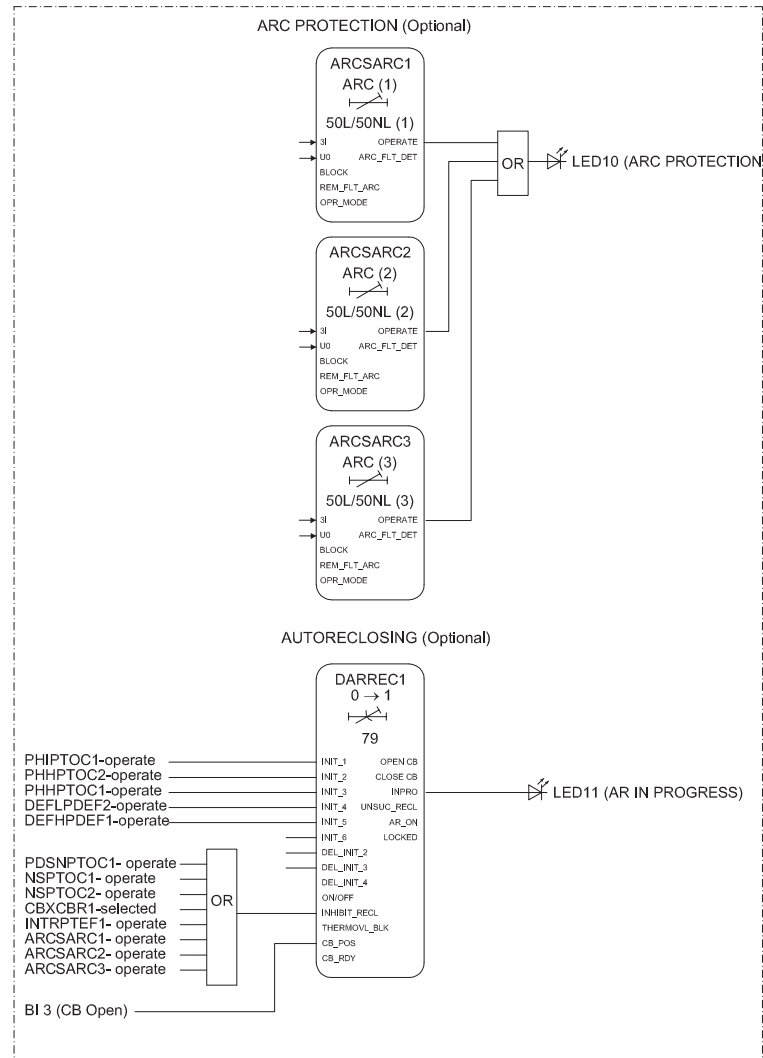


Figure 10: Arc protection

ARC protection (ARCSARC1-3) and auto-reclosing (DARREC1) are included as optional functions.

The ARC protection offers individual function blocks for three ARC sensors that can be connected to the IED. Each ARC protection function block has two different operation modes, with or without the phase and residual current check. Operate signals from the ARC protection function blocks are connected to the Master Trip and also to the alarm LED 10 as a common operate indication.

The auto-recloser is configured to be initiated by operate signals from a number of protection stages through the INIT1-5 inputs. It is possible to create individual auto-reclose sequences for each input.

The auto-reclose function can be blocked with the INHIBIT_RECL input. As a default, the operation of selected protection functions are connected to this input. A control command to the circuit breaker, either local or remote, also blocks the auto-reclose function via the CBXCBB-selected signal.

The circuit breaker availability for the auto-reclosure sequence is expressed with the CB_RDY input in DARREC1. In the configuration, this signal is not connected to any of the binary inputs. As a result, the function assumes that the breaker is available all the time.

The auto-reclose sequence in progress indication is connected to the alarm LED 11.

3.3.3.2

Functional diagrams for disturbance recorder and trip circuit supervision

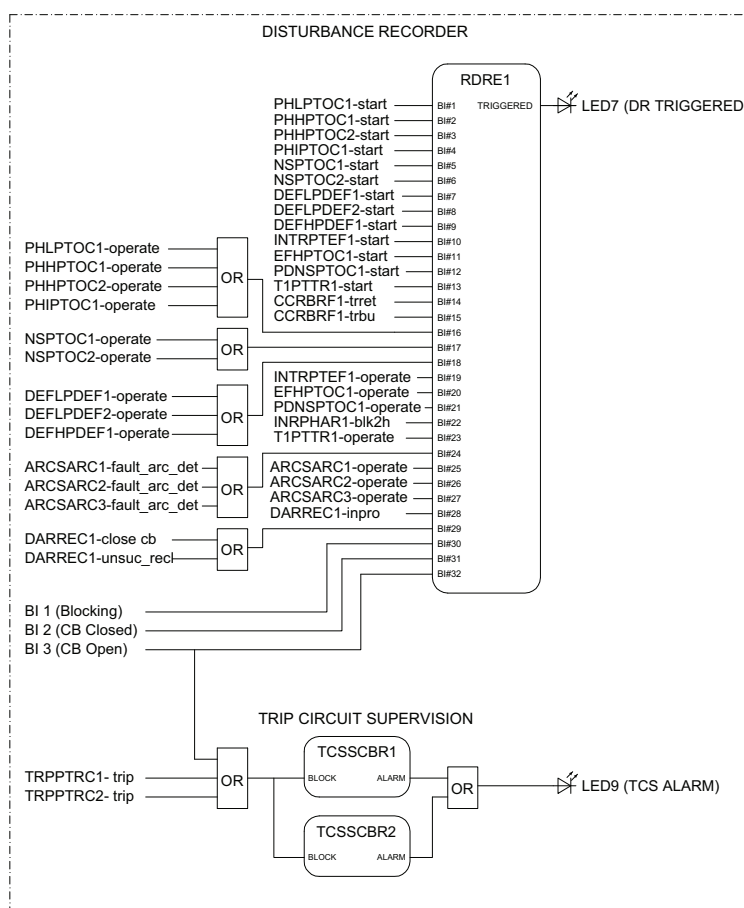


Figure 11: Disturbance recorder

The disturbance recorder has 64 digital inputs out of which 32 are connected as a default. All start and operate signals from the protection stages are routed to trigger the disturbance recorder or alternatively only to be recorded by the disturbance recorder depending on the parameter settings. Additionally, the selected auto-

recloser, the ARC protection signals and the three binary inputs from X120 are also connected.

Two separate TCS functions have been included: TCSSCBR1 for PO3 (X100:16-19) and TCSSCBR2 for PO4 (X100:20-23). Both functions are blocked by the Master Trip and the circuit breaker open position signal. The TCS alarm indication is connected to LED 9.

3.3.3.3

Functional diagrams for control and interlocking

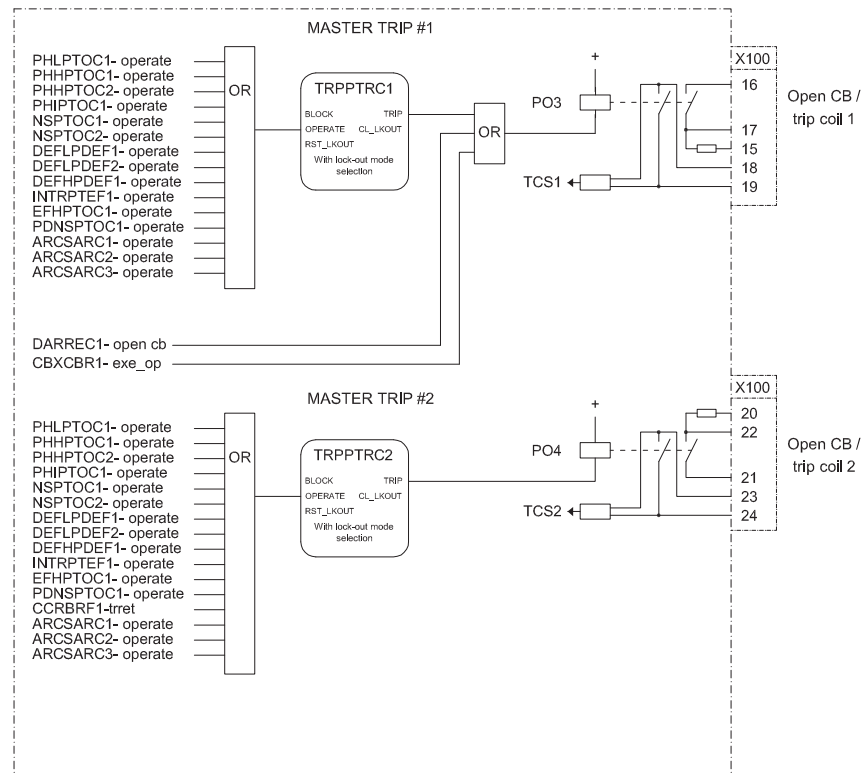


Figure 12: Master trip

The operate signals from the protections described above are connected to the two trip output contacts PO3 (X100:16-19) and PO4 (X100:20-23) via the corresponding Master Trips TRPPTRC1 and TRPPTRC2. The open control commands to the circuit breaker from local or remote CBXCBR1-exe_op or from the auto-recloser DARREC1-open_cb are connected directly to the output PO3 (X100:16-19).

The TRPPTRC1 and 2 blocks provide the lockout/latching function, event generation and the trip signal duration setting. If the lockout operation mode is selected, one binary input can be re-assigned to the RST_LKOUT input of the Master Trip to enable external reset with a push button.

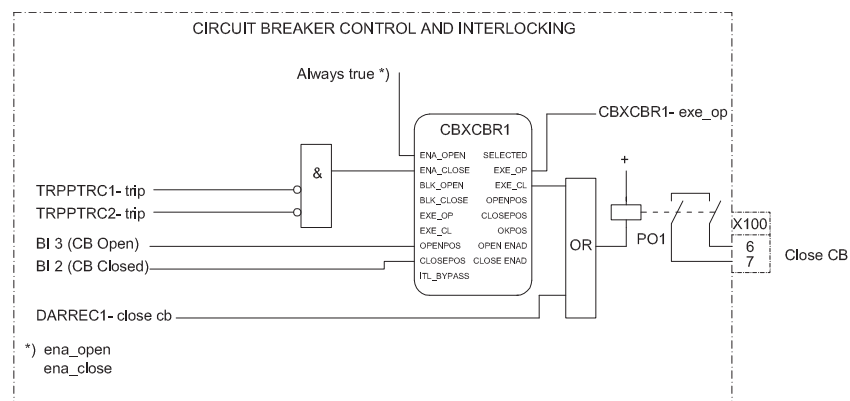


Figure 13: Circuit breaker control

The ENA_CLOSE input, that is, enable the closing of the circuit breaker, in the breaker control function block CBXCBR is a combination of the status of the Master Trip. The open operation is always enabled.



If the ENA_CLOSE signal is completely removed from the breaker control function block CBXCBR with SMT, the function assumes that the breaker close commands are allowed continuously.

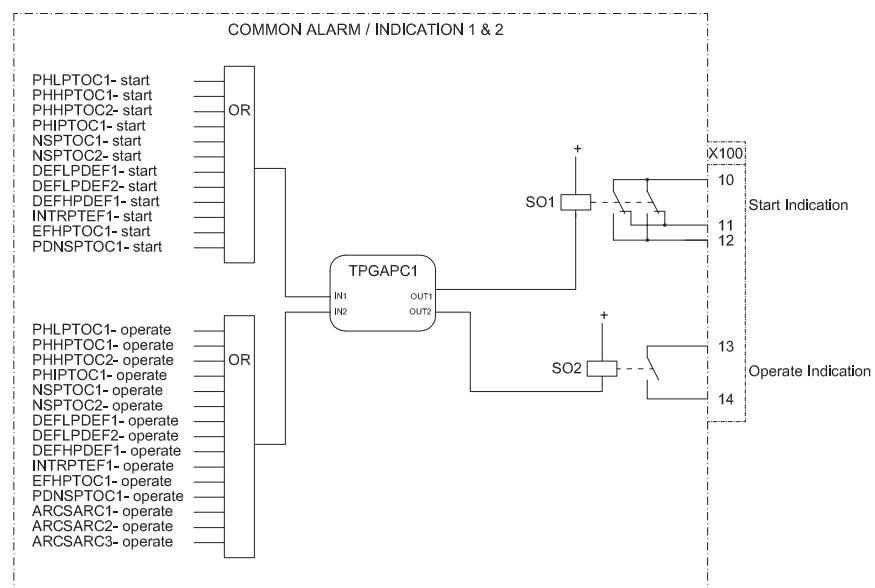


Figure 14: Alarm indication

The signal outputs from the IED are connected to give dedicated information on:

- start of any protection function SO1 (X100:10-12)
- operation (trip) of any protection function SO2 (X100:13-15).

The TPGAPC1 is a timer and used for setting the minimum pulse length for the outputs. There are four generic timers (TPGAPC1..4) available in the IED. The remaining ones not described in the functional diagram are available in SMT for connection where applicable.

3.4 Standard configuration B including directional earth-fault protection and CB condition monitoring

3.4.1 Applications

The standard configuration for directional earth-fault protection is mainly intended for cable and overhead line feeder applications in isolated and resonant-earthed distribution networks. The IED with this standard configuration is delivered from the factory with default settings and parameters. The end-user flexibility for incoming, outgoing and internal signal designation within the IED enables this configuration to be further adapted to different primary circuit layouts and the related functionality needs by modifying the internal functionality with SMT and PST.

3.4.2 Functions

Table 6: Functions included in the REF615 standard configuration with directional earth-fault protection

Function	IEC 61850	IEC	ANSI
Three-phase non-directional overcurrent protection, low stage	PHLPTOC1	3I>	51P-1
Three-phase non-directional overcurrent protection, high stage, instance 1	PHHPTOC1	3I>> (1)	51P-2 (1)
Three-phase non-directional overcurrent protection, high stage, instance 2	PHHPTOC2	3I>> (2)	51P-2 (2)
Three-phase non-directional overcurrent protection, instantaneous stage	PHIPTOC1	3I>>>	50P/51P
Arc protection	ARCSARC1 ARCSARC2 ARCSARC3	ARC (1) ARC (2) ARC (3)	50L/50NL (1) 50L/50NL (2) 50L/50NL (3)
Directional earth-fault protection, low stage, instance 1	DEFLPDEF1	I ₀ > → (1)	67N-1 (1)
Directional earth-fault protection, low stage, instance 2	DEFLPDEF2	I ₀ > → (2)	67N-1 (2)
Directional earth-fault protection, high stage	DEFHPDEF1	I ₀ >> →	67N-2
Transient/intermittent earth-fault protection	INTRPTEF1	I ₀ > → IEF	67NIEF
Table continues on next page			

Function	IEC 61850	IEC	ANSI
Non-directional earth-fault protection, high stage, calculated I_0 current (Double earth-fault protection)	EFHPTOC1	$I_0 >>$	51N-2
Negative-sequence overcurrent protection, instance 1	NSPTOC1	$I_2 > (1)$	46 (1)
Negative-sequence overcurrent protection, instance 2	NSPTOC2	$I_2 > (2)$	46 (2)
Phase discontinuity	PDNSPTOC1	$I_2/I_1 >$	46PD
Three-phase inrush detector	INRPBAR1	$3I_2f >$	68
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR1	$3I_{th} >$	49F
Autoreclosure	DARREC1	$O \rightarrow I$	79
Circuit breaker failure protection	CCBRBRF1	$3I > /I_0 > BF$	51BF/51NBF
Master Trip	TRPPTRC1 TRPPTRC2	Master trip (1) Master trip (2)	94/86 (1) 94/86 (2)
Trip circuit supervision, instance 1	TCSSCBR1	TCS (1)	TCM (1)
Trip circuit supervision, instance 2	TCSSCBR2	TCS (2)	TCM (2)
Disturbance recorder	RDRE1	-	-
Circuit breaker condition monitoring	SSCBR1	CBCM	CBCM
Three-phase current measurement	CMMXU1	$3I$	$3I$
Sequence current measurement	CSMSQI1	I_1, I_2, I_0	I_1, I_2, I_0
Residual current measurement	RESCMMXU1	I_0	I_n
Residual voltage measurement	RESVMMXU1	U_0	V_n

3.4.2.1

Default I/O connections

Binary Input	Default usage	Connector-Pins
X110-BI2	Directional Earth Fault Protection's Basic Angle Control	X110-3,4
X110-BI3	Circuit Breaker low Gas Pressure indication	X110-5,6
X110-BI4	Circuit Breaker Spring Charged indication	X110-6,7
X110-BI5	CB Truck in (Service position) indication	X110-8,9
X110-BI6	CB Truck out (Test position) indication	X110-10,9
X110-BI7	Earthing Switch Closed indication	X110-11,12
X110-BI8	Earthing Switch Open indication	X110-13,12
X120-BI1	Blocking of Overcurrent Instantaneous Stage	X120-1,2
X120-BI2	Circuit Breaker Closed indication	X120-3,2
X120-BI3	Circuit Breaker Open indication	X120-4,2

Binary Output	Default usage	Connector-Pins
X100-PO1	Close Circuit Breaker	X100-6,7
X100-PO2	Circuit Breaker Failure protection trip to upstream breaker	X100-8,9
X100-PO3	Open Circuit Breaker / trip coil 1	X100-16,17,18,19
X100-PO4	Open Circuit Breaker / trip coil 2	X100-20,21,22,23
X100-SO1	General Start Indication	X100-10,11,12
X100-SO2	General Operate Indication	X100-13,14,15
X110-SO1	Upstream Overcurrent Blocking	X110-14,15,16
X110-SO2	Overcurrent Operate Alarm	X110-17,18,19
X110-SO3	Earth fault Operate Alarm	X110-20,21,22

LED	Default usage
1	Non-Directional Overcurrent Operate
2	Directional/Intermittent Earth fault Operate
3	Double (Cross country) Earth fault Operate
4	Negative Seq. Overcurrent/Phase Discontinuity Operate
5	Thermal Overload Alarm
6	Breaker Failure Operate
7	Disturbance Recorder Triggered
8	Circuit Breaker Condition Monitoring Alarm
9	Trip Circuit Supervision Alarm
10	ARC Protection Operate
11	Auto Reclose Sequence in Progress

3.4.3

Functional diagrams

The functional diagrams describe the default input, output, alarm LED and function-to-function connections. The default connections can be viewed with SMT and changed according to the application requirements, if necessary.

The analog channels, measurements from CTs and VTs, have fixed connections towards the different function blocks inside the IED's standard configuration. Exceptions from this rule are the 12 analog channels available for the disturbance recorder function. These channels are freely selectable and a part of the disturbance recorder's parameter settings, thus not included in the SMT functionality.

The analog channels are assigned to different functions as shown in the functional diagrams. The common signal marked with 3I represents the three phase currents. The signal marked with I_0 represents the measured residual current via a core balance CT. The signal marked with U_0 represents the measured residual voltage via open delta connected VTs.

The EFHPTOC protection function block for double (cross-country) earth-faults uses the calculated residual current originating from the measured phase currents.

3.4.3.1

Functional diagrams for protection

The following functional diagrams describe the IED's protection functionality in detail and according to the factory set default connections in SMT.

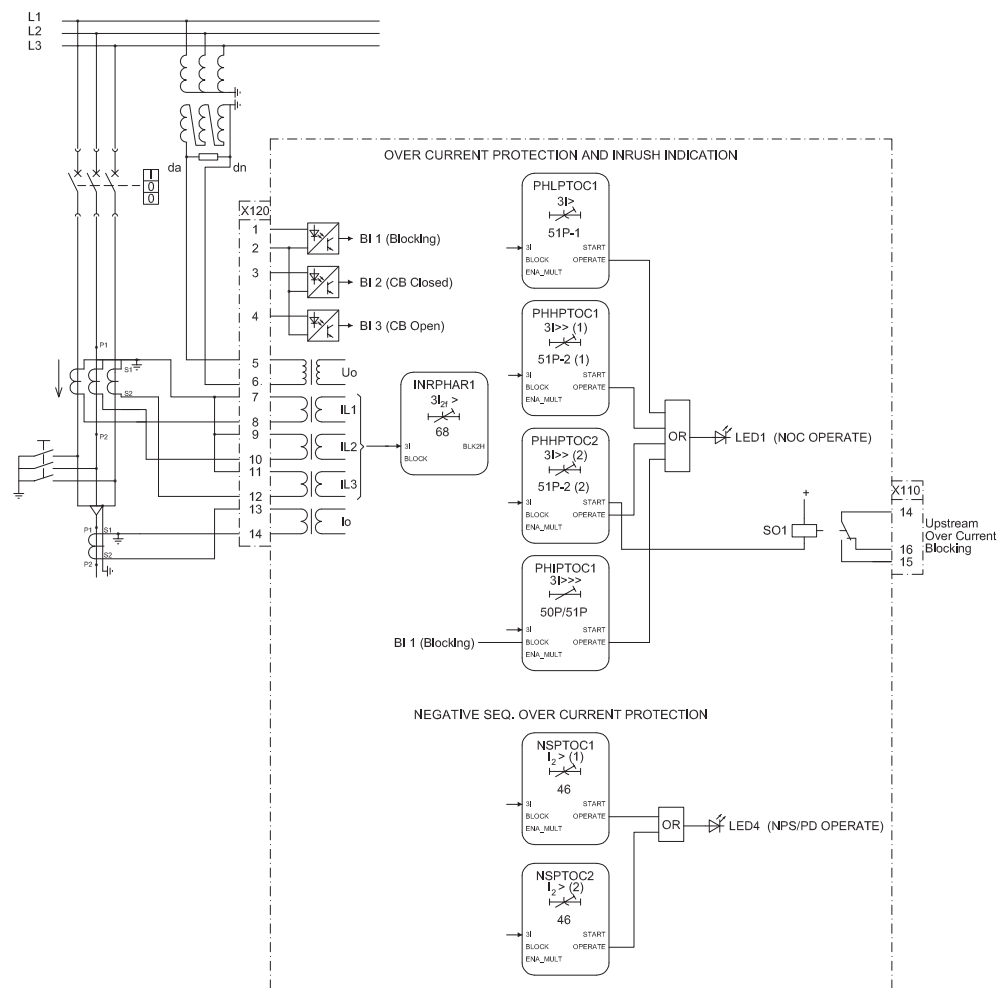


Figure 15: Overcurrent protection

Four overcurrent stages are offered for overcurrent and short-circuit protection. The instantaneous stage (PHIPTOC1) can be blocked by energizing the binary input 1 (X120:1-2). Two negative sequence overcurrent stages (NPSTOC1 and NPSTOC2) are offered for phase unbalance protection. The inrush detection block's (INRPHAR1) output BLK2H caters the possibility to either block the function or multiply the active settings for any of the shown protection function blocks.

All operate signals are connected to the Master Trip and also to the alarm LEDs. LED 1 is used for overcurrent and LED 4 for negative sequence overcurrent protection

operate indication. LED 4 is also used for phase discontinuity protection operate indication.

The upstream blocking from the start of the overcurrent second high stage (PHHPTOC2) is connected to the output SO1 (X110:14-15-16). This output is used for sending a blocking signal to the relevant overcurrent protection stage of the IED at the infeeding bay.

There are four IED variant specific setting groups. Parameters can be set independently for each setting group.

The active setting group (1...4) can be changed with a parameter. The change of an active setting group can also be made via a binary input if the binary input is enabled for this. To enable the change of an active setting group via a binary input, connect a free binary input with SMT to the ActSG input of the SGCB-block.

Table 7: *Binary input states and corresponding active setting groups*

BI State	Active setting group
OFF	1
ON	2

The active setting group defined by a parameter is overridden when a binary input is enabled for changing the active setting group.

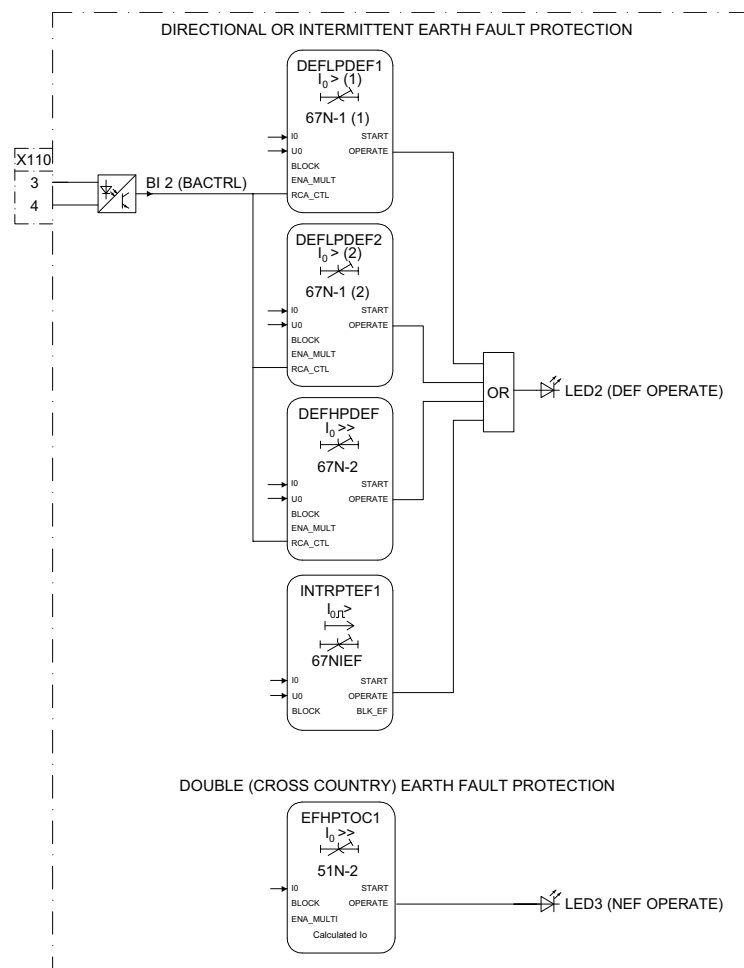


Figure 16: Directional earth-fault protection

Three stages are offered for directional earth-fault protection. In addition, there is a dedicated protection stage (INTRPTEF) either for transient based earth-fault protection or for cable intermittent earth-fault protection in compensated networks.

A dedicated non-directional earth-fault protection block (EFHPTOC) is intended for protection against double earth-fault situations in isolated or compensated networks. This protection function uses the calculated residual current originating from the phase currents.

The binary input 2 (X110:3-4) is intended for directional earth-fault protection blocks' Relay Characteristic Angle (RCA: $0^\circ/-90^\circ$) or operation mode ($I_0 \sin \phi / I_0 \cos \phi$) change. All operate signals are connected to the Master Trip and also to the alarm LEDs. LED 2 is used for directional earth-fault and LED 3 for double earth-fault protection operate indication.

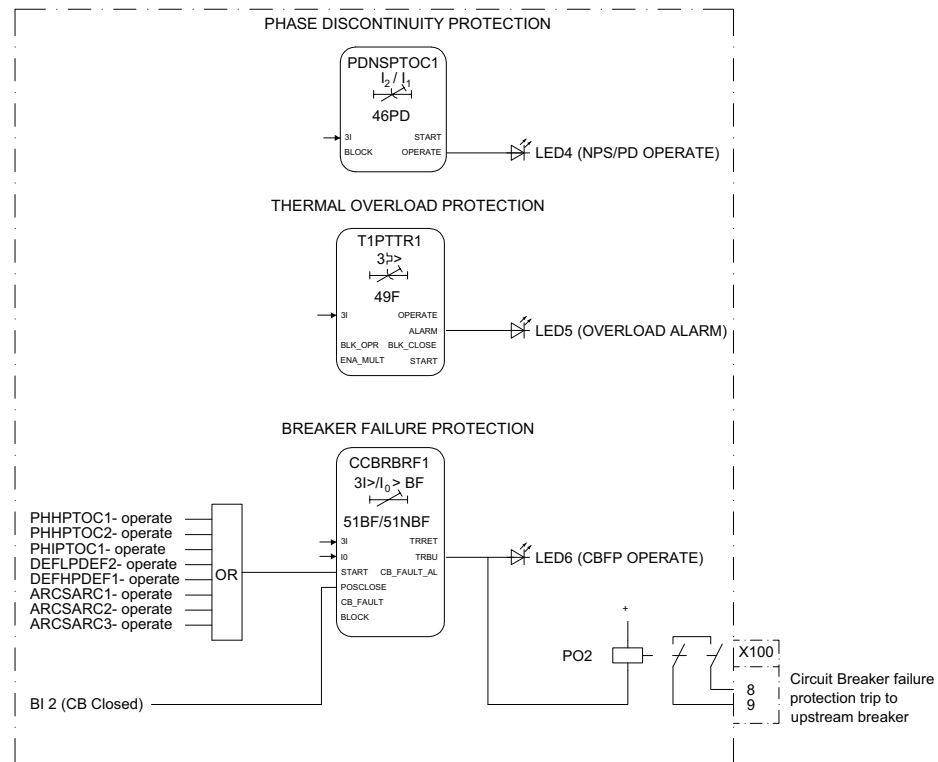


Figure 17: Phase discontinuity, thermal overload and circuit breaker failure protection

The phase discontinuity protection (PDNSPTOC1) provides protection for interruptions in the normal three-phase load supply, for example, in downed conductor situations. The thermal overload protection (T1PTTR1) provides indication on overload situations. The operate signal of the phase discontinuity protection is connected to the Master Trip and also to an alarm LED. LED 4 is used for the phase discontinuity protection operate indication, the same as for negative sequence overcurrent protection operate indication, and LED 5 is used for the thermal overload protection alarm indication.

The breaker failure protection (CCBRBRF1) is initiated via the start input by a number of different protection stages in the IED. The breaker failure protection function offers different operating modes associated with the circuit breaker position and the measured phase and residual currents. The breaker failure protection has two operating outputs: TRRET and TRBU. The TRRET operate output is used for re-tripping its own breaker through the Master Trip 2. The TRBU output is used to give a back-up trip to the breaker feeding upstream. For this purpose, the TRBU operate output signal is connected to the output PO2 (X100: 8-9). LED 6 is used for back-up (TRBU) operate indication.

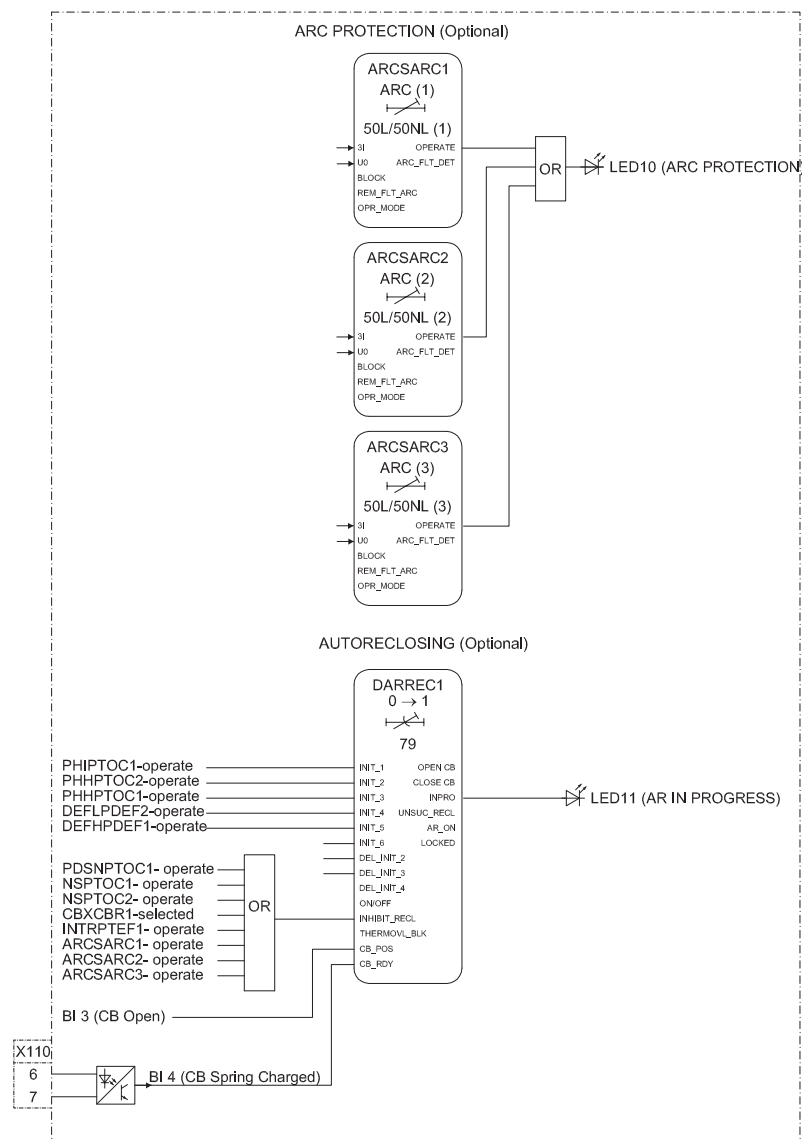


Figure 18: Arc protection

ARC protection (ARCSARC1-3) and auto-reclosing (DARREC1) are included as optional functions.

The ARC protection offers individual function blocks for three ARC sensors that can be connected to the IED. Each ARC protection function block has two different operation modes, with or without the phase and residual current check. Operate signals from the ARC protection function blocks are connected to the Master Trip and also to the alarm LED 10 as a common operate indication.

The auto-recloser is configured to be initiated by operate signals from a number of protection stages through the INIT1-5 inputs. It is possible to create individual auto-reclose sequences for each input.

The auto-reclose function can be blocked with the INHIBIT_RECL input. As a default, the operation of some selected protection functions are connected to this input. A control command to the circuit breaker, either local or remote, also blocks the auto-reclose function via the CBXCBB-selected signal.

The circuit breaker availability for the auto-reclosure sequence is expressed with the binary input 4 (X110:6-7) by connecting the input signal to the CB_RDY input. In case this signal is completely removed from the auto-reclose function block with SMT, the function assumes that the breaker is available all the time.

The auto-reclose sequence in progress indication is connected to the alarm LED 11.

3.4.3.2

Functional diagram for disturbance recorder and trip circuit supervision

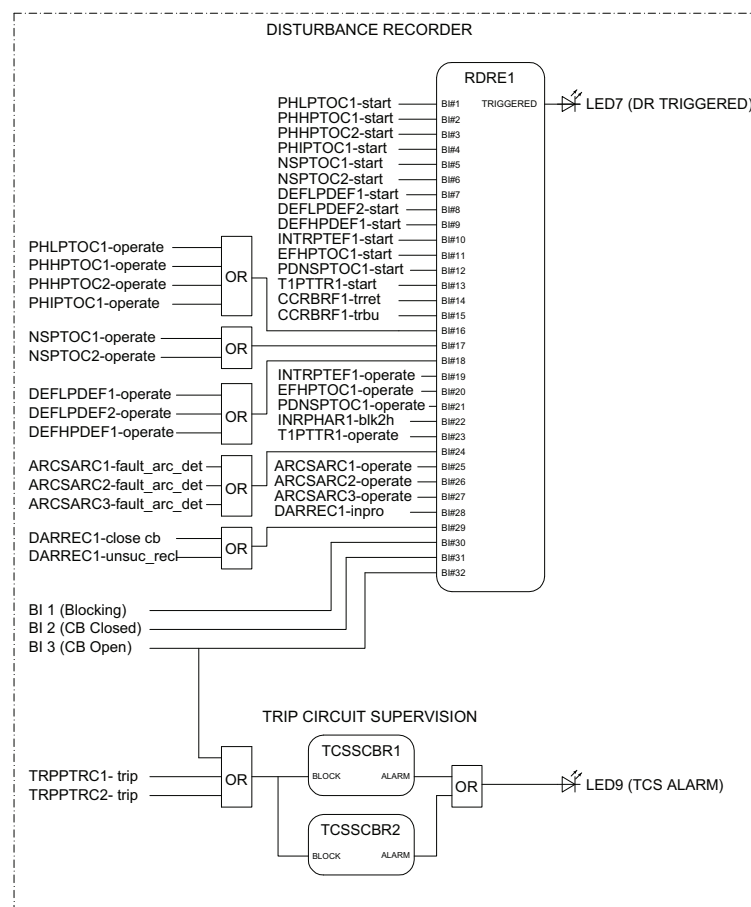


Figure 19: Disturbance recorder

The disturbance recorder has 64 digital inputs out of which 32 are connected as a default. All start and operate signals from the protection stages are routed to trigger the disturbance recorder or alternatively only to be recorded by the disturbance recorder depending on the parameter settings. Additionally, the selected auto-recloser, the ARC protection signals and the three binary inputs from X120 are also connected.

Two separate TCS functions have been included: TCSSCBR1 for PO3 (X100:16-19) and TCSSCBR2 for PO4 (X100:20-23). Both functions are blocked by the Master Trip (TRPPTRC1 and TRPPTRC2) and the circuit breaker open position signal. The TCS alarm indication is connected to LED 9.

3.4.3.3

Functional diagrams for control and interlocking

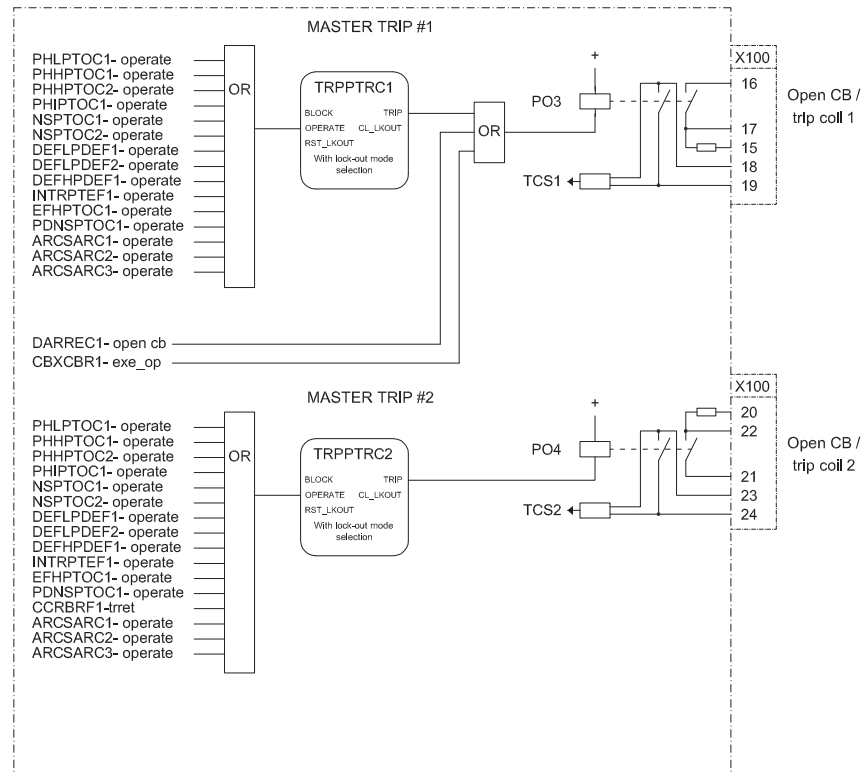


Figure 20: Master trip

The operate signals from the protections described above are connected to the two trip output contacts PO3 (X100:16-19) and PO4 (X100:20-23) via the corresponding Master Trips TRPPTRC1 and TRPPTRC2. Open control commands to the circuit breaker from local or remote CBXCBR1-exe_op or from the auto-recloser DARREC1-open_cb are connected directly to the output PO3 (X100:16-19).

The TRPPTRC1 and 2 blocks provide the lockout/latching function, event generation and the trip signal duration setting. If the lockout operation mode is selected, one binary input can be re-assigned to the RST_LKOUT input of the Master Trip to enable external reset with a push button.



The binary inputs 5 and 6 of the additional card X110 are used for busbar disconnector (DCSXSUI1) or circuit breaker truck position indication.

Primary device position	Input to be energized	
	Input 5 (X110:8-9)	Input 6 (X110:10-9)
Busbar disconnecter closed	X	
Busbar disconnecter open		X
CB truck in service position	X	
CB truck in test position		X

The circuit breaker closing is enabled when the ENA_CLOSE input is activated. This can be done by the configuration logic, which is a combination of the disconnect or breaker truck and earthing switch position statuses and the statuses of the master

trip logics and gas pressure alarm and circuit breaker spring charging. The OKPOS output from the DCSXSWI block defines if the disconnect or breaker truck is definitely either open/in test position or close/in service position. This, together with the open earthing switch and non-active trip signals, activates the close-enable signal to the circuit breaker control function block. The open operation is always enabled. The auto-recloser close command signals are directly connected to the output contact PO1 (X100:6-7).



If the ENA_CLOSE signal is completely removed from the breaker control function block CBXCBB with SMT, the function assumes that the breaker close commands are allowed continuously.

The ITL_BYPASS input can be used, for example, to always enable the closing of the circuit breaker when the circuit breaker truck is out in the test position, despite of the interlocking conditions being active when the circuit breaker truck is closed in service position.

The circuit breaker condition monitoring function (SSCBB) supervises the circuit breaker status based on the binary input information connected and measured current levels. The function introduces various supervision methods. The corresponding supervision alarm signals are routed to LED 8.

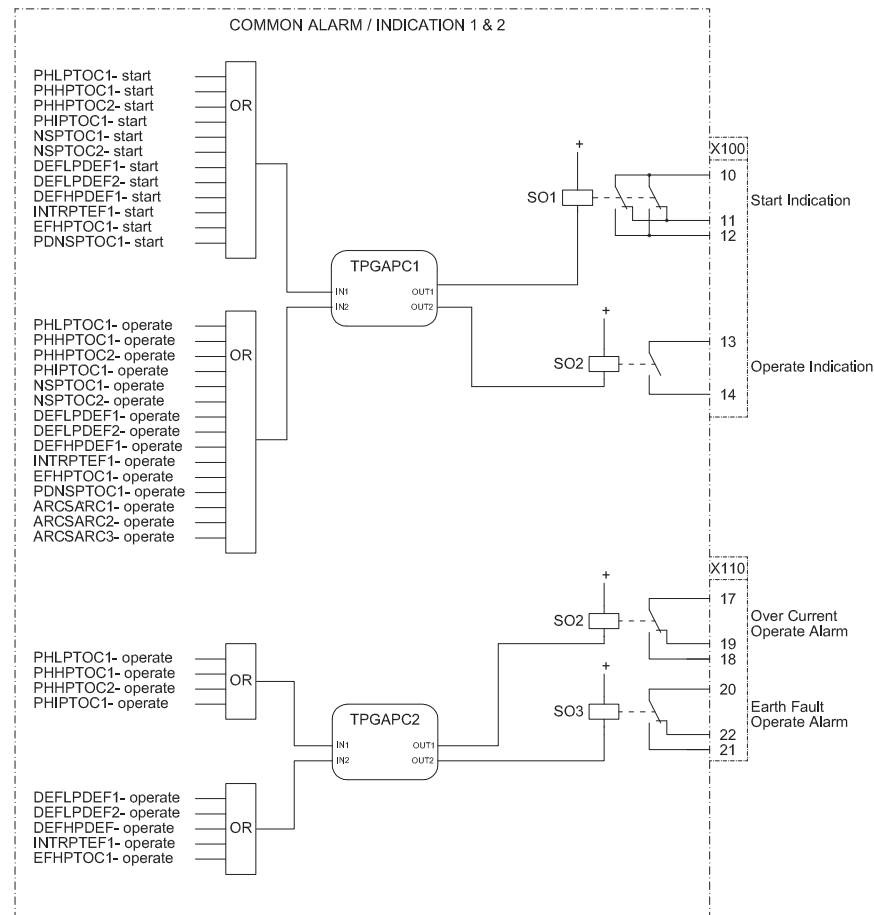


Figure 22: Alarm indication

The signal outputs from the IED are connected to give dedicated information on:

- start of any protection function SO1 (X100:10-12)
- operation (trip) of any protection function SO2 (X100:13-15)
- operation (trip) of any stage of the overcurrent protection function SO2 (X110:17-19)
- operation (trip) of any stage of the earth-fault protection function SO3 (X110:20-22).

The two TPGAPC blocks 1 and 2 are timers and used for setting the minimum pulse length for the outputs. There are four generic timers (TPGAPC1..4) available in the IED. The remaining ones not described in the functional diagram are available in SMT for connection where applicable.

3.5 Standard configuration C including non-directional earth-fault protection

3.5.1 Applications

The standard configuration for non-directional earth-fault protection is mainly intended for cable and overhead line feeder applications in directly or resistance earthed distribution networks. The IED with this standard configuration is delivered from the factory with default settings and parameters. The end-user flexibility for incoming, outgoing and internal signal designation within the IED enables this configuration to be further adapted to different primary circuit layouts and the related functionality needs by modifying the internal functionality with SMT and PST.

3.5.2 Functions

Table 8: Functions included in the REF615 standard configuration with non-directional earth-fault protection

Function	IEC 61850	IEC	ANSI
Three-phase non-directional overcurrent protection, low stage	PHLPTOC1	3I>	51P-1
Three-phase non-directional overcurrent protection, high stage, instance 1	PHHPTOC1	3I>> (1)	51P-2 (1)
Three-phase non-directional overcurrent protection, high stage, instance 2	PHHPTOC2	3I>> (2)	51P-2 (2)
Three-phase non-directional overcurrent protection, instantaneous stage	PHIPTOC1	3I>>>	50P/51P
Arc protection	ARCSARC1 ARCSARC2 ARCSARC3	ARC (1) ARC (2) ARC (3)	50L/50NL (1) 50L/50NL (2) 50L/50NL (3)
Non-directional earth-fault protection, low stage	EFLPTOC1	I ₀ > (1)	51N-1 (1)
Non-directional earth-fault protection, low stage (Non-directional sensitive earth-fault)	EFLPTOC2	I ₀ > (2)	51N-1 (2)
Non-directional earth-fault protection, high stage	EFHPTOC1	I ₀ >>	51N-2
Non-directional earth-fault protection, instantaneous stage	EFIPTOC1	I ₀ >>>	50N/51N
Negative-sequence overcurrent protection, instance 1	NSPTOC1	I ₂ > (1)	46 (1)
Negative-sequence overcurrent protection, instance 2	NSPTOC2	I ₂ > (2)	46 (2)
Phase discontinuity	PDNSPTOC1	I ₂ /I ₁ >	46PD
Three-phase inrush detector	INRPHAR1	3I2f>	68
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR1	3Ith>	49F
Autoreclosure	DARREC1	O → I	79
Circuit breaker failure protection	CCBRBRF1	3I>/I ₀ >BF	51BF/51NBF
Table continues on next page			

Function	IEC 61850	IEC	ANSI
Master Trip	TRPPTRC1 TRPPTRC2	Master Trip (1) Master Trip (2)	94/86 (1) 94/86 (2)
Trip circuit supervision, instance 1	TCSSCBR1	TCS (1)	TCM (1)
Trip circuit supervision, instance 2	TCSSCBR2	TCS (2)	TCM (2)
Disturbance recorder	RDRE1	-	-
Three-phase current measurement	CMMXU1	3I	3I
Sequence current measurement	CSMSQ1	I ₁ , I ₂ , I ₀	I ₁ , I ₂ , I ₀
Residual current measurement	RESCMMXU1	I ₀	I _n

3.5.2.1

Default I/O connections

Binary Input	Default usage	Connector-Pins
X120-BI1	Blocking of Overcurrent Instantaneous Stage	X120-1,2
X120-BI2	Circuit Breaker Closed indication	X120-3,2
X120-BI3	Circuit Breaker Open indication	X120-4,2
X120-BI4	Reset of Master Trip Lockout	X120-5,6

Binary Output	Default usage	Connector-Pins
X100-PO1	Close Circuit Breaker	X100-6,7
X100-PO2	Circuit Breaker Failure protection trip to upstream breaker	X100-8,9
X100-PO3	Open Circuit Breaker / trip coil 1	X100-16,17,18,19
X100-PO4	Open Circuit Breaker / trip coil 2	X100-20,21,22,23
X100-SO1	General Start Indication	X100-10,11,12
X100-SO2	General Operate Indication	X100-13,14,15

LED	Default usage
1	Non-Directional Overcurrent Operate
2	Non-Directional Earth fault Operate
3	Sensitive Earth fault Operate
4	Negative Seq. Overcurrent/Phase Discontinuity Operate
5	Thermal Overload Alarm
6	Breaker Failure Operate
7	Disturbance Recorder Triggered
8	Not connected
9	Trip Circuit Supervision Alarm
10	ARC Protection Operate
11	Auto Reclose Sequence in Progress

3.5.3 Functional diagrams

The functional diagrams describe the default input, output, alarm LED and function-to-function connections. The default connections can be viewed with SMT and changed according to the application requirements, if necessary.

The analog channels, measurements from CTs and VTs, have fixed connections towards the different function blocks inside the IED's standard configuration. Exceptions from this rule are the 12 analog channels available for the disturbance recorder function. These channels are freely selectable and a part of the disturbance recorder's parameter settings, thus not included in the SMT functionality.

The analog channels are assigned to different functions as shown in the functional diagrams. The common signal marked with 3I represents the three phase currents. The signal marked with I_0 represents the measured residual current via a summation connection of the phase current transformers.

3.5.3.1 Functional diagrams for protection

The following functional diagrams describe the IED's protection functionality in detail and according to the factory set default connections in SMT.

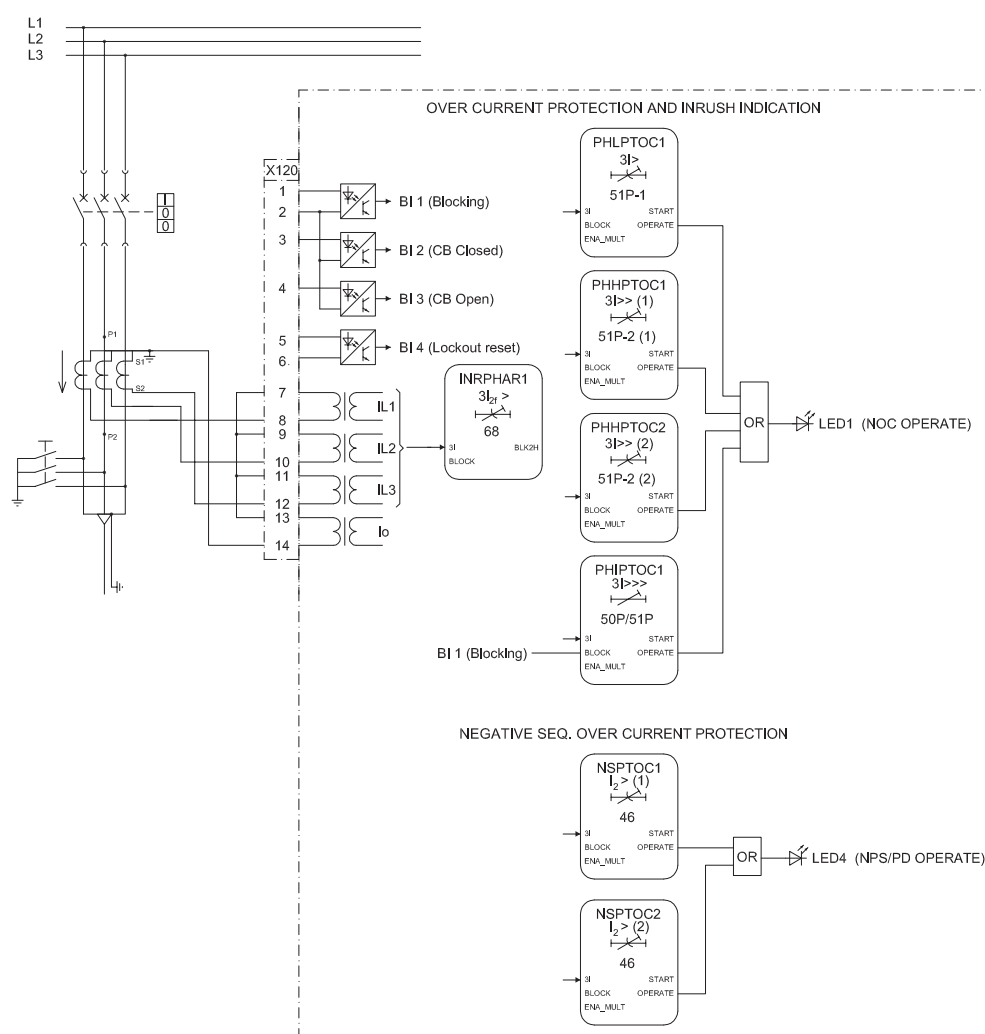


Figure 23: Overcurrent protection

Four overcurrent stages are offered for overcurrent and short-circuit protection. The instantaneous stage (PHIPTOC1) can be blocked by energizing the binary input 1 (X120:1-2). Two negative sequence overcurrent stages (NPSTOC1 and NPSTOC2) are offered for phase unbalance protection. The inrush detection block's (INRP HAR1) output BLK2H caters the possibility to either block the function or multiply the active settings for any of the shown protection function blocks.

All operate signals are connected to the Master Trip and also to the alarm LEDs. LED 1 is used for overcurrent and LED 4 for negative sequence overcurrent protection operate indication. LED 4 is also used for phase discontinuity protection operate indication.

There are four IED variant specific setting groups. Parameters can be set independently for each setting group.

The active setting group (1...4) can be changed with a parameter. The change of an active setting group can also be made via a binary input if the binary input is enabled

for this. To enable the change of an active setting group via a binary input, connect a free binary input with SMT to the ActSG input of the SGCB-block.

Table 9: *Binary input states and corresponding active setting groups*

BI State	Active setting group
OFF	1
ON	2

The active setting group defined by a parameter is overridden when a binary input is enabled for changing the active setting group.

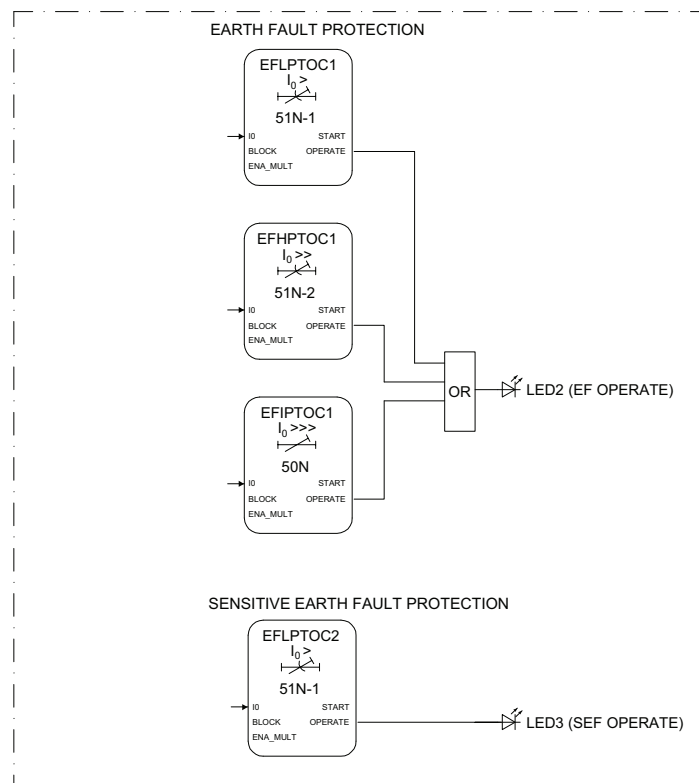


Figure 24: *Non-directional earth-fault protection*

Four stages are offered for non-directional earth-fault protection. One stage is dedicated to sensitive earth-fault protection.

All operate signals are connected to the Master Trip and also to the alarm LEDs. LED 2 is used for directional earth-fault and LED 3 for the sensitive earth-fault protection operate indication.

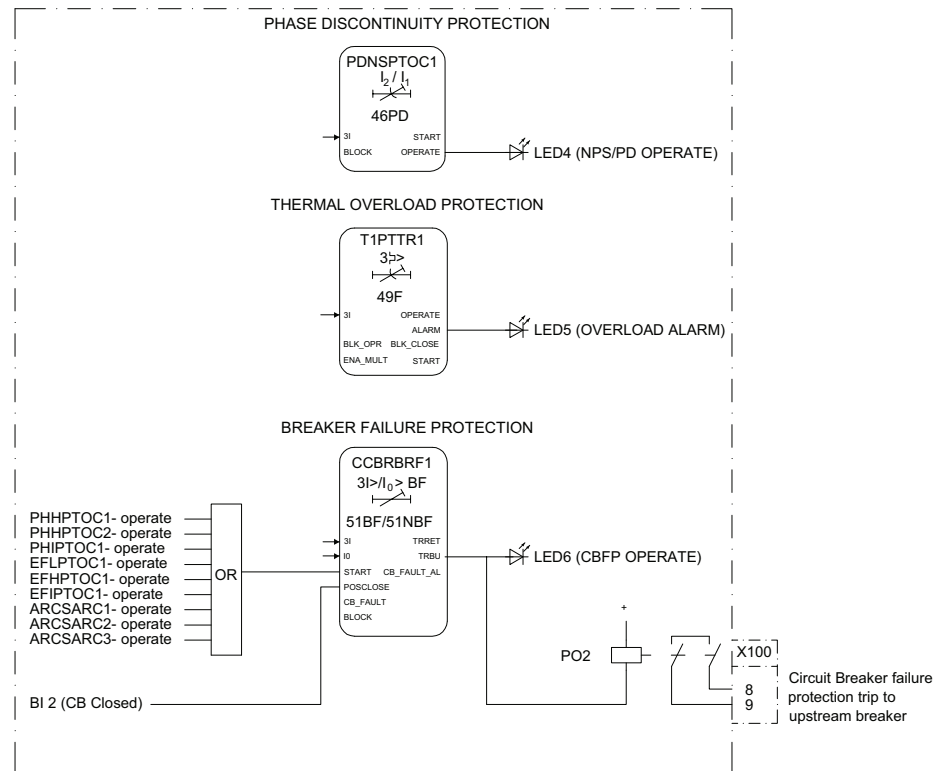


Figure 25: Phase discontinuity, thermal overload and circuit breaker failure protection

The phase discontinuity protection (PDNSPTOC1) provides protection for interruptions in the normal three-phase load supply, for example, in downed conductor situations. The thermal overload protection (T1PTTR1) provides indication on overload situations. The operate signal of the phase discontinuity protection is connected to the Master Trip and also to an alarm LED. LED 4 is used for the phase discontinuity protection operate indication, the same as for negative sequence overcurrent protection operate indication, and LED 5 is used for the thermal overload protection alarm indication.

The breaker failure protection (CCBRBRF1) is initiated via the start input by a number of different protection stages in the IED. The breaker failure protection function offers different operating modes associated with the circuit breaker position and the measured phase and residual currents. The breaker failure protection has two operating outputs: TRRET and TRBU. The TRRET operate output is used for re-tripping its own breaker through the Master Trip 2. The TRBU output is used to give a back-up trip to the breaker feeding upstream. For this purpose, the TRBU operate output signal is connected to the output PO2 (X100: 8-9). LED 6 is used for back-up (TRBU) operate indication.

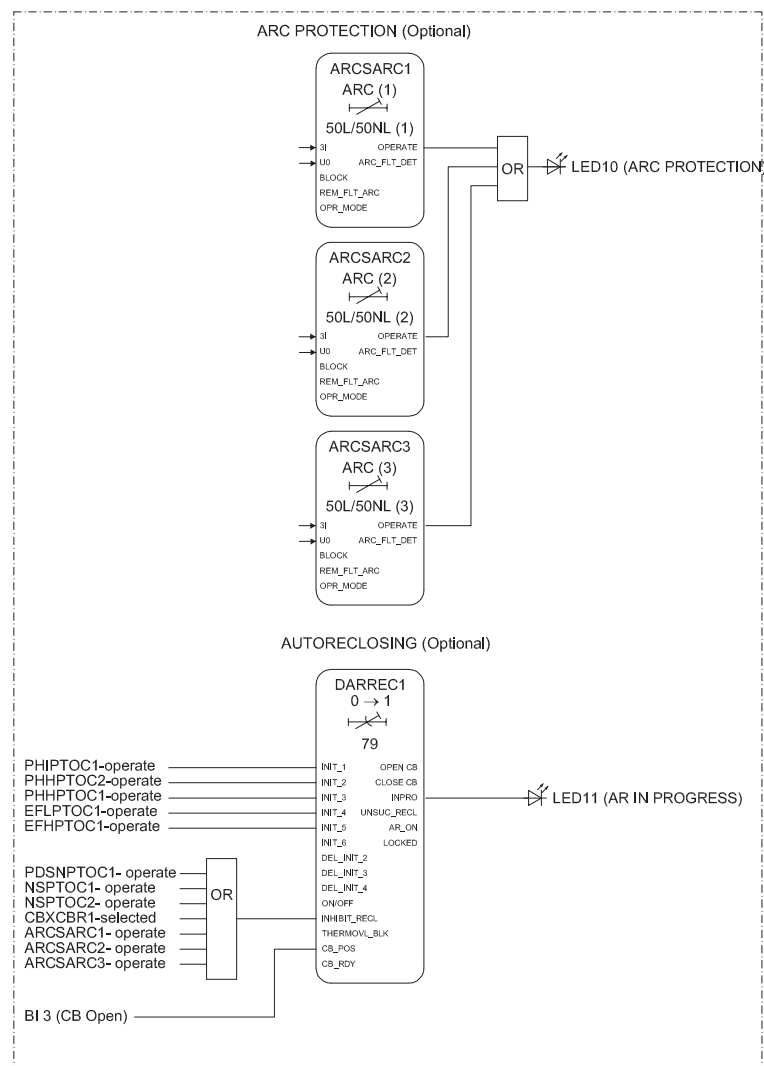


Figure 26: Arc protection

ARC protection (ARCSARC1-3) and auto-reclosing (DARREC1) are included as optional functions.

The ARC protection offers individual function blocks for three ARC sensors that can be connected to the IED. Each ARC protection function block has two different operation modes, with or without the phase and residual current check. Operate signals from the ARC protection function blocks are connected to the Master Trip and also to the alarm LED 10 as a common operate indication.

The auto-recloser is configured to be initiated by operate signals from a number of protection stages through the INIT1-5 inputs. It is possible to create individual auto-reclosing sequences for each input.

The auto-reclosing function can be blocked with the INHIBIT_RECL input. As a default, the operation of some selected protection functions are connected to this

input. A control command to the circuit breaker, either local or remote, also blocks the auto-reclose function via the CBXCBR-selected signal.

The circuit breaker availability for the auto-reclosure sequence is expressed with the CB_RDY input in DARREC1. In the configuration, this signal is not connected to any of the binary inputs. As a result, the function assumes that the breaker is available all the time.

The auto-reclose sequence in progress indication is connected to the alarm LED 11.

3.5.3.2

Functional diagram for disturbance recorder and trip circuit supervision

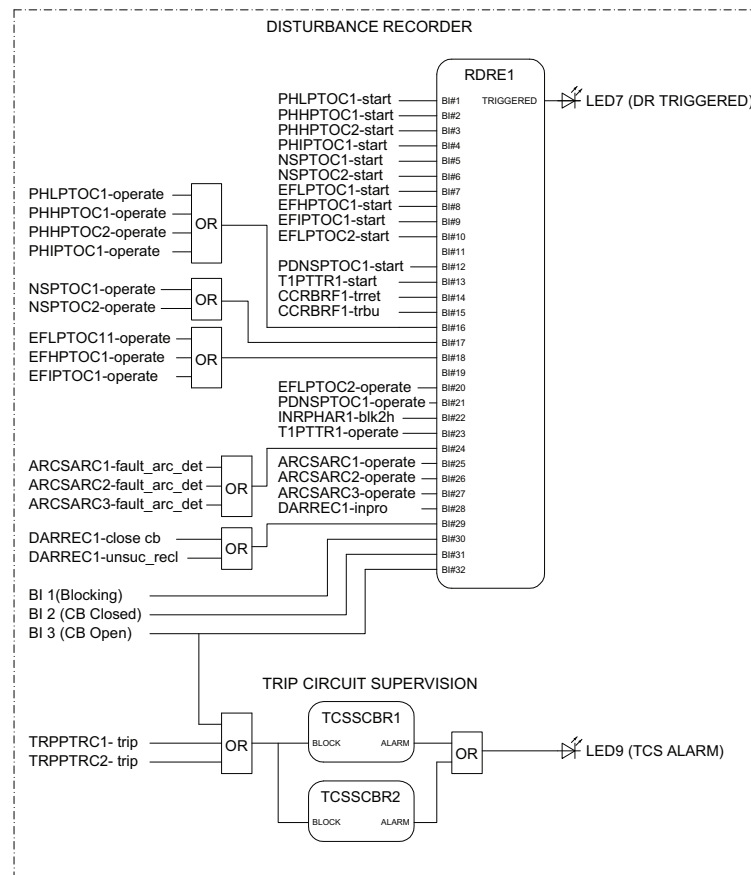


Figure 27: Disturbance recorder

The disturbance recorder has 64 digital inputs out of which 32 are connected as a default. All start and operate signals from the protection stages are routed to trigger the disturbance recorder or alternatively only to be recorded by the disturbance recorder depending on the parameter settings. Additionally, the selected auto-recloser, the ARC protection signals and the three binary inputs from X120 are also connected.

Two separate TCS functions are included: TCSSCBR1 for PO3 (X100:16-19) and TCSSCBR2 for PO4 (X100:20-23). Both functions are blocked by the Master Trip

(TRPPTRC1 and TRPPTRC2) and the circuit breaker open position signal. The TCS alarm indication is connected to LED 9.

3.5.3.3

Functional diagrams for control and interlocking

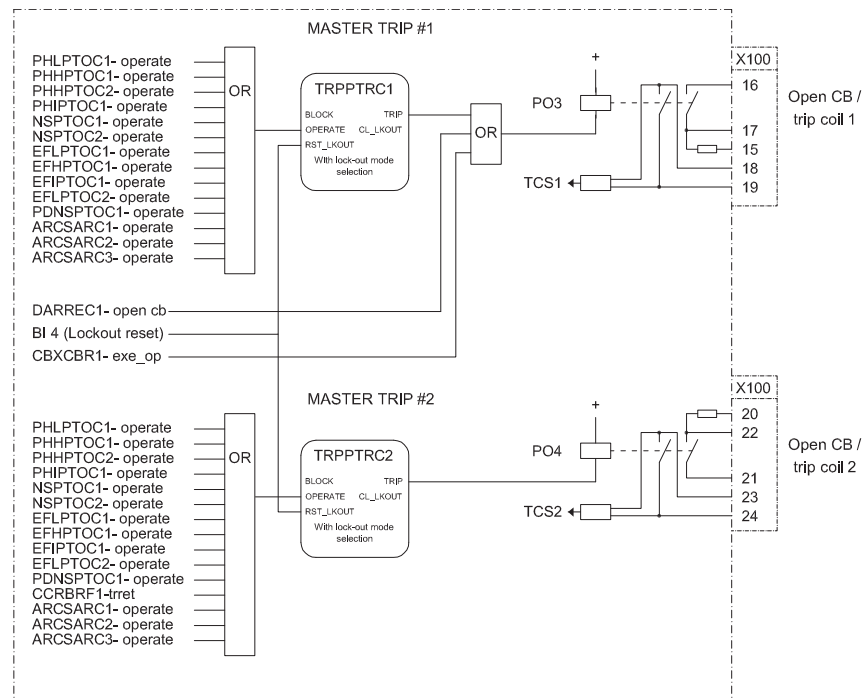


Figure 28: Master trip

The operate signals from the protections described above are connected to both of the two trip output contacts PO3 (X100:16-19) and PO4 (X100:20-23) via the corresponding Master Trips TRPPTRC1 and TRPPTRC2. The open control commands to the circuit breaker from local or remote CBXCBR1-exe_op or from the auto-recloser DARREC1-open_cb are connected directly to the output PO3 (X100:16-19).

The TRPPTRC1 and 2 blocks provide the lockout/latching function, event generation and the trip signal duration setting. In case the lockout operation mode is selected, the binary input 4 (X120:5-6) is assigned to the RST_LKOUT input of the Master Trip to enable external reset with a push button.

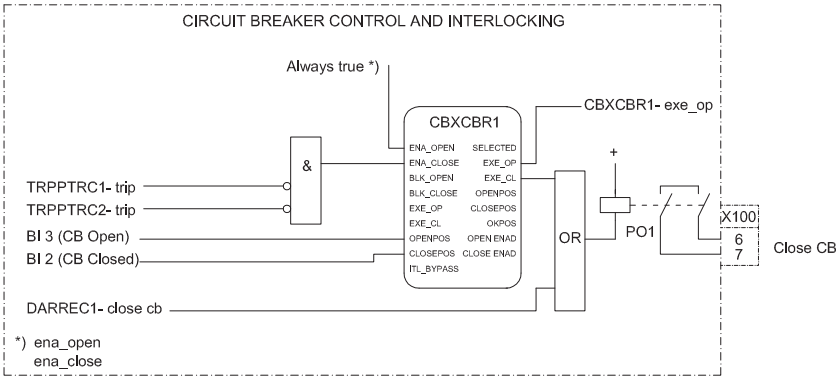


Figure 29: Circuit breaker control

The ENA_CLOSE input, that is, enable the closing of the circuit breaker, in the breaker control function block CBXCBR is a combination of the status of the Master Trip. The open operation is always enabled.



If the ENA_CLOSE signal is completely removed from the breaker control function block CBXCBR with SMT, the function assumes that the breaker close commands are allowed continuously.

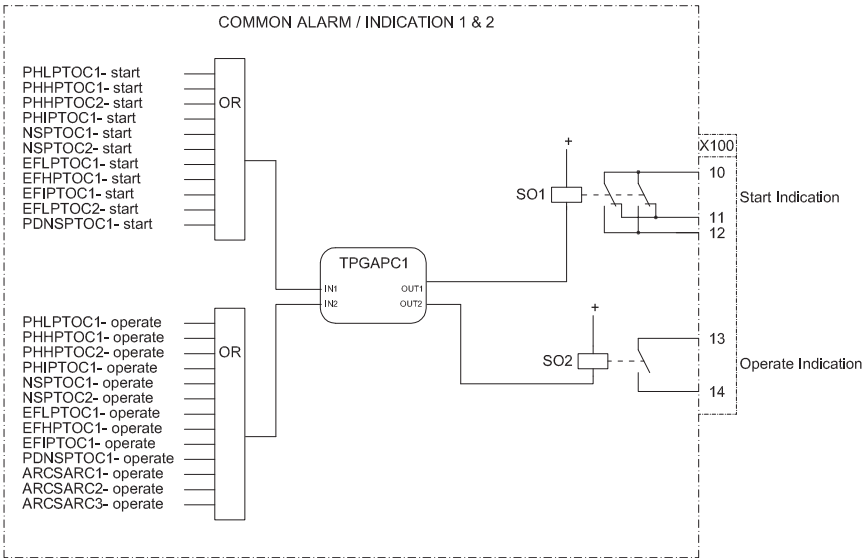


Figure 30: Alarm indication

The signal outputs from the IED have been connected to give dedicated information on:

- start of any protection function SO1 (X100:10-12)
- operation (trip) of any protection function SO2 (X100:13-15).

The two TPGAPC blocks 1 and 2 are timers and used for setting the minimum pulse length for the outputs. There are four generic timers (TPGAPC1..4) available in the IED. The remaining ones not described in the functional diagram are available in SMT for connection where applicable.

3.6 Standard configuration D including non-directional earth-fault protection and CB condition monitoring

3.6.1 Applications

The standard configuration for non-directional earth-fault protection is mainly intended for cable and overhead line feeder applications in directly or resistance earthed distribution networks. The IED with this standard configuration is delivered from the factory with default settings and parameters. The end-user flexibility for incoming, outgoing and internal signal designation within the IED enables this configuration to be further adapted to different primary circuit layouts and the related functionality needs by modifying the internal functionality with SMT and PST.

3.6.2 Functions

Table 10: Functions included in the REF615 standard configuration with non-directional earth-fault protection

Function	IEC 61850	IEC	ANSI
Three-phase non-directional overcurrent protection, low stage	PHLPTOC1	3I>	51P-1
Three-phase non-directional overcurrent protection, high stage, instance 1	PHHPTOC1	3I>> (1)	51P-2 (1)
Three-phase non-directional overcurrent protection, high stage, instance 2	PHHPTOC2	3I>> (2)	51P-2 (2)
Three-phase non-directional overcurrent protection, instantaneous stage	PHIPTOC1	3I>>>	50P/51P
Arc protection	ARCSARC1 ARCSARC2 ARCSARC3	ARC (1) ARC (2) ARC (3)	50L/50NL (1) 50L/50NL (2) 50L/50NL (3)
Non-directional earth-fault protection, low stage	EFLPTOC1	I ₀ > (1)	51N-1 (1)
Non-directional earth-fault protection, low stage (Non-directional sensitive earth-fault)	EFLPTOC2	I ₀ > (2)	51N-1 (2)
Non-directional earth-fault protection, high stage	EFHPTOC1	I ₀ >>	51N-2
Non-directional earth-fault protection, instantaneous stage	EFIPTOC1	I ₀ >>>	50N/51N
Negative-sequence overcurrent protection, instance 1	NSPTOC1	I ₂ > (1)	46 (1)
Table continues on next page			

Function	IEC 61850	IEC	ANSI
Negative-sequence overcurrent protection, instance 2	NSPTOC2	$I_2 > (2)$	46 (2)
Phase discontinuity	PDNSPTOC1	$I_2/I_1 >$	46PD
Three-phase inrush detector	INRPHAR1	$3I_2 f >$	68
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR1	$3I_{th} >$	49F
Autoreclosure	DARREC1	$O \rightarrow I$	79
Circuit breaker failure protection	CCBRBRF1	$3I > I_0 > BF$	51BF/51NBF
Master trip	TRPPTRC1 TRPPTRC2	Master Trip (1) Master Trip (2)	94/86 (1) 94/86 (2)
Trip circuit supervision, instance 1	TCSSCBR1	TCS (1)	TCM (1)
Trip circuit supervision, instance 2	TCSSCBR2	TCS (2)	TCM (2)
Disturbance recorder	RDRE1	-	-
Circuit breaker condition monitoring	SSCBR1	CBCM	CBCM
Three-phase current measurement	CMMXU1	$3I$	$3I$
Sequence current measurement	CSMSQ1	I_1, I_2, I_0	I_1, I_2, I_0
Residual current measurement	RESCMMXU1	I_0	I_n

3.6.2.1

Default I/O connections

Binary Input	Default usage	Connector-Pins
X110-BI2	Auto Reclose External Start Command	X110-3,4
X110-BI3	Circuit Breaker low Gas Pressure indication	X110-5,6
X110-BI4	Circuit Breaker Spring Charged indication	X110-6,7
X110-BI5	CB Truck in (Service position) indication	X110-8,9
X110-BI6	CB Truck out (Test position) indication	X110-10,9
X110-BI7	Earthing Switch Closed indication	X110-11,12
X110-BI8	Earthing Switch Open indication	X110-13,12
X120-BI1	Blocking of Overcurrent Instantaneous Stage	X120-1,2
X120-BI2	Circuit Breaker Closed indication	X120-3,2
X120-BI3	Circuit Breaker Open indication	X120-4,2
X120-BI4	Reset of Master Trip Lockout	X120-5,6

Binary Output	Default usage	Connector-Pins
X100-PO1	Close Circuit Breaker	X100-6,7
X100-PO2	Circuit Breaker Failure protection trip to upstream breaker	X100-8,9
X100-PO3	Open Circuit Breaker / trip coil 1	X100-16,17,18,19
X100-PO4	Open Circuit Breaker / trip coil 2	X100-20,21,22,23
X100-SO1	General Start Indication	X100-10,11,12
X100-SO2	General Operate Indication	X100-13,14,15
Table continues on next page		

Binary Output	Default usage	Connector-Pins
X110-SO1	Upstream Overcurrent Blocking	X110-14,15,16
X110-SO2	Overcurrent Operate Alarm	X110-17,18,19
X110-SO3	Earth fault Operate Alarm	X110-20,21,22

LED	Default usage
1	Non-Directional Overcurrent Operate
2	Non-Directional Earth fault Operate
3	Sensitive Earth fault Operate
4	Negative Seq. Overcurrent/Phase Discontinuity Operate
5	Thermal Overload Alarm
6	Breaker Failure Operate
7	Disturbance Recorder Triggered
8	Circuit Breaker Condition Monitoring Alarm
9	Trip Circuit Supervision Alarm
10	ARC Protection Operate
11	Auto Reclose Sequence in Progress

3.6.3 Functional diagrams

The functional diagrams describe the default input, output, alarm LED and function-to-function connections. The default connections can be viewed with SMT and changed according to the application requirements, if necessary.

The analog channels, measurements from CTs and VTs, have fixed connections towards the different function blocks inside the IED's standard configuration. Exceptions from this rule are the 12 analog channels available for the disturbance recorder function. These channels are freely selectable and a part of the disturbance recorder's parameter settings, thus not included in the SMT functionality.

The analog channels are assigned to different functions as shown in the functional diagrams. The common signal marked with 3I represents the three phase currents. The signal marked with I_0 represents the measured residual current, via a summation connection of the phase current transformers.

3.6.3.1 Functional diagrams for protection

The following functional diagrams describe the IED's protection functionality in detail and according to the factory set default connections in SMT.

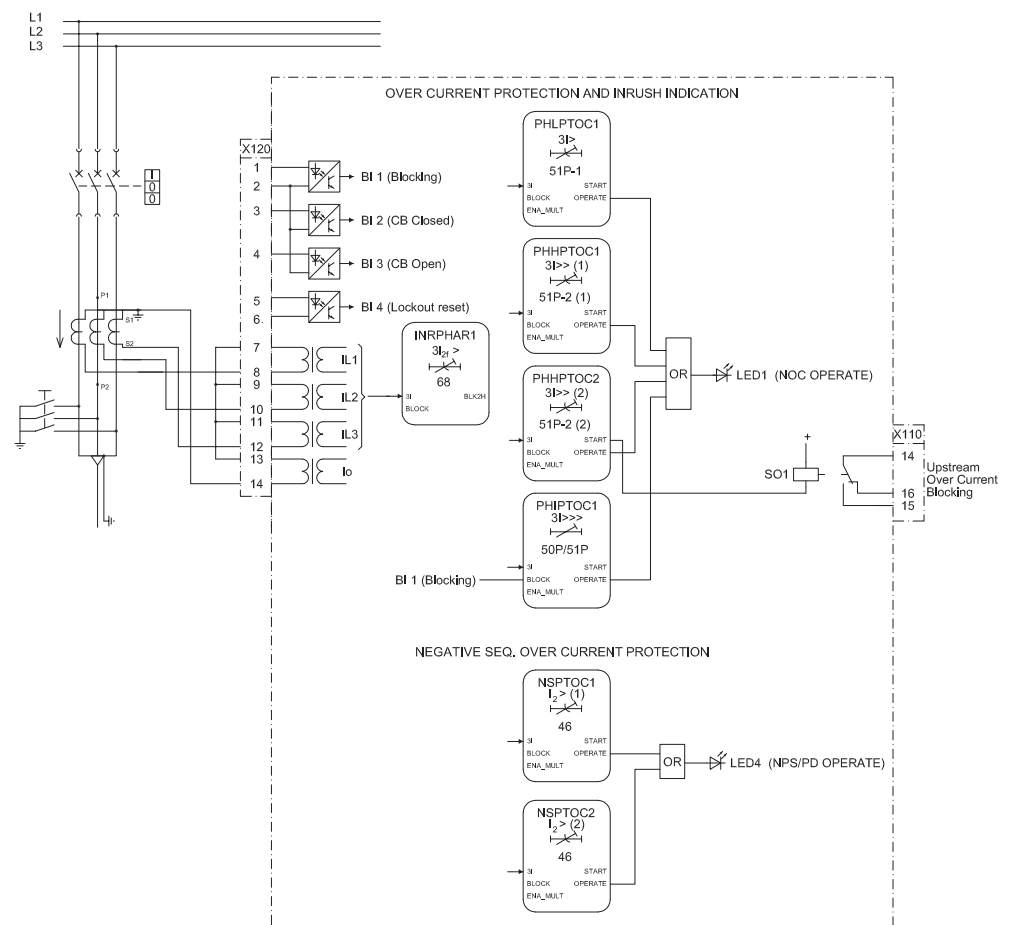


Figure 31: Overcurrent protection

Four overcurrent stages are offered for overcurrent and short-circuit protection. The instantaneous stage (PHIPTOC1) can be blocked by energizing the binary input 1 (X120:1-2). Two negative sequence overcurrent stages (NPSTOC1 and NPSTOC2) are offered for phase unbalance protection. The inrush detection block's (INRPHAR1) output BLK2H caters the possibility to either block the function or multiply the active settings for any of the shown protection function blocks.

All operate signals are connected to the Master Trip and also to the alarm LEDs. LED 1 is used for overcurrent and LED 4 for negative sequence overcurrent protection operate indication. LED 4 is also used for phase discontinuity protection operate indication.

The upstream blocking from the start of the overcurrent second high stage (PHHPTOC2) is connected to the output SO1 (X110:14-15-16). This output is used for sending a blocking signal to the relevant overcurrent protection stage of the IED at the infedding bay.

There are four IED variant specific setting groups. Parameters can be set independently for each setting group.

The active setting group (1...4) can be changed with a parameter. The change of an active setting group can also be made via a binary input if the binary input is enabled for this. To enable the change of an active setting group via a binary input, connect a free binary input with SMT to the ActSG input of the SGCB-block.

Table 11: *Binary input states and corresponding active setting groups*

BI State	Active setting group
OFF	1
ON	2

The active setting group defined by a parameter is overridden when a binary input is enabled for changing the active setting group.

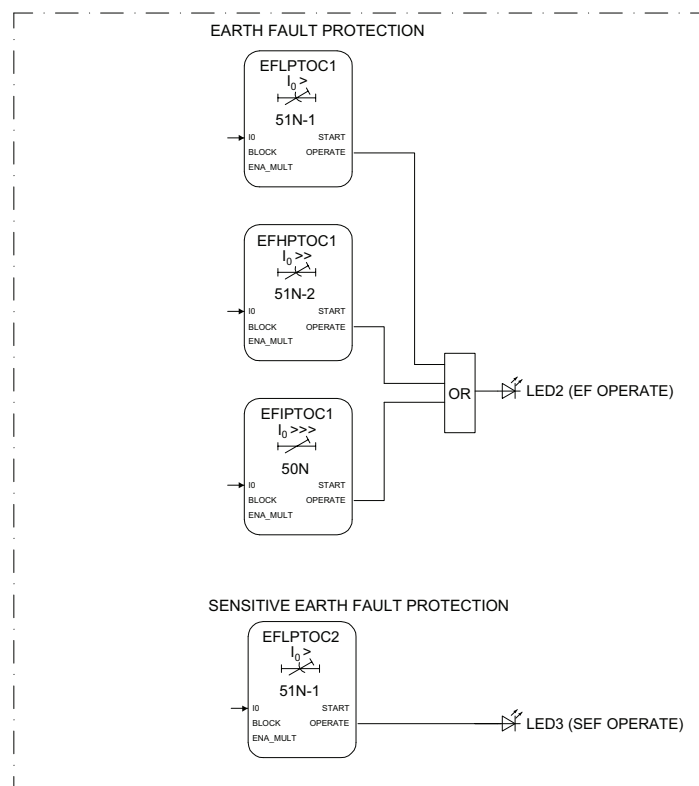


Figure 32: *Non-directional earth-fault protection*

Four stages are offered for non-directional earth-fault protection. One stage is dedicated to sensitive earth-fault protection.

All operate signals are connected to the Master Trip and also to the alarm LEDs. LED 2 is used for directional earth-fault and LED 3 for the sensitive earth-fault protection operate indication.

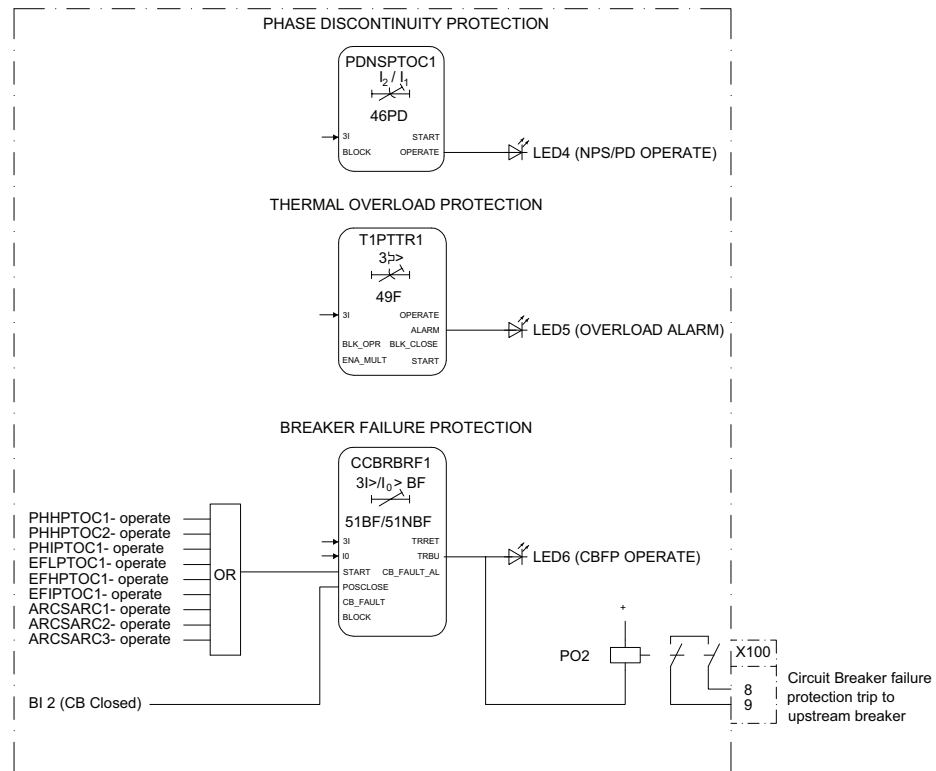


Figure 33: Phase discontinuity, thermal overload and circuit breaker failure protection

The phase discontinuity protection (PDNSPTOC1) provides protection for interruptions in the normal three-phase load supply, for example, in downed conductor situations. The thermal overload protection (T1PTTR1) provides indication on overload situations. The operate signal of the phase discontinuity protection is connected to the Master Trip and also to the alarm LEDs. LED 4 is used for the phase discontinuity protection operate indication, the same as for negative sequence overcurrent protection operate indication, and LED 5 is used for the thermal overload protection alarm indication.

The breaker failure protection (CCBRBRF1) is initiated via the start input by a number of different protection stages in the IED. The breaker failure protection function offers different operating modes associated with the circuit breaker position and the measured phase and residual currents. The breaker failure protection has two operating outputs: TRRET and TRBU. The TRRET operate output is used for re-tripping its own breaker through the Master Trip 2. The TRBU output is used to give a back-up trip to the breaker feeding upstream. For this purpose, the TRBU operate output signal is connected to the output PO2 (X100: 8-9). LED 6 is used for back-up (TRBU) operate indication.

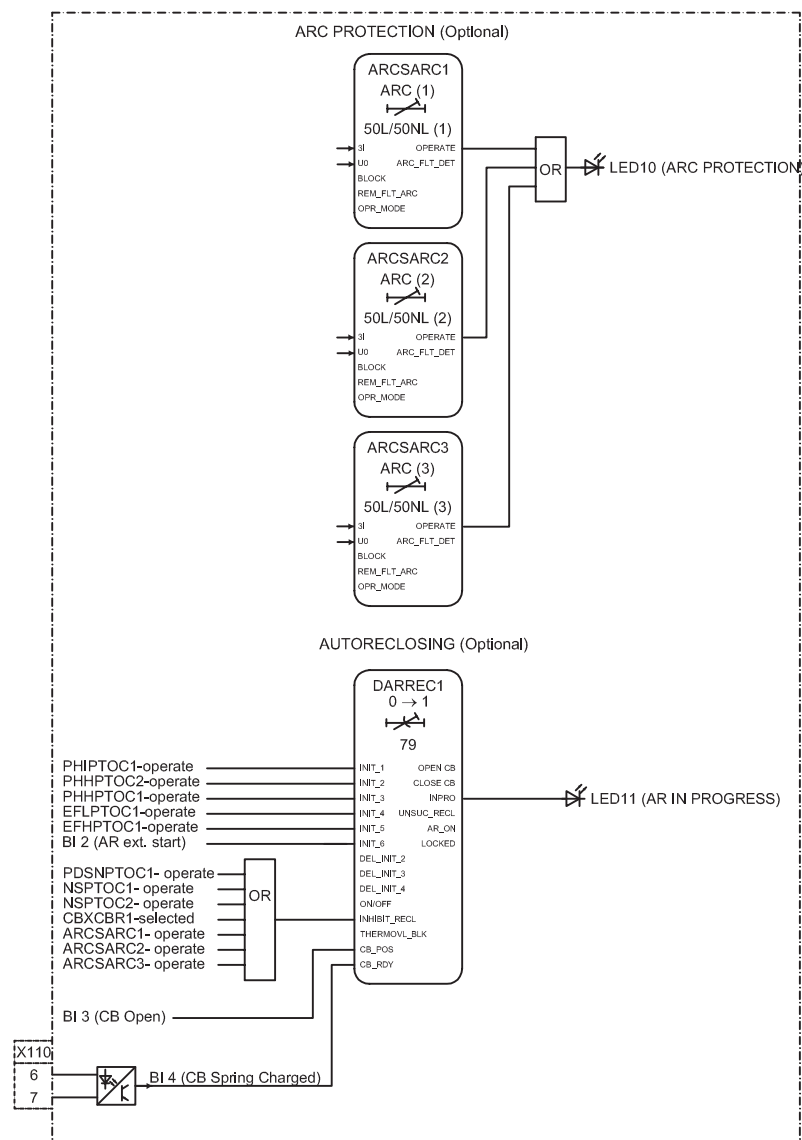


Figure 34: Arc protection

ARC protection (ARCSARC1-3) and auto-reclosing (DARREC1) are included as optional functions.

The ARC protection offers individual function blocks for three ARC sensors that can be connected to the IED. Each ARC protection function block has two different operation modes, with or without the phase and residual current check. Operate signals from the ARC protection function blocks are connected to the Master Trip and also to the alarm LED 10 as a common operate indication.

The auto-recloser is configured to be initiated by operate signals from a number of protection stages through the INIT1-5 inputs. The INIT6 input in the auto-recloser function block is controlled by a binary input 2 (X110:3-4) enabling the use of the external start command. It is possible to create individual auto-reclose sequences for each input.

The auto-reclose function can be blocked with the INHIBIT_RECL input. As a default, the operation of some selected protection functions are connected to this input. A control command to the circuit breaker, either local or remote, also blocks the auto-reclose function via the CBXCBB-selected signal.

The circuit breaker availability for the auto-reclosure sequence is expressed with the binary input 4 (X110:6-7) by connecting the input signal to the CB_RDY input. In case this signal is completely removed from the auto-reclose function block with SMT, the function assumes that the breaker is available all the time.

The auto-reclose sequence in progress indication is connected to the alarm LED 11.

3.6.3.2

Functional diagram for disturbance recorder and trip circuit supervision

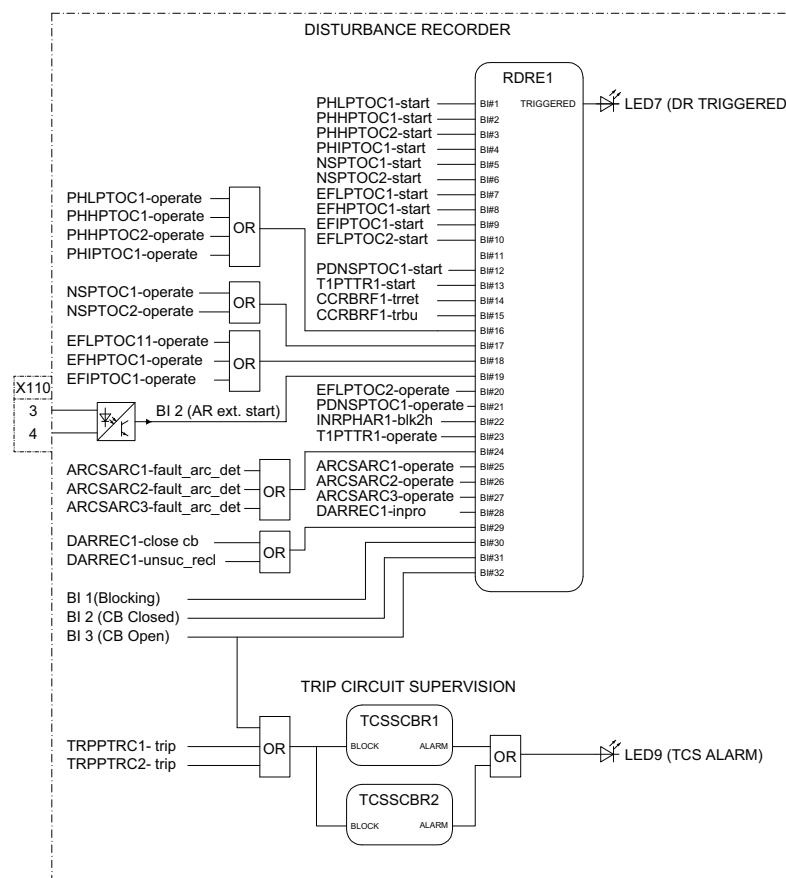


Figure 35: Disturbance recorder

The disturbance recorder has 64 digital inputs out of which 32 are connected as a default. All start and operate signals from the protection stages are routed to trigger the disturbance recorder or alternatively only to be recorded by the disturbance recorder depending on the parameter settings. Additionally, the selected auto-recloser, the ARC protection signals and the three binary inputs from X120 are also connected, as well as the auto-recloser external start command from the binary input 2 (X110:3-4).

Two separate TCS functions are included: TCSSCBR1 for PO3 (X100:16-19) and TCSSCBR2 for PO4 (X100:20-23). Both functions are blocked by the Master Trip (TRPPTRC1 and TRPPTRC2) and the circuit breaker open position signal. The TCS alarm indication is connected to LED 9.

3.6.3.3

Functional diagrams for control and interlocking

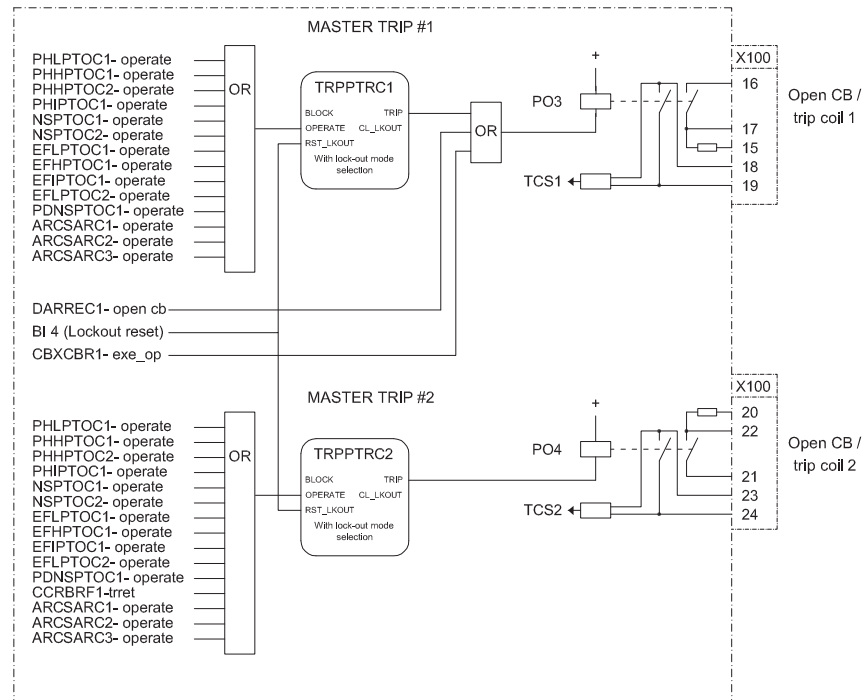


Figure 36: Master trip

The operate signals from the protections described above are connected to the two trip output contacts PO3 (X100:16-19) and PO4 (X100:20-23) via the corresponding Master Trips TRPPTRC1 and TRPPTRC2. The open control commands to the circuit breaker from local or remote CBXCBR1-exe_op or from the auto-recloser DARREC1-open_cb are connected directly to the output PO3 (X100:16-19).

The TRPPTRC1 and 2 blocks provide the lockout/latching function, event generation and the trip signal duration setting. If the lockout operation mode is selected, the binary input 4 (X120:5-6) is assigned to the RST_LKOUT input of the Master Trip to enable external reset with a push button.

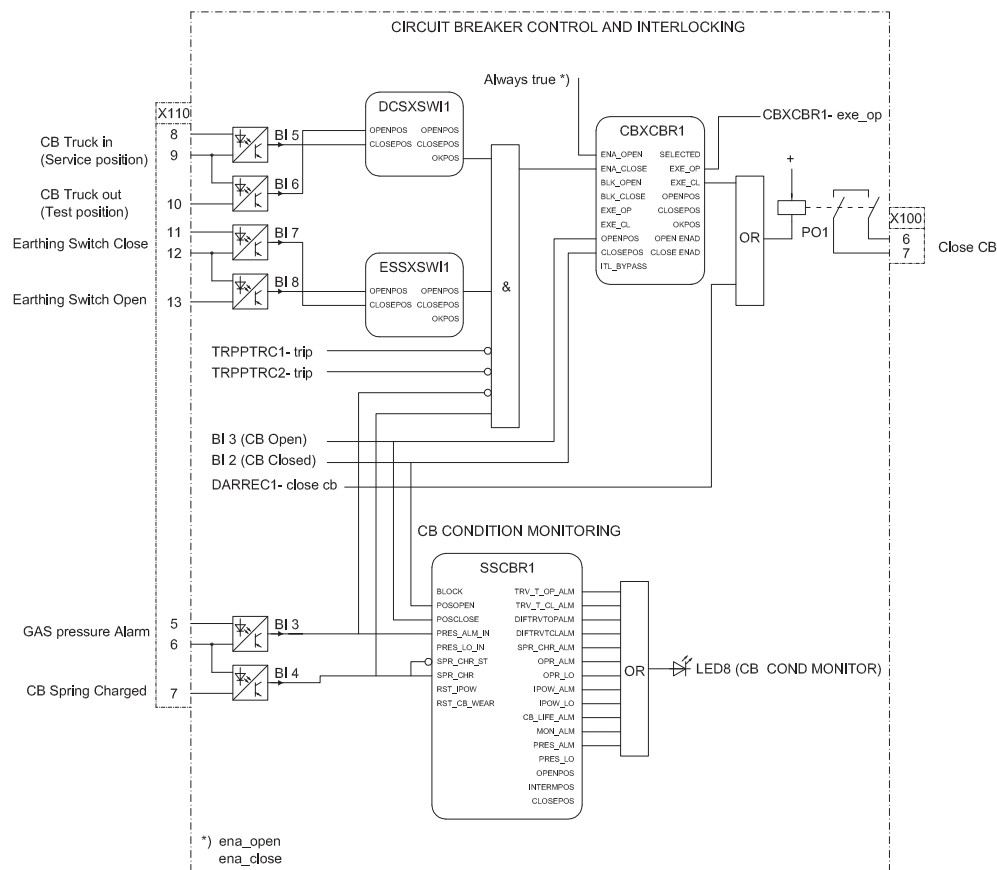


Figure 37: Circuit breaker control

There are three disconnector status blocks (DCSXSXI1...3) available in the IED. The remaining two not described in the functional diagram are available in SMT for connection where applicable.

The binary inputs 5 and 6 of the additional card X110 are used for busbar disconnector (DCSXSXI1) or circuit breaker truck position indication.

Primary device position	Input to be energized	
	Input 5 (X110:8-9)	Input 6 (X110:10-9)
Busbar disconnector closed	X	
Busbar disconnector open		X
CB truck in service position	X	
CB truck in test position		X

The binary inputs 7 and 8 (X110:1-13) are for the position indication of the line side earthing switch.

The circuit breaker closing is enabled when the ENA_CLOSE input is activated. This can be done by the configuration logic, which is a combination of the disconnector or breaker truck and earthing switch position statuses and the statuses of the master

trip logics and gas pressure alarm and circuit breaker spring charging. The OKPOS output from the DCSXSWI block defines if the disconnect or breaker truck is definitely either open/in test position or close/in service position. This, together with the open earthing switch and non-active trip signals, activates the close-enable signal to the circuit breaker control function block. The open operation is always enabled. The auto-recloser close command signals are directly connected to the output contact PO1 (X100:6-7).



If the ENA_CLOSE signal is completely removed from the breaker control function block CBXCBB with SMT, the function assumes that the breaker close commands are allowed continuously.

The ITL_BYPASS input can be used, for example, to always enable the closing of the circuit breaker when the circuit breaker truck is out in the test position, despite of the interlocking conditions being active when the circuit breaker truck is closed in service position.

The circuit breaker condition monitoring function (SSCBB) supervises the circuit breaker status based on the binary input information connected and measured current levels. The function introduces various supervision methods. The corresponding supervision alarm signals are routed to LED 8.

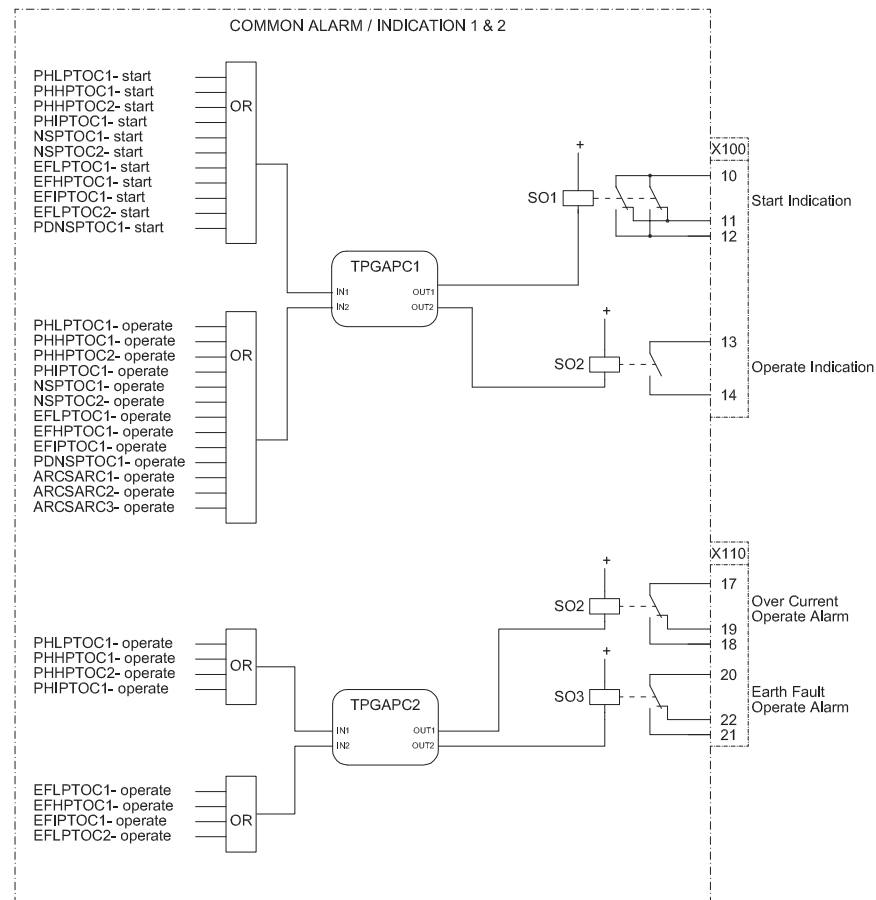


Figure 38: Alarm indication

The signal outputs from the IED are connected to give dedicated information on:

- start of any protection function SO1 (X100:10-12)
- operation (trip) of any protection function SO2 (X100:13-15)
- operation (trip) of any stage of the overcurrent protection function SO2 (X110:17-19)
- operation (trip) of any stage of the earth fault protection function SO3 (X110:20-22).

The two TPGAPC blocks 1 and 2 are timers and used for setting the minimum pulse length for the outputs. There are four generic timers (TPGAPC1..4) available in the IED. The remaining ones not described in the functional diagram are available in SMT for connection where applicable.

Section 4 Basic functions

4.1 General parameters

Table 12: *Analog channel settings, phase currents*

Parameter	Values (Range)	Unit	Step	Default	Description
Secondary current	1=0.2A 2=1A 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 13: *Analog channel settings, residual current*

Parameter	Values (Range)	Unit	Step	Default	Description
Secondary current	1=0.2A 2=1A 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 14: *Analog channel settings, residual voltage*

Parameter	Values (Range)	Unit	Step	Default	Description
Secondary voltage	1=100V 2=110V 3=115V 4=120V			1=100V	Secondary voltage
Primary voltage	0.001...440.000	kV	0.001	20.000	Primary voltage
Amplitude corr.	0.900...1.100		0.001	1.000	Amplitude correction

Table 15: *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 16: *Alarm LED settings*

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm LED mode	0=Follow-S ¹⁾ 1=Follow-F ²⁾ 2=Latched-S ³⁾ 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 1=Follow-F 2=Latched-S 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 1=Follow-F 2=Latched-S 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 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 4
Description				Alarm LEDs LED 4	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 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 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 6

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Description				Alarm LEDs LED 6	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 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 1=Follow-F 2=Latched-S 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 1=Follow-F 2=Latched-S 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 1=Follow-F 2=Latched-S 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 1=Follow-F 2=Latched-S 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 17: *Authorization settings*

Parameter	Values (Range)	Unit	Step	Default	Description
Local override	0=False ¹⁾ 1=True ²⁾			1=True	Disable authority
Remote override	0=False ³⁾ 1=True ⁴⁾			1=True	Disable authority
Local viewer				0	Set password
Local operator				0	Set password
Local engineer				0	Set password
Local 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 18: *Binary input settings*

Parameter	Values (Range)	Unit	Step	Default	Description
Threshold voltage	18...176	Vdc	2	18	Digital input threshold voltage
Input osc. level	2...50		1	30	Digital input oscillation suppression threshold
Input osc. hyst	2...50		1	10	Digital input oscillation suppression hysteresis

Table 19: *Ethernet front port settings*

Parameter	Values (Range)	Unit	Step	Default	Description
IP address				192.168.000.254	IP address for front port (fixed)
Mac address				XX-XX-XX-XX-XX-XX	Mac address for front port

Table 20: *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 21: *General system settings*

Parameter	Values (Range)	Unit	Step	Default	Description
Rated frequency	1=50Hz 2=60Hz			1=50Hz	Rated frequency of the network
Phase rotation	1=ABC 2=ACB			1=ABC	Phase rotation order
Blocking mode	1=Freeze timer 2=Block all 3=Block OPERATE output			1=Freeze timer	Behaviour for function BLOCK inputs
Bay name				REF615	Bay name in system

Table 22: *Non group settings*

Parameter	Values (Range)	Unit	Step	Default	Description
Date				0	Date
Time				0	Time
Time format	1=24H:MM:SS:MS 2=12H:MM:SS:MS			1=24H:MM:SS:MS	Time format
Date format	1=DD.MM.YYYY 2=DD/MM/YYYY 3=DD-MM-YYYY 4=MM.DD.YYYY 5=MM/DD/YYYY 6=YYYY-MM-DD 7=YYYY-DD-MM 8=YYYY/DD/MM			1=DD.MM.YYYY	Date format
Local time offset	-720...720	min		0	Local time offset in minutes

Table 23: *HMI settings*

Parameter	Values (Range)	Unit	Step	Default	Description
FB naming convention	1=IEC61850 2=IEC61617 3=IEC-ANSI			1=IEC61850	FB naming convention used in IED
Default view	1=Measurements 2=Main menu			1=Measurements	LHMI default view
Backlight timeout	10...3600	s	1	180	LHMI backlight timeout
Web HMI mode	1=Active read only 2=Active 3=Disabled			3=Disabled	Web HMI functionality
Web HMI timeout	120...3600	s	1	180	Web HMI login timeout

Table 24: *MODBUS settings*

Parameter	Values (Range)	Unit	Step	Default	Description
InOv	0=False 1=True			0=False	Modbus Internal Overflow: TRUE-System level overflow occurred (indication only)
Serial port 1	0=Not in use 1=COM 1 2=COM 2			1=COM 1	COM port for Serial interface 1
Address 1	1...255			1	Modbus unit address on Serial interface 1
Link mode 1	1=RTU 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		4	End frame delay in chars on Serial interface 1
Serial port 2	0=Not in use 1=COM 1 2=COM 2			0=Not in use	COM port for Serial interface 2
Address 2	1...255			2	Modbus unit address on Serial interface 2

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Link mode 2	1=RTU 2=ASCII			1=RTU	Modbus link mode on Serial interface 2
Start delay 2	0...20	char		4	Start frame delay in chars on Serial interface 2
End delay 2	0...20	char		4	End frame delay in chars on Serial interface 2
MaxTCPClients	0...5			5	Maximum number of Modbus TCP/IP clients
TCPWriteAuthority	0=No clients 1=Reg. clients 2=All clients			2=All clients	Write authority setting for Modbus TCP/IP clients
EventID	0=Address 1=UID			0=Address	Event ID selection
TimeFormat	0=UTC 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

Table 25: *Serial communication settings*

Parameter	Values (Range)	Unit	Step	Default	Description
Fiber mode	0=No fiber 1=Fiber light ON loop 2=Fiber light OFF loop 3=Fiber light ON star 4=Fiber light OFF star			0=No fiber	Fiber mode for COM1
Serial mode	1=RS485 2Wire 2=RS485 4Wire			1=RS485 2Wire	Serial mode for COM1
CTS delay	0...60000			0	CTS delay for COM1
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
RTS delay	0...60000			0	RTS delay for COM1
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate for COM1
Parity	0=none 1=odd 2=even			2=even	Parity for COM1

Table 26: *Time settings*

Parameter	Values (Range)	Unit	Step	Default	Description
Date				0	Date
Time				0	Time
Time format	1=24H:MM:SS:MS 2=12H:MM:SS:MS			1=24H:MM:SS:MS	Time format
Date format	1=DD.MM.YYYY 2=DD/MM/YYYY 3=DD-MM-YYYY 4=MM.DD.YYYY 5=MM/DD/YYYY 6=YYYY-MM-DD 7=YYYY-DD-MM 8=YYYY/DD/MM			1=DD.MM.YYYY	Date format
Local time offset	-720...720	min		0	Local time offset in minutes
Synch source	0=None 1=SNTP 2=Modbus 5=IRIG-B			1=SNTP	Time synchronization source
IP SNTP primary				010.058.125.165	IP address for SNTP primary server
IP SNTP secondary				192.168.002.165	IP address for SNTP secondary server
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 1=Mon 2=Tue 3=Wed 4=Thu 5=Fri 6=Sat 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

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
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 1=Mon 2=Tue 3=Wed 4=Thu 5=Fri 6=Sat 7=Sun			0=Not in use	Daylight savings time off, day of week

Table 27: *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 28: *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

Table 29: *X110 BIO binary input signals*

Name	Type	Description
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 30: *X110 BIO binary input settings*

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

Table 31: *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 32: *X120 AIM binary input settings*

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

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Input 2 inversion	0=False 1=True			0=False	Connectors 3-2c
Input 3 inversion	0=False 1=True			0=False	Connectors 4-2c
Input 4 inversion	0=False 1=True			0=False	Connectors 5-6

Table 33: *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 34: *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 35: *X130 BIO binary input settings*

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

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Input 4 inversion	0=False 1=True			0=False	Connectors 6-5c
Input 5 inversion	0=False 1=True			0=False	Connectors 7-8c
Input 6 inversion	0=False 1=True			0=False	Connectors 9-8c

4.2 Self-supervision

The IED is provided with an extensive self-supervision system which continuously supervises the software and the electronics. It handles run-time fault situations and informs the user about an existing fault via the LHMI and the communication.

There are two types of fault indications:

- Internal faults
- Warnings

4.2.1 Internal faults



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 also 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.

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

Table 36: *Internal fault indications and codes*

Fault indication	Fault code	Additional information
Internal Fault System error	2	An internal system error has occurred.
Internal Fault File system error	7	A file system error has occurred.
Internal Fault Test	8	Internal fault test activated manually by the user.
Table continues on next page		

Fault indication	Fault code	Additional information
Internal Fault SW watchdog error	10	Watchdog reset has occurred too many times within an hour.
Internal Fault SO-relay(s),X100	43	Faulty Signal Output relay(s) in card located in slot X100.
Internal Fault SO-relay(s),X110	44	Faulty Signal Output relay(s) in card located in slot X110.
Internal Fault SO-relay(s),X130	46	Faulty Signal Output relay(s) in card located in slot X130.
Internal Fault PO-relay(s),X100	53	Faulty Power Output relay(s) in card located in slot X100.
Internal Fault PO-relay(s),X110	54	Faulty Power Output relay(s) in card located in slot X110.
Internal Fault PO-relay(s),X130	56	Faulty Power Output relay(s) in card located in slot X130.
Internal Fault Light sensor error	57	Faulty ARC light sensor input(s).
Internal Fault Conf. error,X000	62	Card in slot X000 is wrong type.
Internal Fault Conf. error,X100	63	Card in slot X100 is wrong type or does not belong to the original composition.
Internal Fault Conf. error,X110	64	Card in slot X110 is wrong type, is missing or does not belong to the original composition.
Internal Fault Conf. error,X120	65	Card in slot X120 is wrong type, is missing or does not belong to the original composition.
Internal Fault Conf. error,X130	66	Card in slot X130 is wrong type, is missing or does not belong to the original composition.
Internal Fault Card error,X000	72	Card in slot X000 is faulty.
Internal Fault Card error,X100	73	Card in slot X100 is faulty.
Internal Fault Card error,X110	74	Card in slot X110 is faulty.
Internal Fault Card error,X120	75	Card in slot X120 is faulty.
Internal Fault Card error,X130	76	Card in slot X130 is faulty.
Internal Fault LHMI module	79	LHMI module is faulty. The fault indication may not be seen on the LHMI during the fault.
Internal Fault RAM error	80	Error in the RAM memory on the CPU card.
Internal Fault ROM error	81	Error in the ROM memory on the CPU card.
Table continues on next page		

Fault indication	Fault code	Additional information
Internal Fault EEPROM error	82	Error in the EEPROM memory on the CPU card.
Internal Fault FPGA error	83	Error in the FPGA on the CPU card.
Internal Fault RTC error	84	Error in the RTC on the CPU card.

4.2.2

Warnings

Further, 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 appears 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 37: *Warning indications and codes*

Warning indication	Warning code	Additional information
Warning Watchdog reset	10	A watchdog reset has occurred.
Warning Power down det.	11	The auxiliary supply voltage has dropped too low.
Warning IEC61850 error	20	Error when building the IEC 61850 data model.
Warning Modbus error	21	Error in the Modbus communication.
Warning DNP3 error	22	Error in the DNP3 communication.
Warning Dataset error	24	Error in the Data set(s).
Warning Report cont. error	25	Error in the Report control block(s).
Warning GOOSE contr. error	26	Error in the GOOSE control block(s).
Warning SCL config error	27	Error in the SCL configuration file or the file is missing.
Warning Logic error	28	Too many connections in the configuration.
Warning SMT logic error	29	Error in the SMT connections.
Warning GOOSE input error	30	Error in the GOOSE connections.
Warning GOOSE rec. error	32	Error in the GOOSE message receiving.
Warning AFL error	33	Analog channel configuration error.

Table continues on next page

Warning indication	Warning code	Additional information
Warning Unack card comp.	40	A new composition has not been acknowledged/accepted.
Warning ARC1 cont. light	85	A continuous light has been detected on the ARC light input 1.
Warning ARC2 cont. light	86	A continuous light has been detected on the ARC light input 2.
Warning ARC3 cont. light	87	A continuous light has been detected on the ARC light input 3.

4.3 Time synchronization

The IED uses SNTP server or GPS controlled IRIG-B time code generator to update its real time clock. The time stamp is used for synchronizing the events.

The IED can use one of two SNTP servers, the primary server 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 to the primary server at every third SNTP request attempt.

If both SNTP servers are offline, the event time stamps have the time invalid status. The time is requested from the SNTP server every 60 seconds.



If the Modbus RTU/ASCII protocol is used, the time synchronization can be received from Modbus master instead of SNTP. When Modbus TCP is used, SNTP 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.

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.



IRIG-B time synchronization requires a COM card with an IRIG-B input. The applicable COM card alternatives are COMB03A, COMB07A, COMB11A, COMB12A, COMB13A or COMB14A.

4.4 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 (1...4) can be changed by parameter or via binary input, 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 SGCB-block input named ActSG using PCM600 Signal Matrix Tool.

Table 38: *Active setting group binary input state*

BI state	Active setting group
OFF	1
ON	2

The active setting group defined by parameter is overridden when a binary input is enabled for changing the active setting group.

Table 39: *Settings*

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

All the parameters are not included in these setting groups, for example, non-setting group parameters. Those parameters are presented in connection to application functions.

Section 5 Protection functions

5.1 Three-phase current protection

5.1.1 Three-phase non-directional overcurrent protection PHxPTOC

5.1.1.1 Identification

Table 40: *Function identification*

Different stages:	Low stage	High stage	Instantaneous stage
IEC 61850 identification:	PHLPTOC	PHHPTOC	PHIPTOC
IEC 60617 identification:	3I>	3I>>	3I>>>
ANSI/IEEE C37.2 device number:	51P-1	51P-2	50P/51P

5.1.1.2 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.

5.1.1.3 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 overcurrent protection

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

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

account the selectivity requirements, switching-in currents, and the thermal and mechanical withstand of the transformer and outgoing feeders.

Traditionally, overcurrent protection of the transformer has been arranged as shown in [Figure 39](#). The low-set stage PHLPTOC operates time-selectively both in transformer and LV-side busbar faults. The high-set stage PHHPTOC operates instantaneously making use of current selectivity only in transformer HV-side faults. If there is a possibility, that the fault current can also be fed from the LV-side up to the HV-side, the transformer must also be equipped with LV-side overcurrent protection. Inrush current detectors are used in start-up situations to multiply the current start value setting in each particular relay where the inrush current can occur. The overcurrent and contact based circuit breaker failure protection CCBRBRF is used to confirm the protection scheme in case of circuit breaker malfunction.

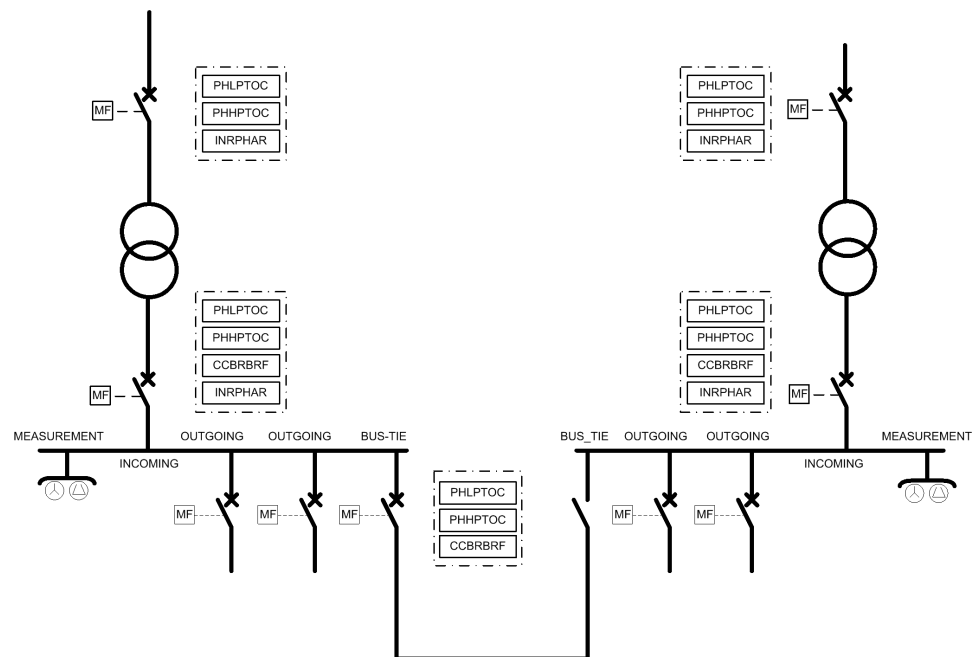


Figure 39: Example of traditional time selective transformer overcurrent protection

The operating times of the main and back-up overcurrent protection of the above scheme become quite long, this applies especially in the busbar faults and also in the transformer LV-terminal faults. In order to improve the performance of the above scheme, a multiple-stage overcurrent protection with reverse blocking is proposed. [Figure 40](#) shows this arrangement.

Transformer and busbar overcurrent protection with reverse blocking principle

By implementing a full set of overcurrent protection stages and blocking channels between the protection stages of the incoming feeders, bus-tie and outgoing feeders, it is possible to speed up the operation of overcurrent protection in the busbar and transformer LV-side faults without impairing the selectivity. Also, the security degree

of busbar protection is increased, because there is now a dedicated, selective and fast busbar protection functionality, which is based on the blockable overcurrent protection principle. The additional time selective stages on the transformer HV- and LV-sides provide increased security degree of 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 40](#) 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 41: *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	-	+ +
HV/3I>>	DT	blockable/time selective	+/-	+
HV/3I>>>	DT	current selective	+ +	-
LV/3I>	DT/IDMT	time selective	-	+ +
LV/3I>>	DT	time selective	-	+
LV/3I>>>	DT	blockable	+	+

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.

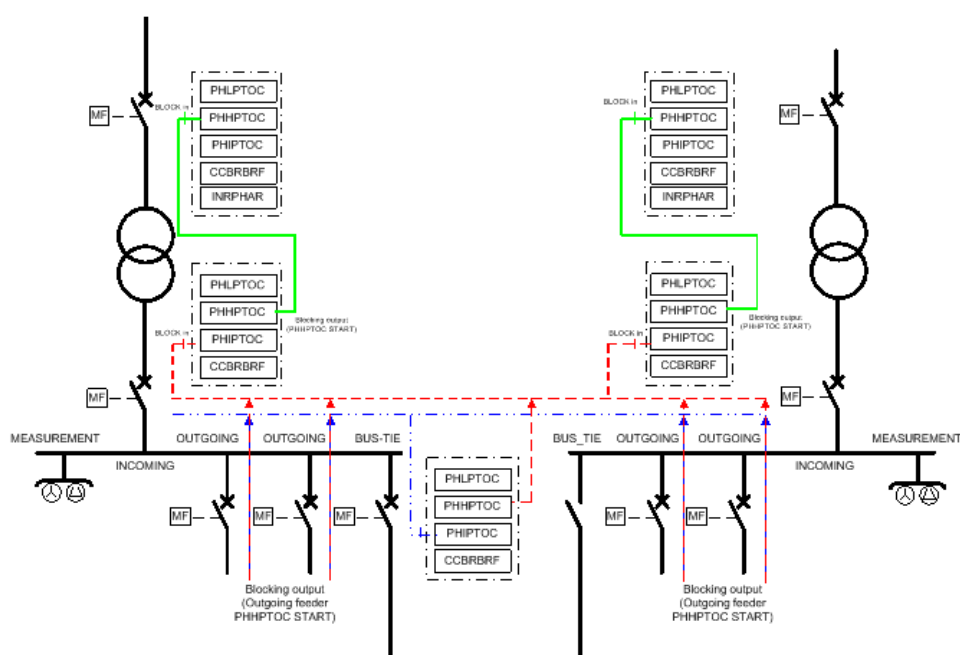


Figure 40: *Numerical overcurrent protection functionality for a typical sub-transmission/distribution substation (feeder protection not shown). Blocking output = digital output signal from the start of a protection stage, Blocking in = digital input signal to block the operation of a protection stage*

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 over current 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 41](#) 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.

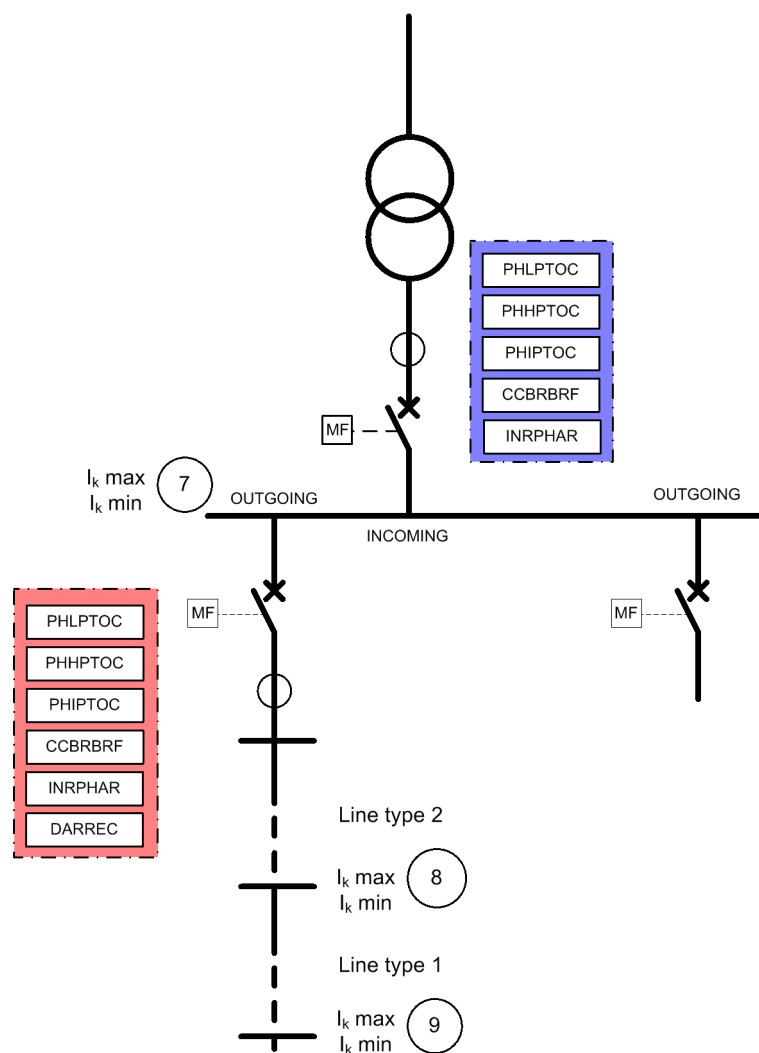


Figure 41: Functionality of numerical multiple-stage overcurrent protection

The coordination plan is an effective tool to study the operation of time selective operation characteristics. All the points mentioned earlier, required to define the overcurrent protection parameters, can be expressed simultaneously in a coordination plan. In [Figure 42](#) the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

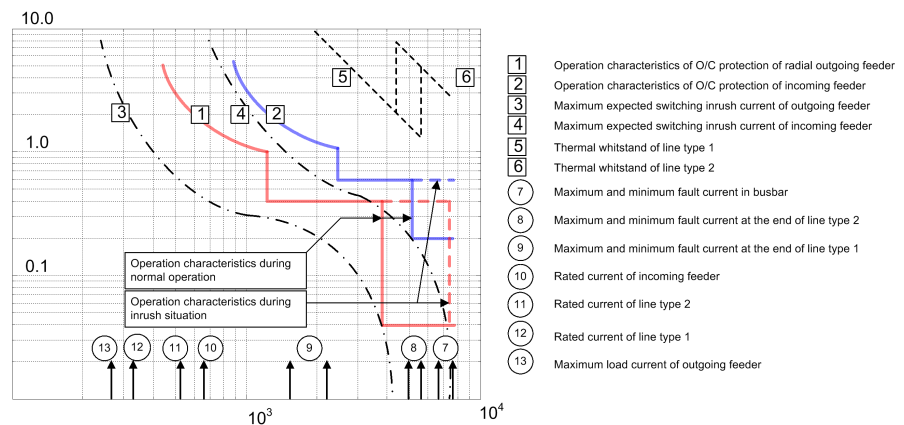


Figure 42: Example coordination of numerical multiple-stage over current protection

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

5.1.2.1 Identification

Table 42: Function identification

IEC 61850 identification:	T1PTTR
IEC 60617 identification:	3lth>
ANSI/IEEE C37.2 device number:	49F

5.1.2.2 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.

5.1.2.3**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, gets 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.

5.2**Earth-fault protection****5.2.1****Non-directional earth-fault protection EFxPTOC****5.2.1.1****Identification**

Table 43: *Function identification*

Different stages:	Low stage	High stage	Instantaneous stage
IEC 61850 identification:	EFLPTOC	EFHPTOC	EFIPTOC
IEC 60617 identification:	$I_0 >$	$I_0 >>$	$I_0 >>>$
ANSI/IEEE C37.2 device number:	50N-1	50N-2	50N/51N

5.2.1.2

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.

5.2.1.3

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.

5.2.2

Directional earth-fault protection DEFxPDEF

5.2.2.1

Identification

Table 44: *Function identification*

Different stages:	Low stage	High stage
IEC 61850 identification:	DEFLPDEF	DEFHPDEF
IEC 60617 identification:	$I_0 > ->$	$I_0 >> ->$
ANSI/IEEE C37.2 device number:	67N-1	67N-2

5.2.2.2

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 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.

5.2.2.3

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).

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. 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.

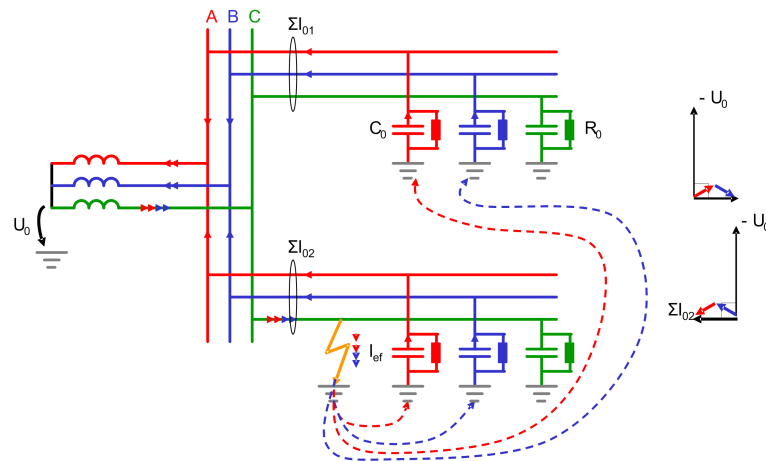


Figure 43: Earth-fault situation in an isolated network

Directional earth-fault protection in a compensated network

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. 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.

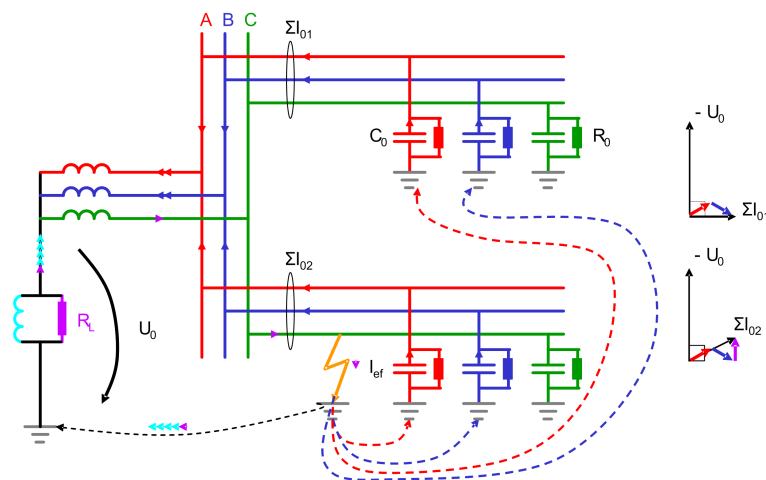


Figure 44: Earth-fault situation in a resonance-earthed network

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 45: *Relay characteristic angle control in $I_0\sin(\varphi)$ and $I_0\cos(\varphi)$ operation criteria*

Operation criteria setting:	RCA_CTL = FALSE	RCA_CTL = TRUE
$I_0\sin(\varphi)$	Actual operation criteria: $I_0\sin(\varphi)$	Actual operation criteria: $I_0\cos(\varphi)$
$I_0\cos(\varphi)$	Actual operation criteria: $I_0\cos(\varphi)$	Actual operation criteria: $I_0\sin(\varphi)$

Table 46: *Characteristic angle control in phase angle operation mode*

Characteristic angle setting	RCA_CTL = FALSE	RCA_CTL = TRUE
-90°	$\varphi_{RCA} = -90^\circ$	$\varphi_{RCA} = 0^\circ$
0°	$\varphi_{RCA} = 0^\circ$	$\varphi_{RCA} = -90^\circ$

Usage of the extended phase angle characteristic

In addition to the RCA_CTL input, the extended phase angle characteristic can be used to disconnect the compensation coil 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.

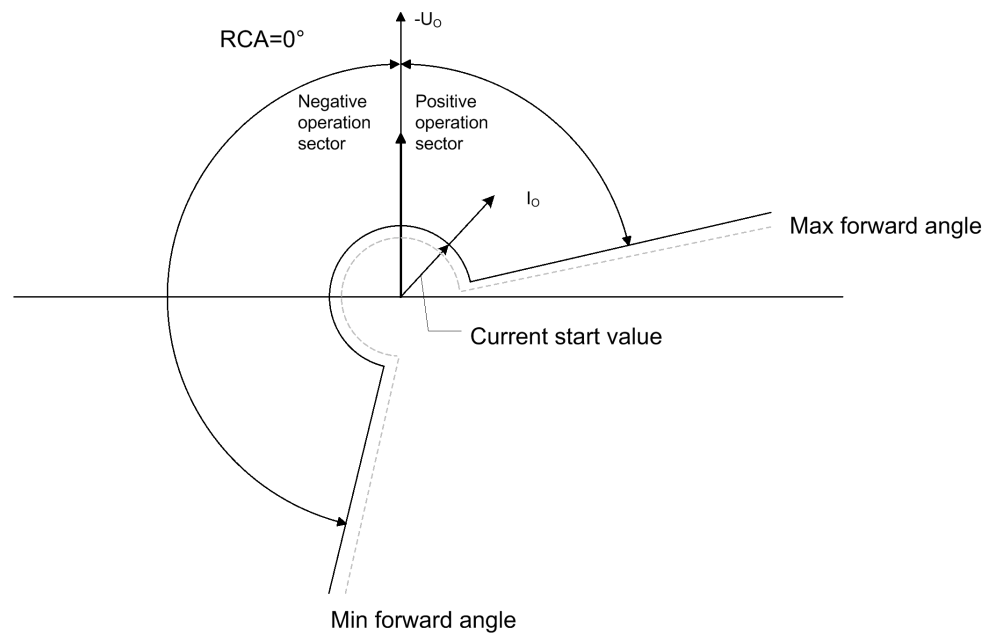


Figure 45: Extended operation area in directional earth-fault protection

5.2.2.4

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. 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. 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 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 network, the characteristic angle is -60 degrees (for phase angle). Alternatively, $I_0 \sin(\varphi)$ operation can be used, though 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, 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.

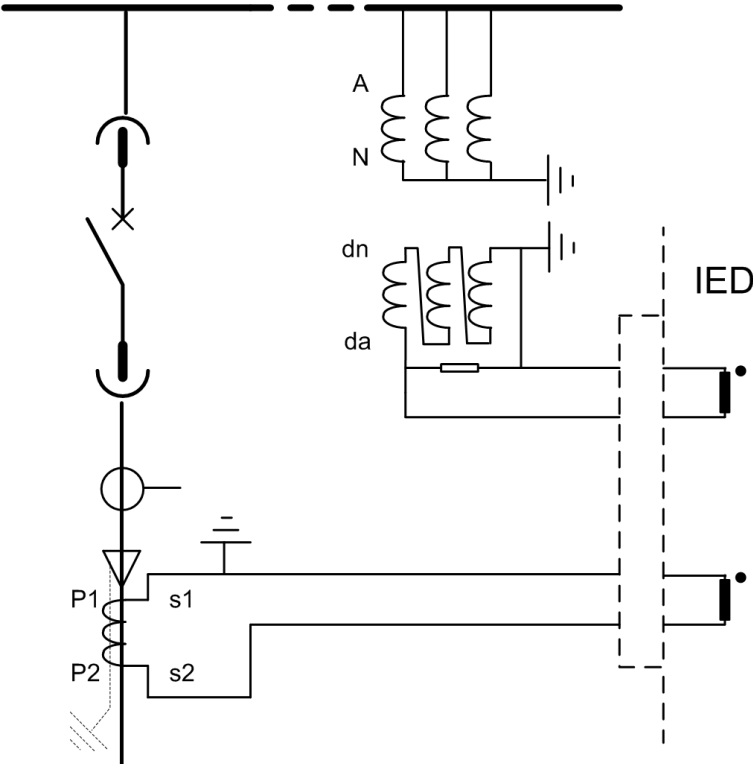


Figure 46: Connection of measuring transformers

5.2.3 Transient/intermittent earth-fault protection INTRPTEF

5.2.3.1 Identification

Table 47: Function identification

IEC 61850 identification:	INTRPTEF
IEC 60617 identification:	I0> ->IEF
ANSI/IEEE C37.2 device number:	67NIEF

5.2.3.2 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.

5.2.3.3

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 in compensated networks

An intermittent earth fault is a special type of fault that is encountered especially in compensated networks with underground cables. With underground distribution cables, the wire insulators may get damaged due to short transients in I_0 and rapid changes in U_0 caused by water creating a connection between the connector and the ground. This can be characterized as a series of cable insulation breakdowns because of the reduced voltage withstand.

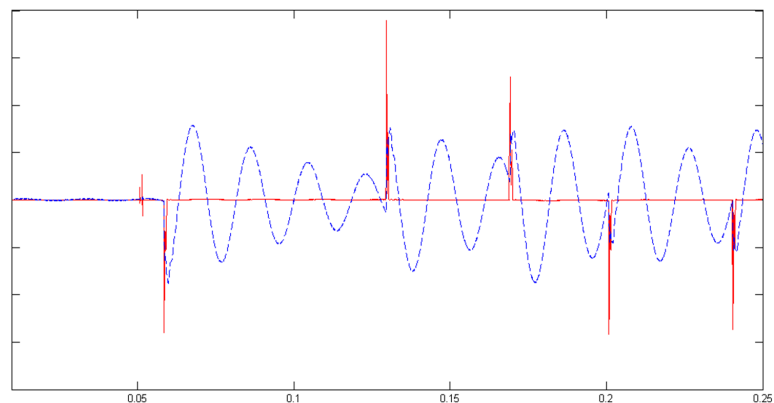


Figure 47: Typical intermittent earth-fault residual current and residual voltage signals on a faulty feeder

Intermittent earth-fault transients cause damping sinusoidal residual voltage. In case of successive intermittent transients, the residual voltage level may continuously stay high. The substation residual voltage has usually been used in the substation back-up protection for feeder earth faults when it is applied to the trip feeders feeding the busbar. In intermittent earth-fault situations, this may cause the back-up protection to trip without the dedicated intermittent earth-fault protection function for the corresponding feeder.

INTRPTEF can be used in parallel with non-directional and directional earth-fault functions. The function can reliably detect whether the fault is in the forward or reverse area when looking from the feeder's perspective. In case of a forward type

fault, that is, when the fed cable is faulty, a trip signal is sent to the circuit breaker. In case of a reverse type fault, meaning that the fault is on some other feeders, the BLK_EF output is activated for a fixed time of 25 ms. This signal can be used for blocking the earth-fault functions to prevent erroneous trips when the function is set to operate with "Intermittent EF" mode.

In the following example, an intermittent earth-fault situation is shown in a neutral compensated network. The faulty feeder (feeder j) feeds the fault current to the fault point. In the healthy feeder (feeder v), the fault current is also detected but the direction is reverse.

INTRPTEF detects transients in the residual current and residual voltage signals in forward direction in the feeder (j). The adjustable drop-off timer starts counting when a transient is detected. When the number of transients occurring within the drop-off time meets the set limit, the function starts and stays active until transients are no longer detected. When the operate delay time has elapsed, INTRPTEF operates if it detects the next successive transients and the counter value is correct. The function sends a trip command to the circuit breaker regarding the faulty feeder accordingly.



The requirement that one additional transient is needed after the operate delay time is exceeded can cause additional operate time delays. However, this functionality is implemented to prevent unwanted trips.

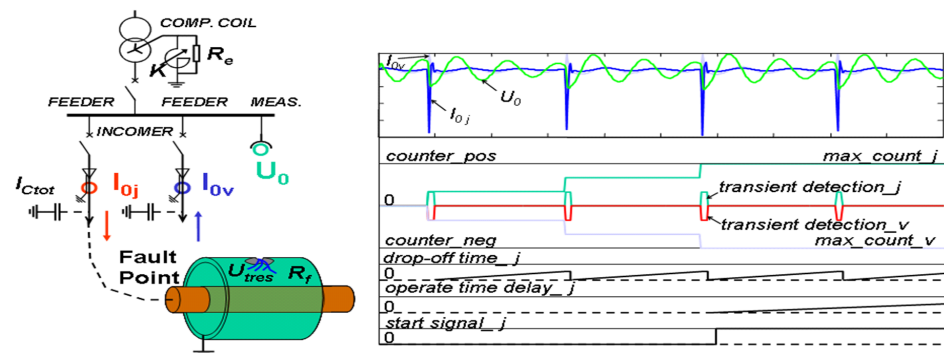


Figure 48: Intermittent earth-fault situation in neutral compensated network

Transient earth fault in networks

Transient earth fault is a special type of fault which can be detected by using the INTRPTEF function in transient mode. In this mode the fault direction is detected from the first transient pulse in the residual current. The algorithm requires also the residual voltage to exceed the set value. The function starts when the transient is detected in the set direction and the residual voltage is over the set limit. The function stays in the start state as long as the residual voltage limit is exceeded. When INTRPTEF has started and the operate delay time has elapsed, the function operates and sends a trip command to the circuit breaker. The following figure shows the transient earth fault detection and operation of the INTRPTEF function.

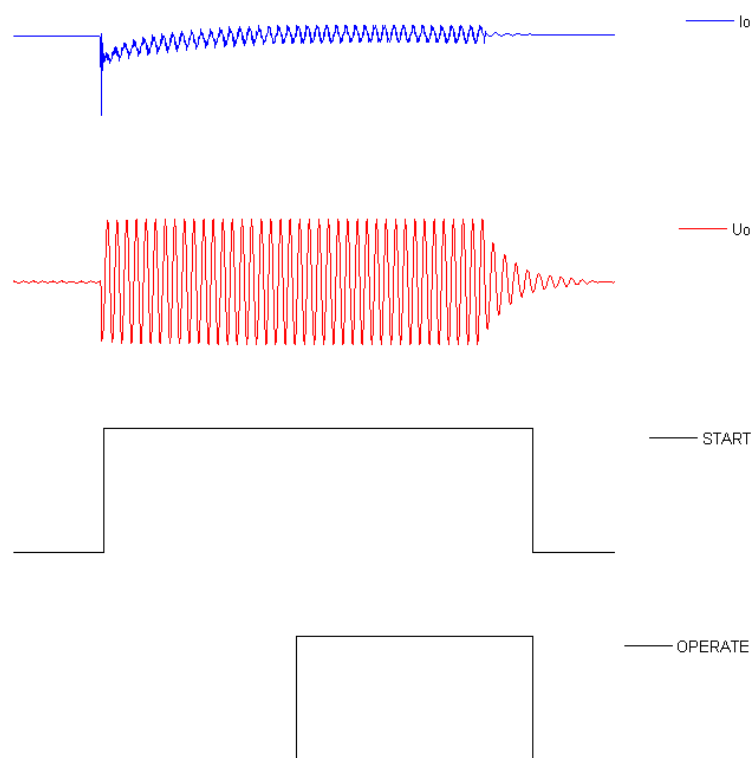


Figure 49: Transient earth-fault situation and operation of INTRPTEF during a fault

5.3 Unbalance protection

5.3.1 Negative phase-sequence current protection NSPTOC

5.3.1.1 Identification

Table 48: *Function identification*

IEC 61850 identification:	NSPTOC
IEC 60617 identification:	I2>
ANSI/IEEE C37.2 device number:	46

5.3.1.2 Functionality

The negative phase-sequence current protection NSPTOC is used for increasing sensitivity to detect single phasing situations, unbalanced loads due to, for example, broken conductors or to unsymmetrical feeder voltages.

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.

5.3.1.3 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 over-current protection also provides a back-up protection functionality for the feeder earth-fault protection in solid and low resistance earthed networks.

The negative sequence overcurrent protection provides the back-up earth-fault protection on the high voltage side of a delta-wye connected power transformer for earth faults taking place on the wye-connected low voltage side. If an earth fault occurs on the wye-connected side of the power transformer, negative sequence current quantities appear on the delta-connected side of the power transformer.

The most common application for the negative sequence overcurrent protection is probably rotating machines, where negative sequence current quantities indicate unbalanced loading conditions (unsymmetrical voltages). Unbalanced loading

normally causes extensive heating of the machine and can result in severe damages even over a relatively short time period.

Multiple time curves and time multiplier settings are also available for coordinating with other devices in the system.

5.3.2 Phase discontinuity PDNSPTOC

5.3.2.1 Identification

Table 49: *Function identification*

IEC 61850 identification:	PDNSPTOC
IEC 60617 identification:	I2/I1>
ANSI/IEEE C37.2 device number:	46PD

5.3.2.2 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.

5.3.2.3 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 using [Equation 1](#)

$$I_1 = \frac{1}{3} (I_a + aI_b + a^2I_c)$$

(Equation 1)

The negative sequence current is calculated using [Equation 2](#)

$$I_2 = \frac{1}{3}(I_a + a^2 I_b + a I_c)$$

(Equation 2)

I_a, I_b, I_c = phase current vectors

a = 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 using [Equation 3](#)

$$I_{ratio} = \frac{I_2}{I_1}$$

(Equation 3)

A situation when a phase A conductor is broken is shown in [Figure 50](#)

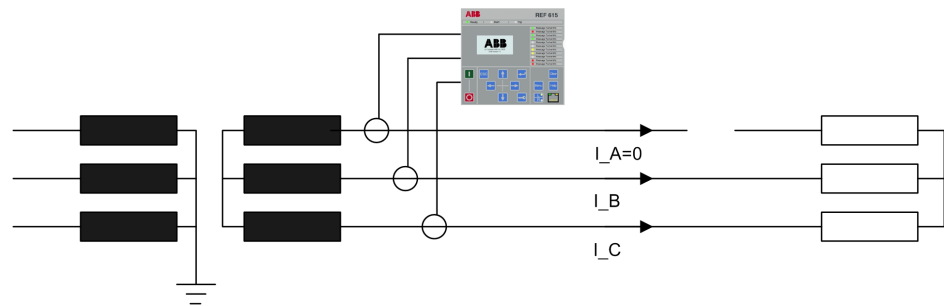


Figure 50: Broken conductor fault in phase A in a distribution or subtransmission feeder

Current quantities during the broken fault in phase A, together with the ratio of negative and positive sequence currents, are presented in [Figure 51](#)

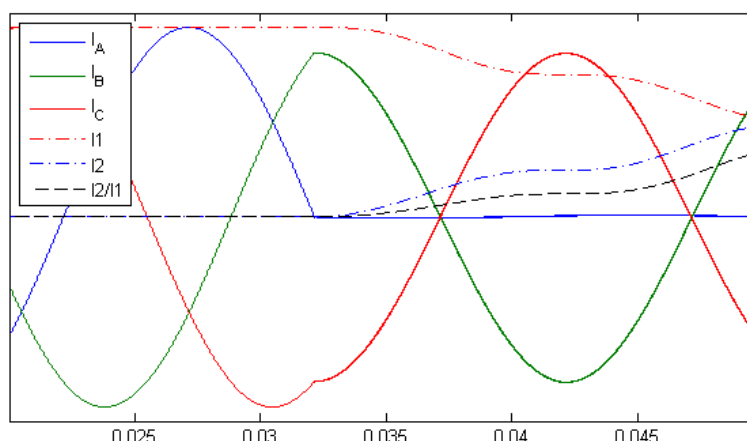


Figure 51: Three-phase currents, positive and negative sequence currents and the ratio of sequence currents during broken conductor fault in phase A

5.4 Arc protection ARCSARC

5.4.1 Identification

Table 50: Function identification

IEC 61850 identification:	ARCSARC
IEC 60617 identification:	ARC
ANSI/IEEE C37.2 device number:	50L/50NL

5.4.2 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.

5.4.3 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 digital 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 digital input or 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.

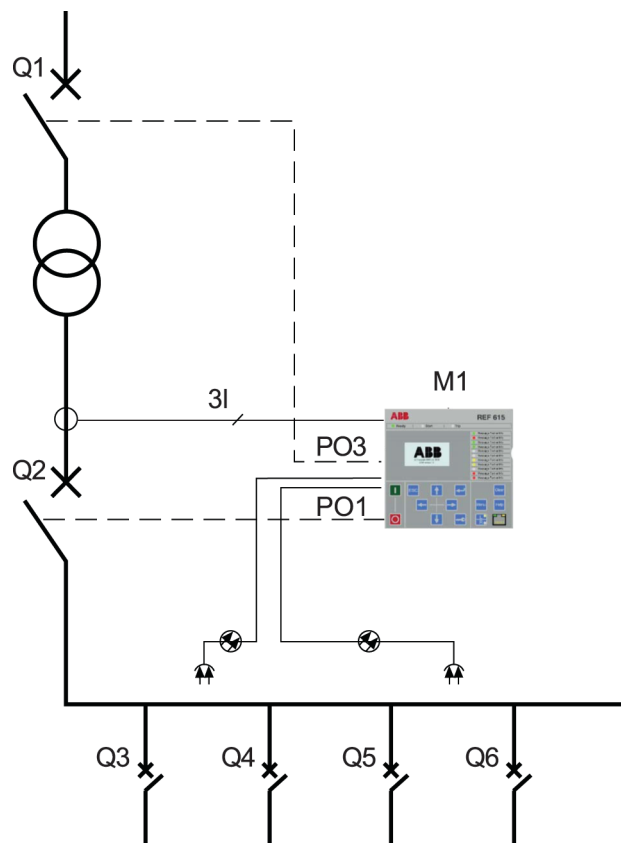


Figure 52: Arc protection with one IED

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.

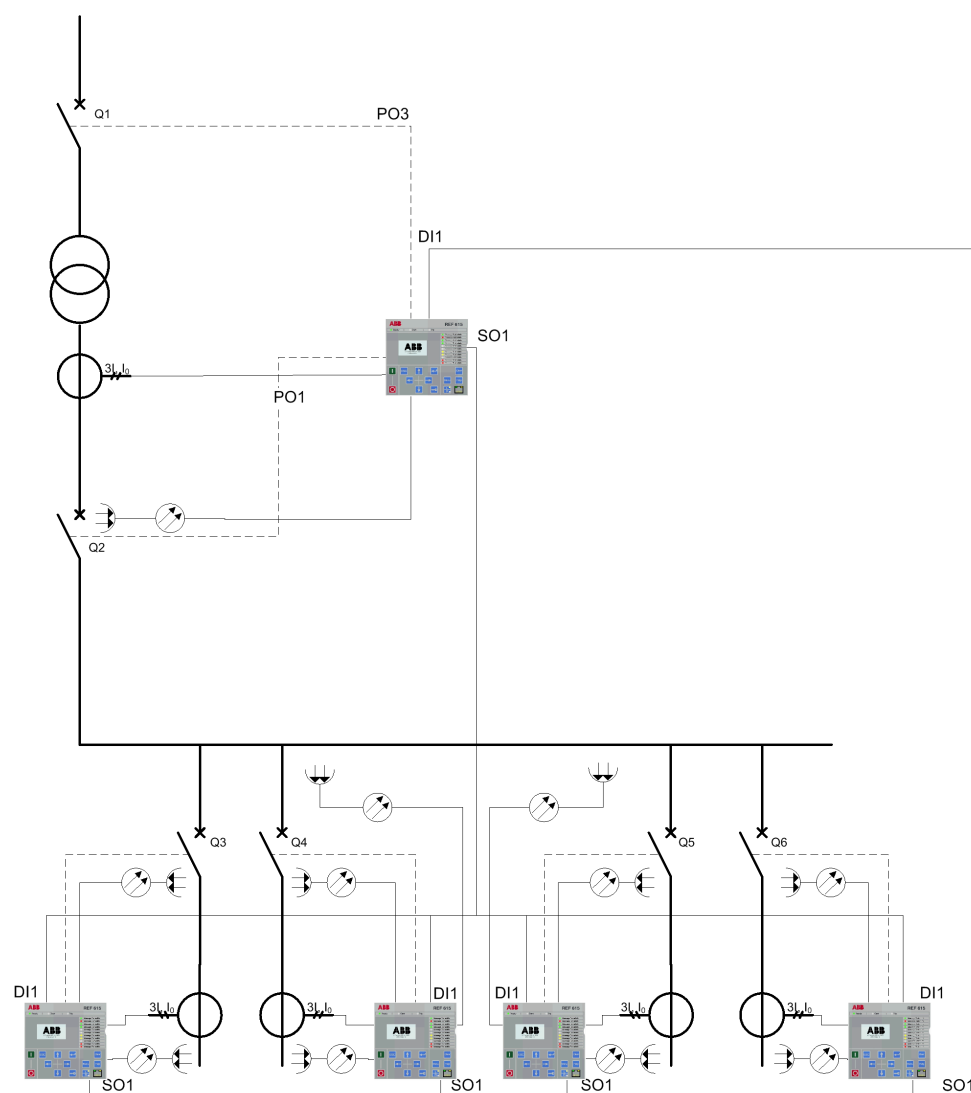


Figure 53: Arc protection with several IEDs

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.

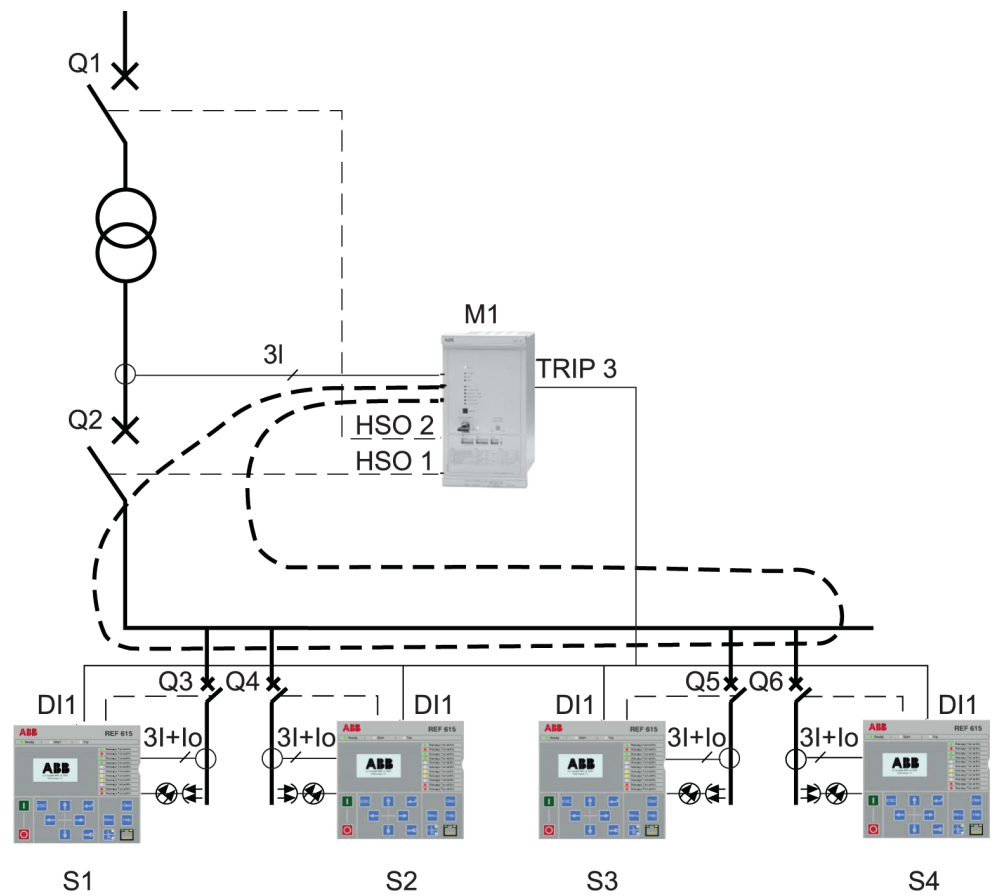


Figure 54: Arc protection with several IEDs and a separate arc protection system

Section 6 Protection related functions

6.1 Three-phase inrush detector INRPHAR

6.1.1 Identification

Table 51: *Function identification*

IEC 61850 identification:	INRPHAR
IEC 60617 identification:	3I2f>
ANSI/IEEE C37.2 device number:	68

6.1.2 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.

6.1.3 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.

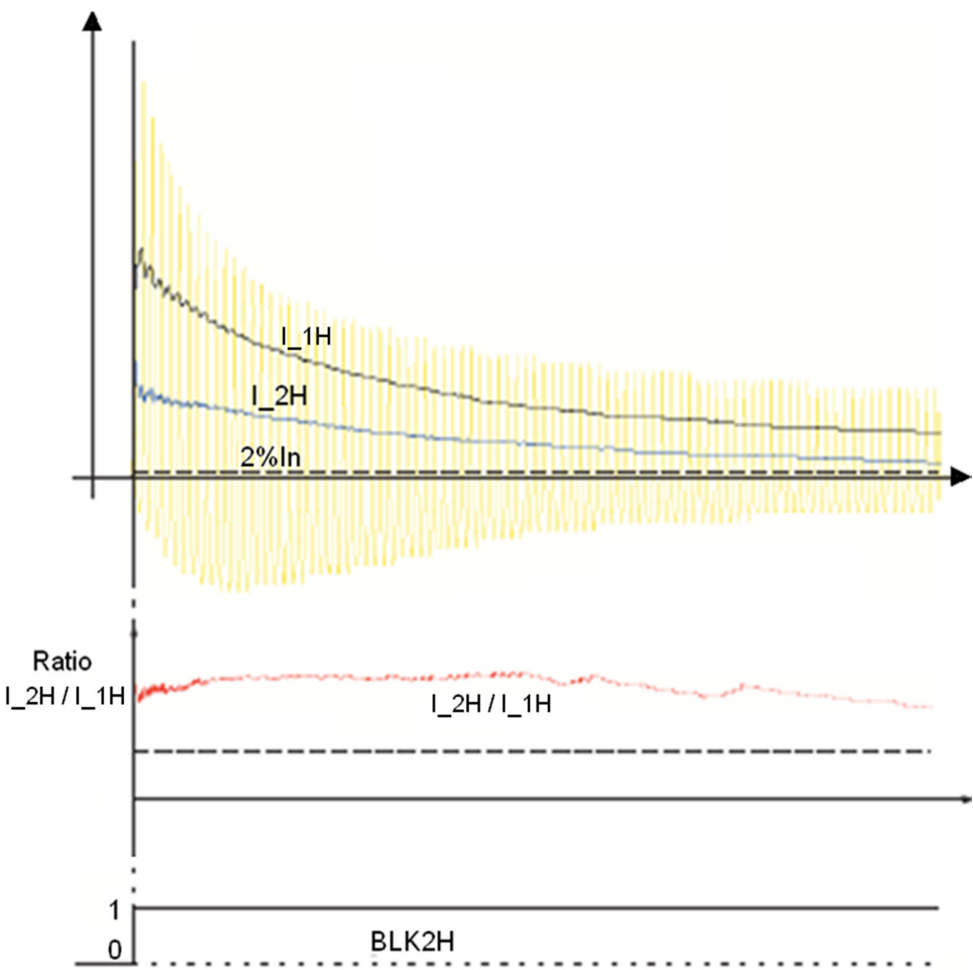


Figure 55: Inrush current in transformer

6.2 Circuit breaker failure protection CCBRBRF

6.2.1 Identification

Table 52: Function identification

IEC 61850 identification:	CCBRBRF
IEC 60617 identification:	$3I > I_0 > BF$
ANSI/IEEE C37.2 device number:	51BF/51NBF

6.2.2 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. CCBRRBF 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.

6.2.3 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, CCBRRBF 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 CCBRRBF 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.

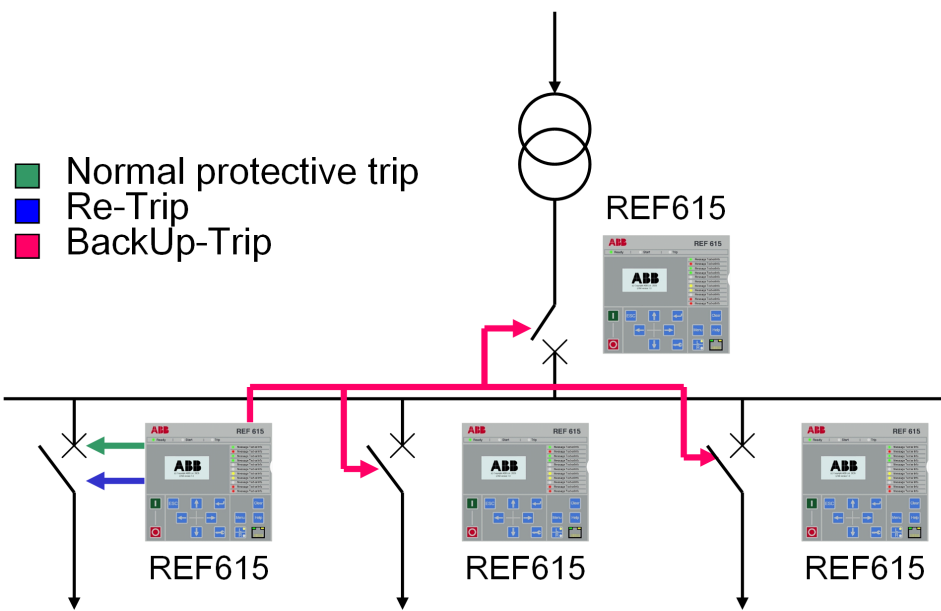


Figure 56: Typical breaker failure protection scheme in distribution substations

6.3 Protection trip conditioning TRPPTRC

6.3.1 Identification

Table 53: Function identification

IEC 61850 identification:	TRPPTRC
IEC 60617 identification:	I->O
ANSI/IEEE C37.2 device number:	94

6.3.2 Functionality

The protection trip conditioning function (TRPPTRC) is intended to be 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 trip pulse length and decide whether the trip pulse is latched or non-latched and whether it should be in lockout mode when the trip signal is issued.

6.3.3 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 CBXCBB 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 digital 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.

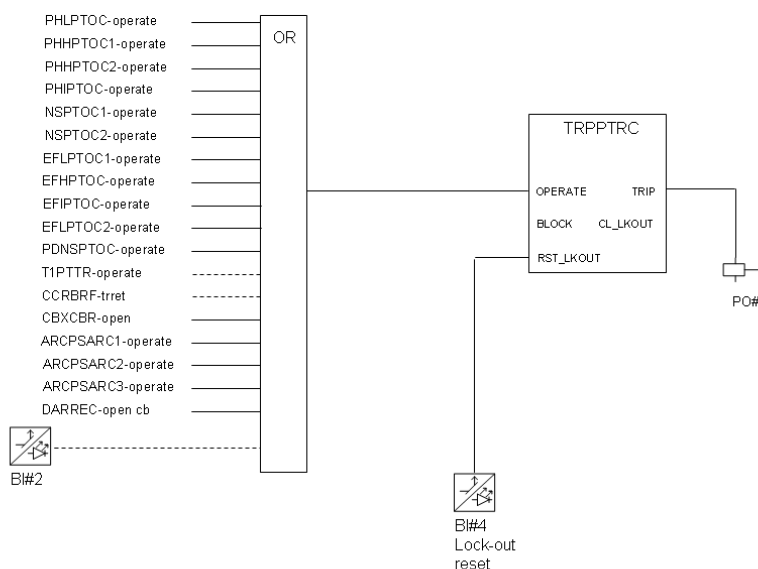


Figure 57: Typical TRPPTRC connection

Lock-out

TRPPTRC is provided with possibilities to activate a lockout. The lockout can be set to activate only the block closing output `CL_LKOUT`, or to initiate the block closing output and, at the same time, maintain the trip signal (latched trip). The lockout can be manually reset after checking the primary fault by activating the input `RST_LKOUT`.

Blocking

TRPPTRC can be blocked in two different ways. Its use depends on the application. Blocking can be activated internally by the logic, or by the operator using a communication channel. Total blockage of the trip function is done by activating the `BLOCK` input. It can be used to block the output of the trip logic in the event of internal failures. The operator can control the lockout function by activating the `BLK_LKOUT` input which blocks the lockout output.

Section 7 Supervision functions

7.1 Trip circuit supervision TCSSCBR

7.1.1 Identification

Table 54: *Function identification*

IEC 61850 identification:	TCSSCBR
IEC 60617 identification:	TCS
ANSI/IEEE C37.2 device number:	TCM

7.1.2 Functionality

The trip circuit supervision function (TCSSCBR) is designed for supervision purposes of control circuits. 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.

7.1.3 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.

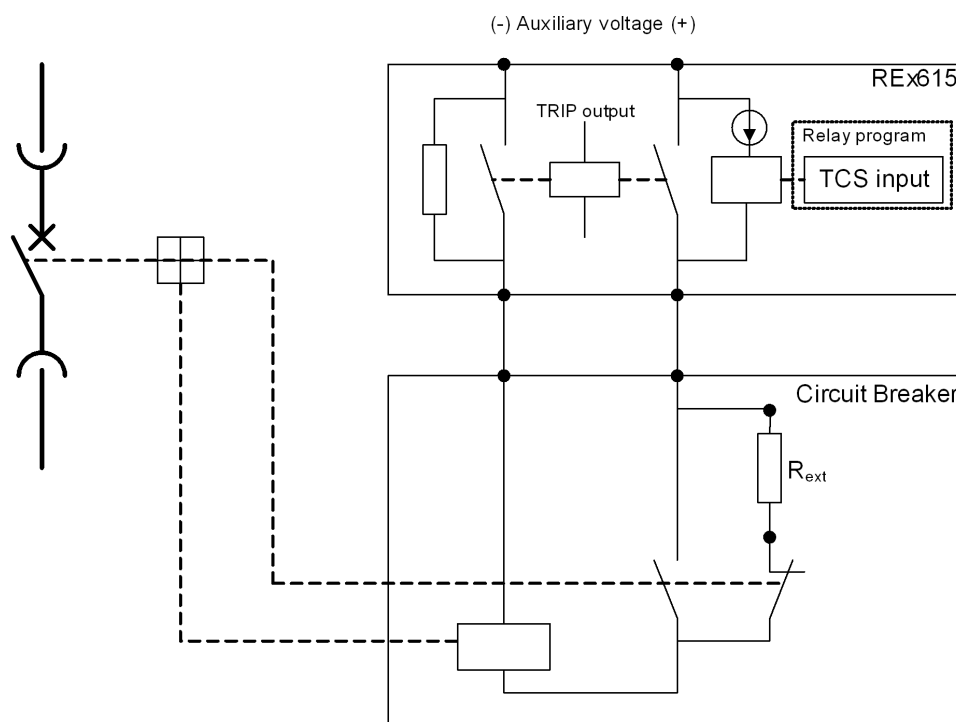


Figure 58: *Circuit breaker trip-circuit supervision application with an external resistor*

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.

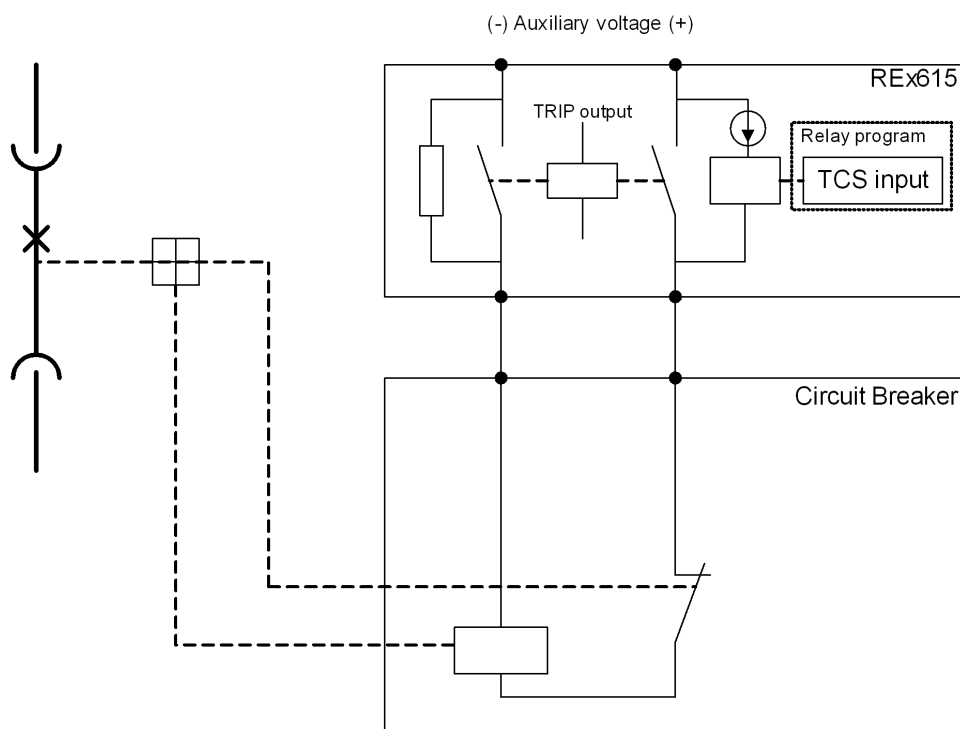


Figure 59: *Circuit breaker trip-circuit supervision application without an external resistor*

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.

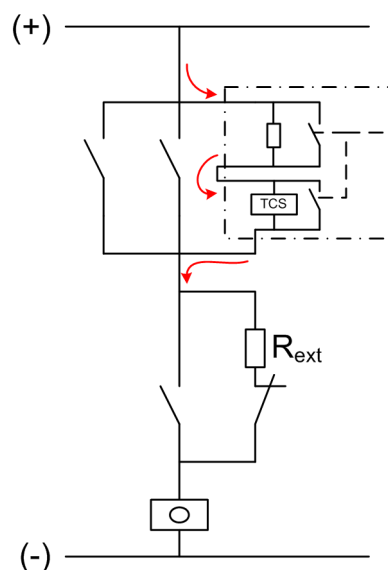


Figure 60: Current flow in parallel trip contacts and trip-circuit supervision

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.

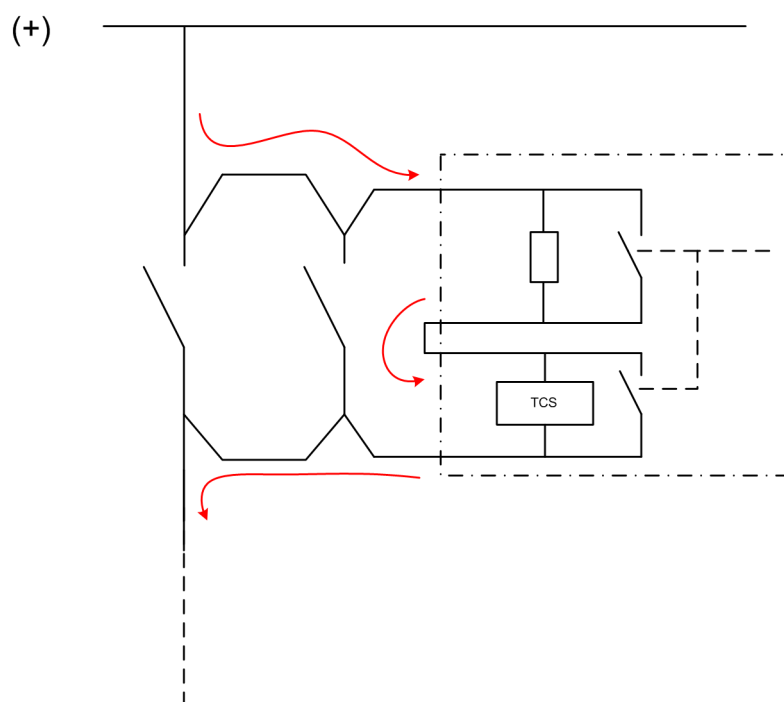


Figure 61: Improved connection for parallel trip contacts

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:

$$U_c - (R_{ext} + R_{int} + R_s) \times I_c \geq 20V \text{ AC / DC}$$

(Equation 4)

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, 1kW
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 55: Values recommended for the external resistor R_{ext}

Operating voltage U_c	Shunt resistor R_{ext}
48 V DC	1.2 k Ω , 5 W
60 V DC	5.6 k Ω , 5 W
110 V DC	22 k Ω , 5 W
220 V DC	33 k Ω , 5 W

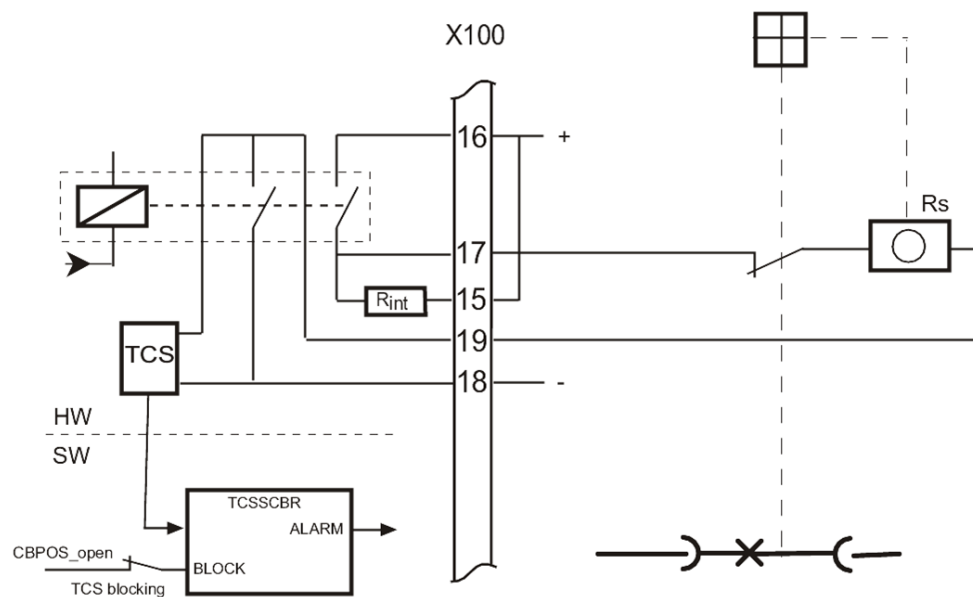


Figure 62: Operating principle of the trip-circuit supervision without an external resistor. The TCS blocking switch is set to block the TCSSCBR when the circuit breaker is open.

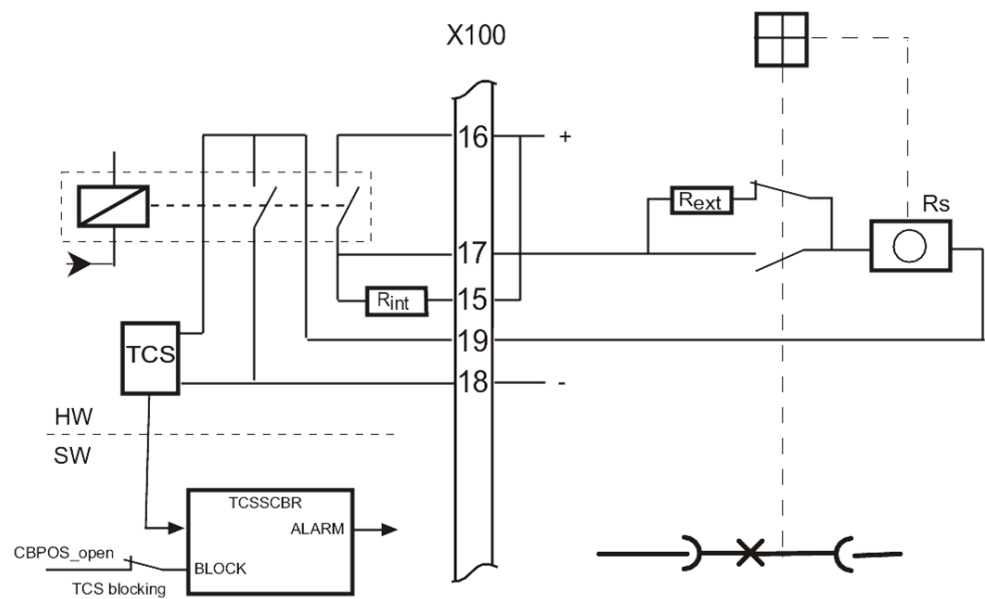


Figure 63: Operating principle of the trip-circuit supervision with an external resistor. The TCSSCBR blocking switch is open enabling the trip-circuit supervision to be independent of the circuit breaker position

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. 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.

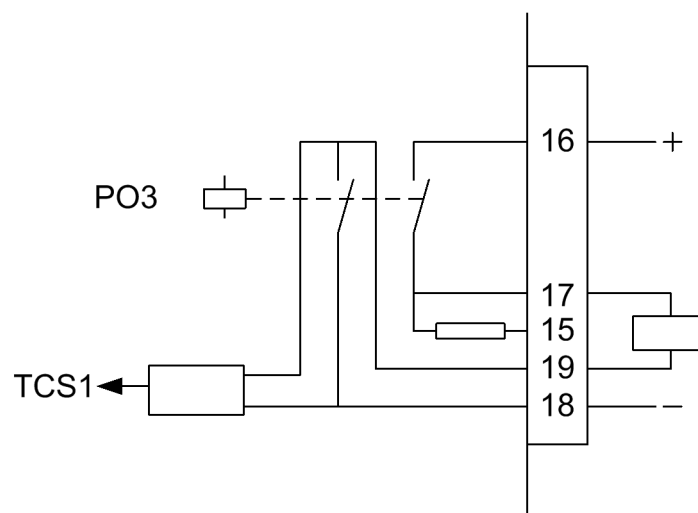


Figure 64: Connection of a power output in a case when TCS is not used and the internal resistor is disconnected

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.

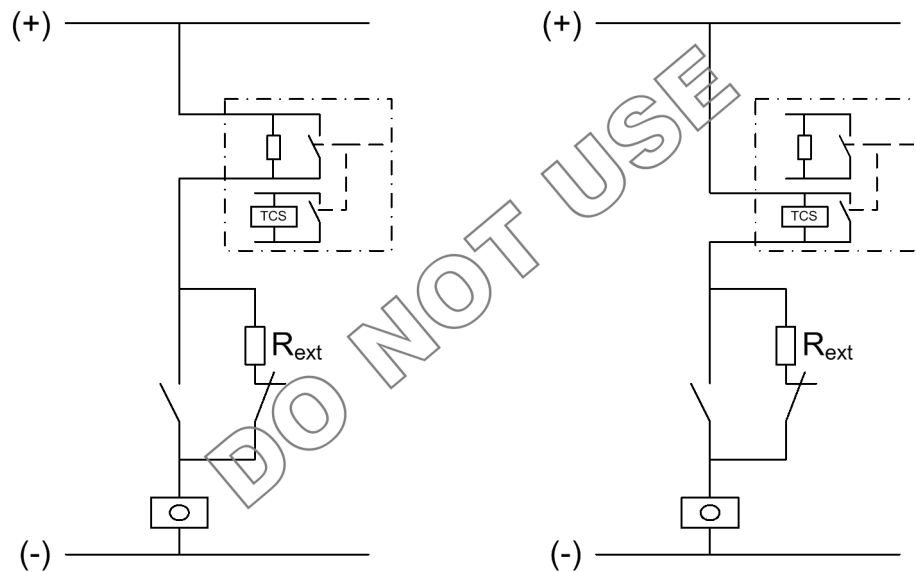


Figure 65: Incorrect connection of trip-circuit supervision

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.

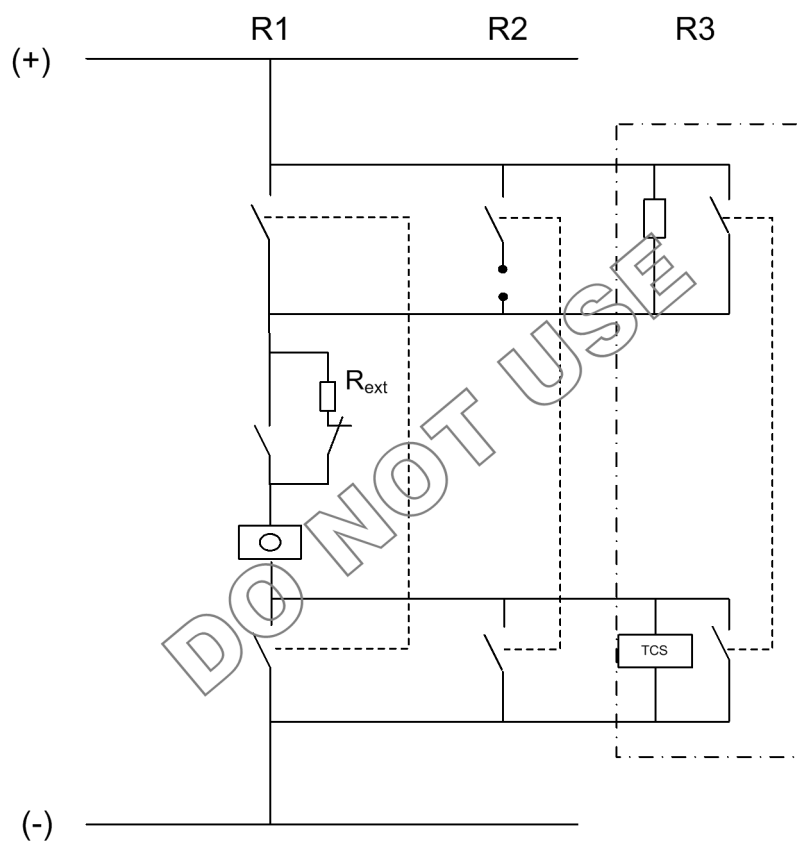


Figure 66: Incorrect testing of IEDs

Section 8 Condition monitoring functions

8.1 Circuit breaker condition monitoring SSCBR

8.1.1 Identification

Table 56: *Function identification*

IEC 61850 identification:	SSCBR
IEC 60617 identification:	CBCM
ANSI/IEEE C37.2 device number:	CBCM

8.1.2 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^2t 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.

8.1.3 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

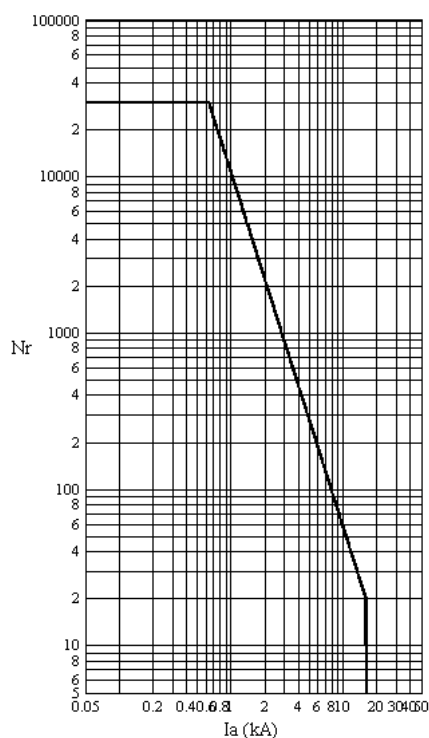


Figure 67: Trip Curves for a typical 12kV, 630A, 16kA Vacuum Interrupter

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:

$$DirectionalCoef = \frac{\log\left(\frac{B}{A}\right)}{\log\left(\frac{I_f}{I_r}\right)} = -2.2609$$

(Equation 5)

I_r Rated operating current = 630A
 I_f Rated fault current = 16kA
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 630A and 20 operations at the rated fault current 16kA. Therefore, if the tripping current is 10kA, one operation at 10kA 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 10kA, 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.

Section 9 Measurement functions

9.1 Basic measurements

9.1.1 Three-phase current CMMXU

9.1.1.1 Identification

Table 57: *Function identification*

IEC 61850 identification:	CMMXU
IEC 60617 identification:	3I
ANSI/IEEE C37.2 device number:	3I

9.1.2 Neutral current RESCMMXU

9.1.2.1 Identification

Table 58: *Function identification*

IEC 61850 identification:	RESCMMXU
IEC 60617 identification:	I0
ANSI/IEEE C37.2 device number:	I0

9.1.3 Sequence current CSMSQI

9.1.3.1 Identification

Table 59: *Function identification*

IEC 61850 identification:	CSMSQI
IEC 60617 identification:	I1, I2, I0
ANSI/IEEE C37.2 device number:	I1, I2, I0

9.1.4 Residual voltage RESVMMXU

9.1.4.1 Identification

Table 60: *Function identification*

IEC 61850 identification:	RESVMMXU
IEC 60617 identification:	U0
ANSI/IEEE C37.2 device number:	U0

9.1.5 **Functions**

The three-phase current measurement function, CMMXU, is used for monitoring and metering the phase currents of the power system.

The residual current measurement function, RESCMMXU, is used for monitoring and metering the residual current of the power system.

The sequence current measurement, CSMSQI, is used for monitoring and metering the phase sequence currents.

The residual voltage measurement function, RESVMMXU, is used for monitoring and metering the residual voltage of the power system.

The information of the measured quantity is available for the operator both locally in LHMI and remotely to a network control center via communication.

9.1.6 **Measurement function applications**

The measurement functions are used for power system measurement, supervision, and reporting to LHMI, a monitoring tool within PCM600, or to the station level, for example, via IEC 61850. The possibility to continuously monitor the measured values of active power, reactive power, currents, voltages, frequency, 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 relays to verify the proper operation and connection of instrument transformers; that is, current transformers (CTs) and voltage transformers (VTs). The proper operation of the relay analog measurement chain can be verified during normal service by a periodic comparison of the measured value from the relay to other independent meters.

When the zero signal is measured, the noise in the input signal can still produce small measurement values. The zero point clamping function can be used to ignore the noise in the input signal and, hence, prevent the noise to be shown in the user display. Zero clamping is done for the measured analog signals and angle values.

The demand values can be 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 demand value calculation reports a new value when the demand interval has elapsed.

The limit supervision indicates if the measured signal exceeds the set limits by activating the alarm/warning outputs of the function. These outputs can be used to configure the reporting function (events). The supervision function has four different limits:

- low alarm limit
- low warning limit
- high warning limit
- high alarm limit

There is an exception in limit supervision concerning the residual current and the residual voltage measurement: only high alarm limits are available. In three-phase current measurement, the alarm/high indications are given for the phase that has the maximum measured value. However, a range indication is given to each phase.

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 will help in keeping the communication load in minimum and yet measurement values will be reported frequently enough.

9.2 Disturbance recorder

9.2.1 Functionality

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 relay signals, for example the start or trip signals of the relay stages, or external blocking or control signals. Binary relay signals such as a protection start or trip signal, or an external relay 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.

9.2.2 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. It can record up to 12 analog signal types of the IED, connected to the analog channels of the disturbance recorder, and up to 64 status values of digital signals, connected to the binary channels of the disturbance recorder. 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.

Section 10 Control functions

10.1 Circuit breaker control CBXCBR

10.1.1 Identification

Table 61: *Function identification*

IEC 61850 identification:	CBXCBR
IEC 60617 identification:	I<->0 CB
ANSI/IEEE C37.2 device number:	I<->0 CB

10.1.2 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 cycle. The operator can read and write the counter value remotely from an operator place or via LHMI.

10.1.3 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:

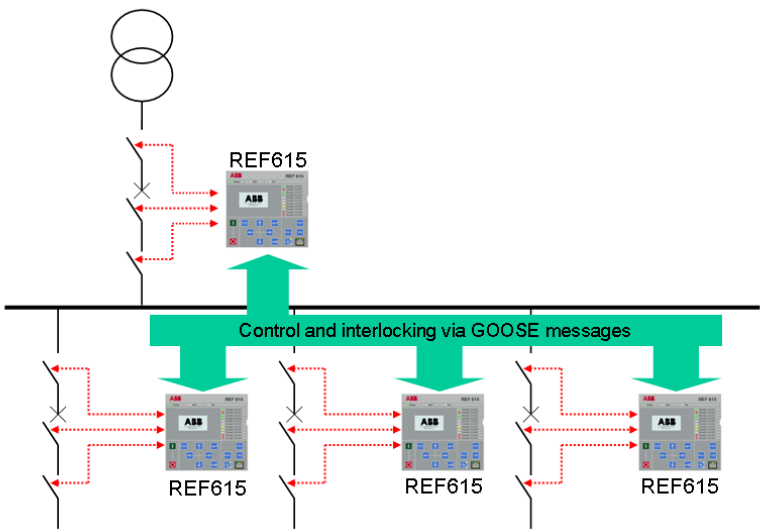


Figure 68: Status indication based interlocking via GOOSE messaging

10.2 Disconnector control DCSXSWI and earthing switch control ESSXSWI

10.2.1 Identification

Table 62: Function identification

IEC 61850 identification:	DCSXSWI	ESSXSWI
IEC 60617 identification:	I<->0 DC	I<->0 ES
ANSI/IEEE C37.2 device number:	I<->0 DC	I<->0 ES

10.2.2 Functionality

The control 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 earthing switches can be monitored with the DCSXSWI function.

The functions are designed according to the IEC 61850-7-4 standard with the logical node XSWI.

10.2.3

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.

10.3

Interaction between control modules

A typical substation feeder with IED control function consists of a combination of logical nodes or functions:

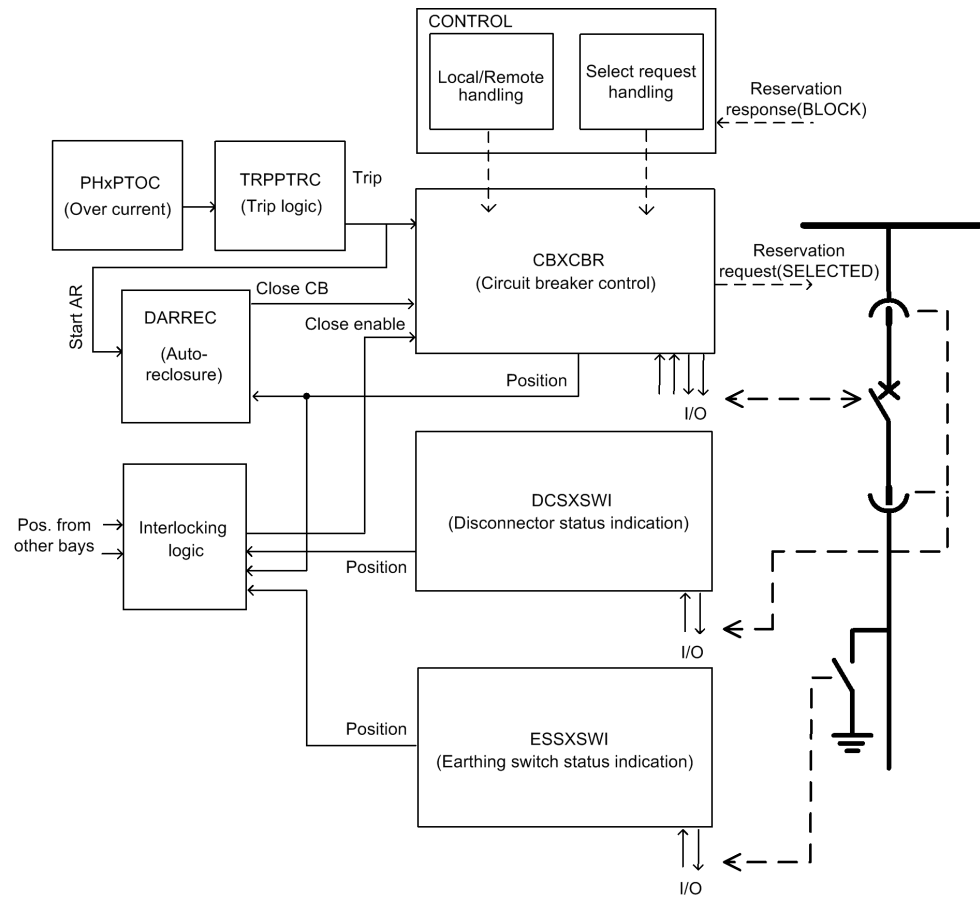


Figure 69: Example overview of interactions between functions in a typical distribution feeder

- The circuit breaker control function CBXCBR is the process interface to the circuit breaker for IED control
- The circuit switch DCSXSWI is the process interface to the disconnecter switch for the IED status indication
- The earthing switch ESSXSWI is the process interface to the earthing switch for the IED status indication
- Reservation deals with the reservation function
- The overcurrent protection PHxPTOC trips the breaker in case of overcurrent or short circuit
- The protection trip conditioning TRPPTRC connects the operate outputs of one or more protection functions to a common trip to be transmitted to CBXCBR
- The auto-reclose function DARREC automatically closes a tripped breaker in connection with a number of configurable conditions.

10.4 Auto recloser DARREC

10.4.1 Identification

Table 63: *Function identification*

IEC 61850 logical node name:	DARREC
IEC 60617 identification:	O-->I
ANSI/IEEE C37.2 device number:	79

10.4.2 Functionality

About 80 to 85 percent of faults in the MV overhead lines are transient and automatically cleared with a momentary de-energization of the line. The rest of the faults, 15 to 20 percent, can be cleared by longer interruptions. The de-energization of the fault location for a selected time period is implemented through automatic reclosing, during which most of the faults can be cleared.

In case of a permanent fault, the automatic reclosing is followed by final tripping. A permanent fault must be located and cleared before the fault location can be re-energized.

The auto-reclose function (AR) can be used with any circuit breaker suitable for auto-reclosing. The function provides five programmable auto-reclose shots which can perform one to five successive auto-reclosings of desired type and duration, for instance one high-speed and one delayed auto-reclosing

When the reclosing is initiated with starting of the protection function, the auto-reclose function can execute the final trip of the circuit breaker in a short operate time, provided that the fault still persists when the last selected reclosing has been carried out.

10.4.3 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 64: *Important definitions related to auto-reclosing*

auto-reclose shot	an operation where after a preset time the breaker is closed from the breaker tripping caused by protection
auto-reclose sequence	a predefined method to do reclose attempts (shots) to restore the power system
SOTF	If the protection detects a fault immediately after an open circuit breaker has been closed, it indicates that the fault was already there. It can be, for example, a forgotten earthing after maintenance work. Such closing of the circuit breaker is known as switch on to fault. Autoreclosing in such conditions is prohibited.
final trip	Occurs in case of a permanent fault, when the circuit breaker is opened for the last time after all programmed auto-reclose operations. Since no auto-reclosing follows, the circuit breaker remains open. This is called final trip or definite trip.

10.4.3.1

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.

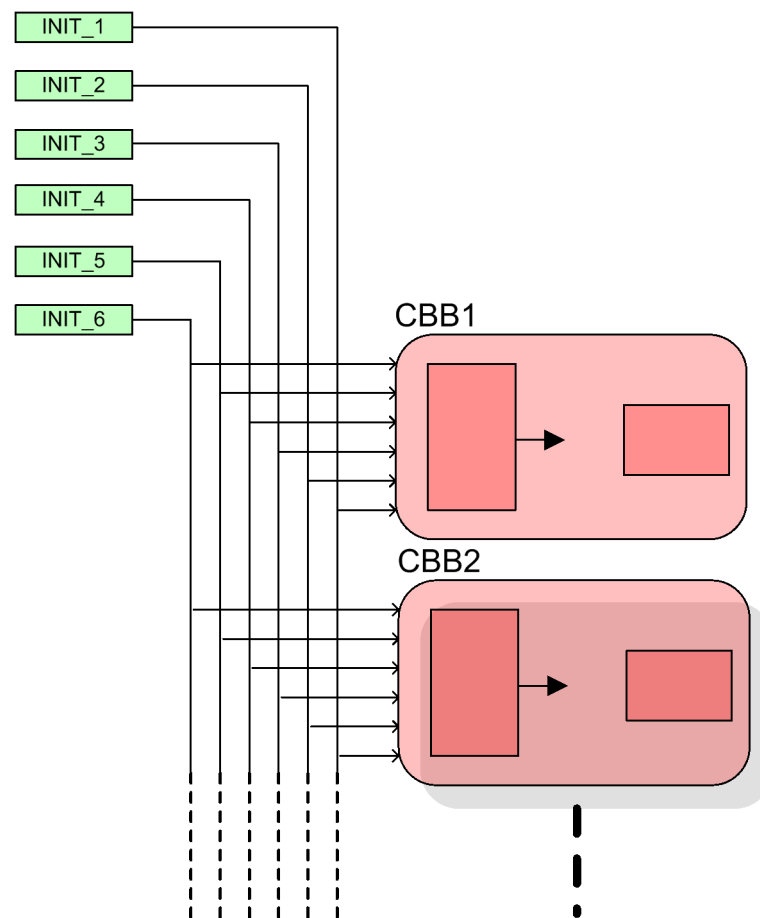


Figure 70: Simplified CBB initiation diagram

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.

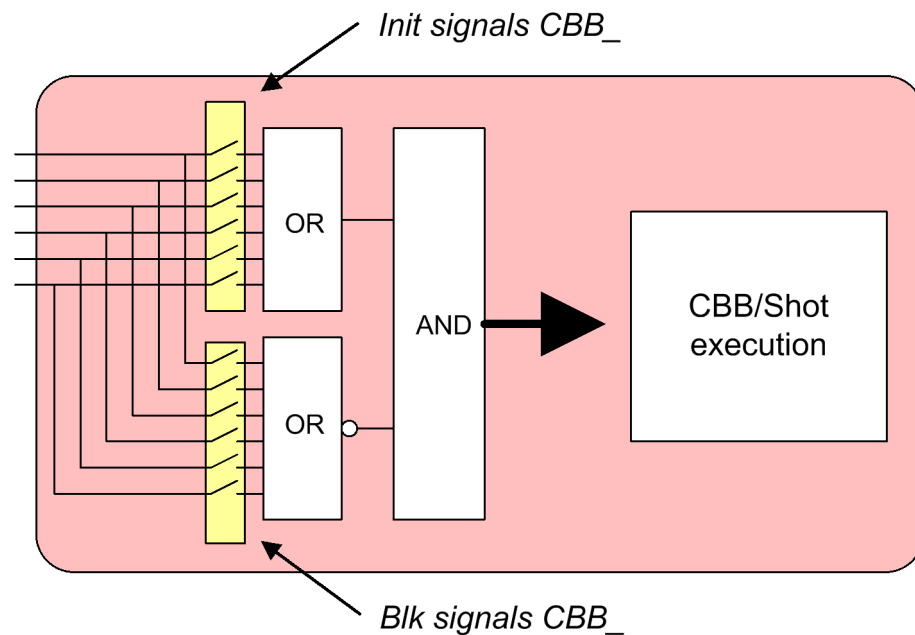


Figure 71: Simplified CBB diagram

Each CBB has individual *Init signals CBB_* and *Blk signals CBB_* settings. Therefore, each initiation line can be used for both initiating and blocking any or all auto-reclose shots.

Other conditions that must be fulfilled before any CBB can be initiated are, for example, the closed position of the circuit breaker.

10.4.3.2

Sequence

The auto reclose sequence is implemented by using CBBs. The highest possible amount of CBBs is seven. If the user wants to have, for example, a sequence of three shots, only the first three CBBs are needed. Using building blocks instead of fixed shots gives enhanced flexibility, allowing multiple and adaptive sequences.

Each CBB is identical. The *Shot number CBB_* setting defines at which point in the auto-reclose sequence the CBB should be performed, that is, whether the particular CBB is going to be the first, second, third, fourth or fifth shot.

During the initiation of a CBB, the conditions of initiation and blocking are checked. This is done for all CBBs simultaneously. Each CBB that fulfils the initiation conditions requests an execution.

The function also keeps track of shots already performed, that is, at which point the auto-reclose sequence is from shot 1 to lockout. For example, if shots 1 and 2 have already been performed, only shots 3 to 5 are allowed.

Additionally, the *Enable shot jump* setting gives two possibilities:

- Only such CBBs that are set for the next shot in the sequence can be accepted for execution. For example, if the next shot in the sequence should be shot 2, a request from CBB set for shot 3 is rejected.
- Any CBB that is set for the next shot or any of the following shots can be accepted for execution. For example, if the next shot in the sequence should be shot 2, also CBBs that are set for shots 3, 4 and 5 are accepted. In other words, shot 2 can be ignored.

In case there are multiple CBBs allowed for execution, the CBB with the smallest number is chosen. For example, if CBB2 and CBB4 request an execution, CBB2 is allowed to execute the shot.

The auto-reclose function can perform up to five auto-reclose shots or cycles.

10.4.3.3

Configuration examples

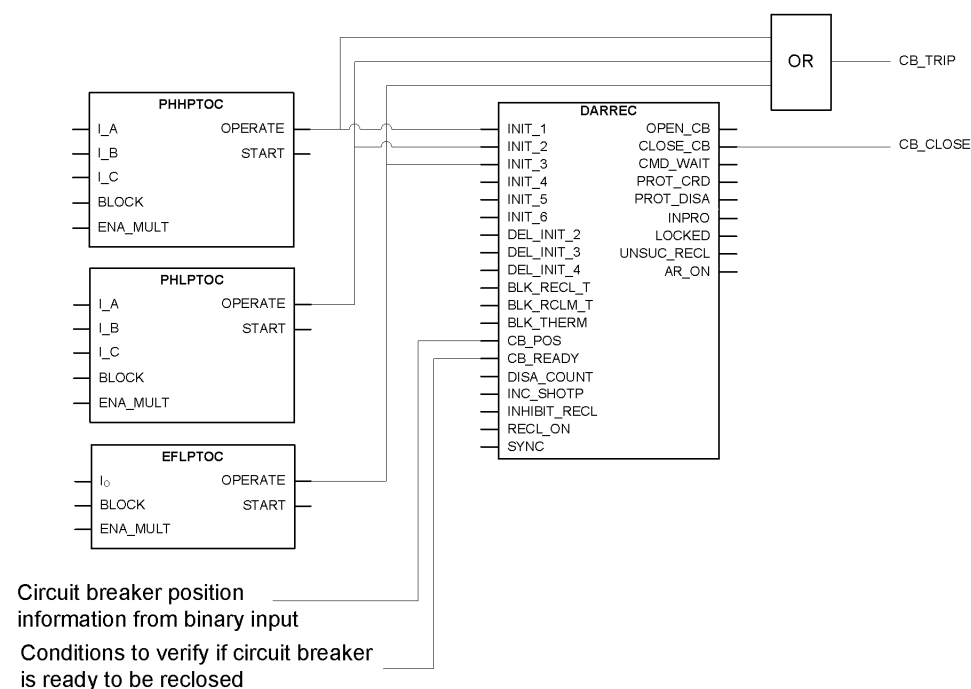


Figure 72: Example connection between protection and auto-reclose functions in IED configuration

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.

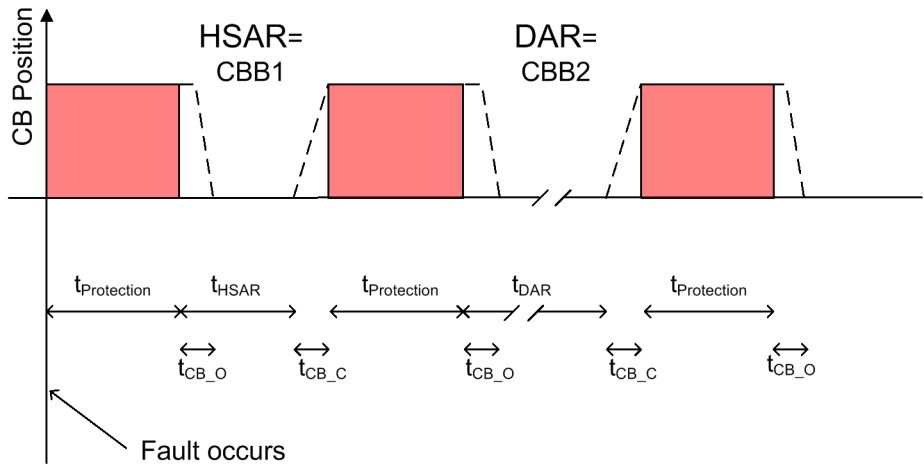


Figure 73: Auto-reclose sequence with two shots

t_{HSAR} =	Time delay of high-speed auto-reclosing, here: <i>First reclose time</i>
t_{DAR} =	Time delay of delayed auto-reclosing, here: <i>Second reclose time</i>
$t_{Protection}$ =	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:

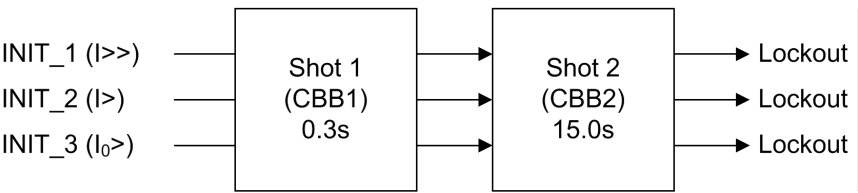


Figure 74: Two shots with three initiation lines

Table 65: *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 ($I_{0>}$). 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 $I_{0>}$, is set as a delayed auto-reclosing and executed after an unsuccessful high-speed auto-reclosing of a corresponding sequence.

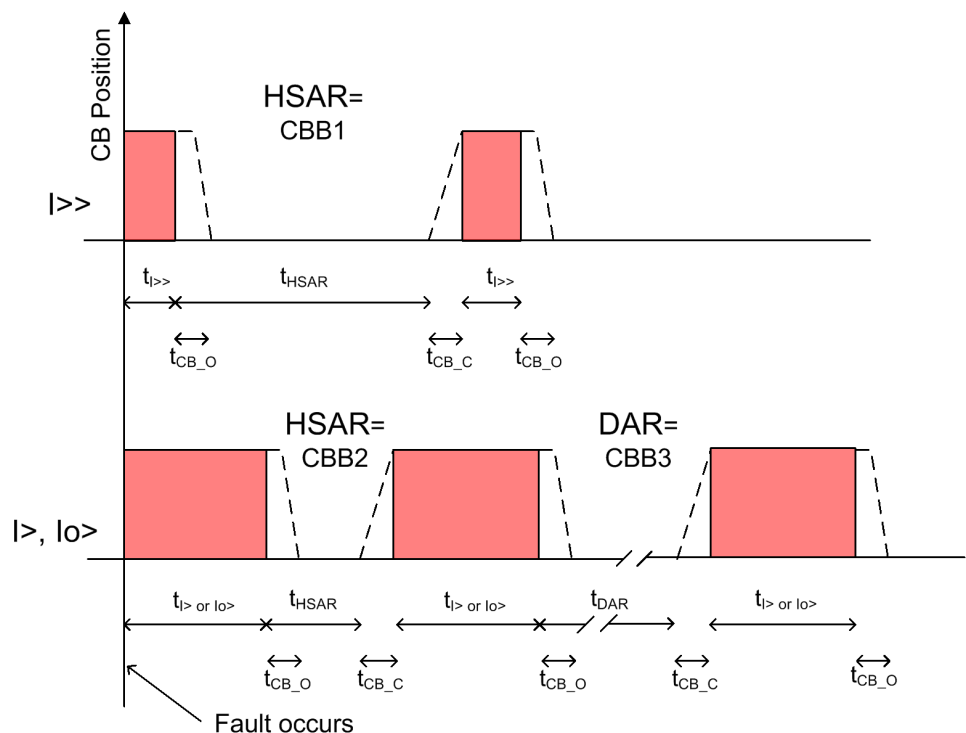


Figure 75: *Auto-reclose sequence with two shots with different shot settings according to initiation signal*

$t_{HSAR} =$	Time delay of high-speed auto-reclosing, here: <i>First reclose time</i>
$t_{DAR} =$	Time delay of delayed auto-reclosing, here: <i>Second reclose time</i>
$t_{I>}$	Operating time for the $I>$ protection stage to clear the fault
$t_{I> \text{ or } I_0>}$	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:

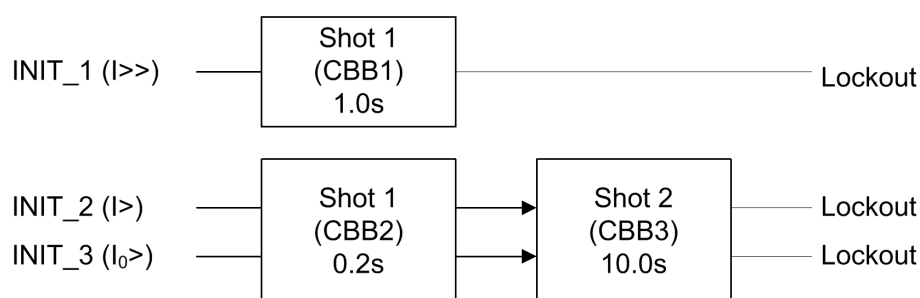


Figure 76: Three shots with three initiation lines

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 66: 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

10.4.3.4

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.

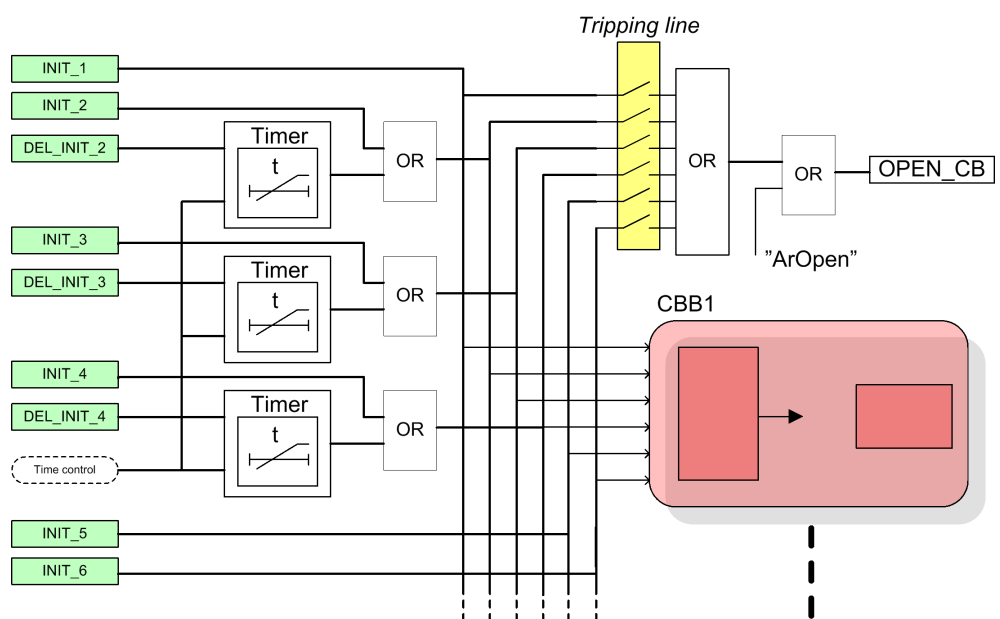


Figure 77: Simplified logic diagram of initiation lines

Each delayed initiation line has four different time settings:

Table 67: Settings for delayed initiation lines

Setting name	Description and purpose
<i>Str x delay shot 1</i>	Time delay for the DEL_INIT_x line, where x is the number of the line 2, 3 or 4. Used for shot 1.
<i>Str x delay shot 2</i>	Time delay for the DEL_INIT_x line, used for shot 2.
<i>Str x delay shot 3</i>	Time delay for the DEL_INIT_x line, used for shot 3.
<i>Str x delay shot 4</i>	Time delay for the DEL_INIT_x line, used for shots 4 and 5. Optionally, can also be used with SOTF.

10.4.3.5

Shot initiation from protection start signal

In it simplest, all auto-reclose shots are initiated by protection trips. As a result, all trip times in the sequence are the same. This is why using protection trips may not be the optimal solution. Using protection start signals instead of protection trips for initiating shots shortens the trip times.

Example 1

When a two-shot-sequence is used, the start information from the protection function is routed to the `DEL_INIT 2` input and the operate information to the `INIT_2` input. The following conditions have to apply:

- protection operate time = 0.5s
- *Str 2 delay shot 1* = 0.05s
- *Str 2 delay shot 2* = 60s
- *Str 2 delay shot 3* = 60s

Operation in a permanent fault:

1. Protection starts and activates the `DEL_INIT 2` input.
2. After 0.05 seconds, the first autoreclose shot is initiated. The function opens the circuit breaker: the `OPEN_CB` output activates. The total trip time is the protection start delay + 0.05 seconds + the time it takes to open the circuit breaker.
3. After the first shot, the circuit breaker is reclosed and the protection starts again.
4. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time, activating the `INIT 2` input. The second shot is initiated.
5. After the second shot, the circuit breaker is reclosed and the protection starts again.
6. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time. No further shots are programmed after the final trip. The function is in lockout and the sequence is considered unsuccessful.

Example 2

The delays can be used also for fast final trip. The conditions are the same as in Example 1, with the exception of *Str 2 delay shot 3* = 0.10 seconds.

The operation in a permanent fault is the same as in Example 1, except that after the second shot when the protection starts again, *Str 2 delay shot 3* elapses before the protection operate time and the final trip follows. The total trip time is the protection start delay + 0.10 seconds + the time it takes to open the circuit breaker.

10.4.3.6

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.

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 68: 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:

$$\text{Current start value} < 0.7 \times (I_{kmin} / I_{1n})$$

I_{1n} is the nominal primary current of the CT.

The factor 0.7 takes into account the protection relay inaccuracy, current transformer errors, and imperfections of the short circuit calculations.

The adequate performance of the CT should be checked when the setting of the high set stage 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 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:

$$F_a > 20 * \text{Current start value} / I_{1n}$$

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

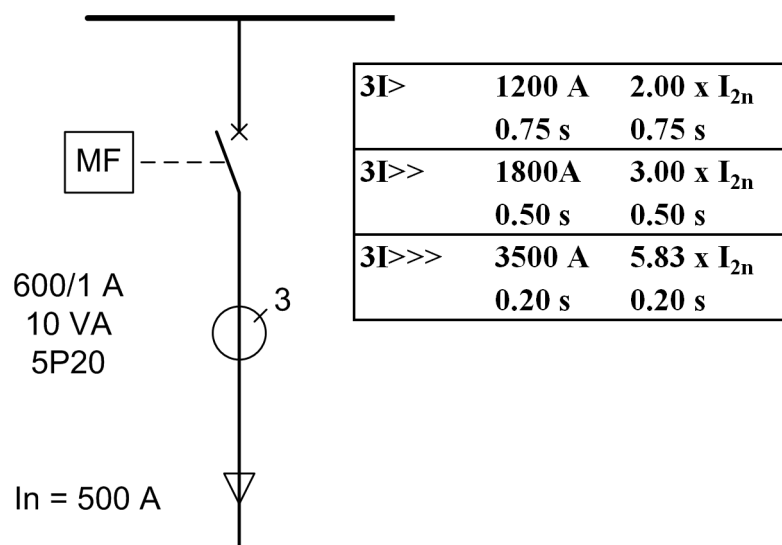


Figure 78: Example of three-stage overcurrent protection

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 Glossary

100BASE-FX	A physical media defined in the IEEE 802.3 Ethernet standard for local area networks (LANs). 100BASE-FX uses fiber optic cabling.
100BASE-TX	A physical media defined in the IEEE 802.3 Ethernet standard for local area networks (LANs). 100BASE-TX uses twisted-pair cabling category 5 or higher with RJ-45 connectors.
AI	Analog input
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
BI	Binary input
BI/O	Binary input/output
BO	Binary output
CB	Circuit breaker
CBB	Cycle building block
CPU	Central Processing Unit
CT	Current transformer
DT	Definite time
EEPROM	Electrically Erasable Programmable Read-Only Memory
FPGA	Field Programmable Gate Array
GOOSE	Generic Object Oriented Substation Event
GPS	Global Positioning System
HMI	Human-machine interface
HW	Hardware
IEC	International Electrotechnical Commission
IEC 61850	International standard for substation communication and modelling.
IEC 61850-8-1	A communication protocol based on the IEC 61850 standard series and a standard for substation modelling.
IED	Intelligent Electronic Device
IP address	Internet protocol address is 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 a location for the TCP/IP protocol.
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.
Modbus TCP/IP	Modbus RTU protocol which uses TCP/IP and Ethernet to carry data between devices.
MV	Medium voltage
PCM600	Protection and Control IED Manager
PO	Power output
PST	Parameter Setting Tool
RAM	Random access memory
REF615	Feeder protection relay
RJ-45	Galvanic connector type.
ROM	Read Only Memory
RS-485	Serial link according to EIA standard RS485.
RTC	Real Time Clock
RTU	Remote Terminal Unit
SCL	Substation Configuration Language
SMT	Signal Matrix Tool
SNTP	Simple Network Time Protocol
SO	Signal output
SOTF	Switch on to fault
SW	Software
TCS	Trip-circuit supervision
VT	Voltage transformer
WAN	Wide area network
WHMI	Web Human-Machine Interface



ABB Oy
Distribution Automation
P.O. Box 699
FI-65101 VAASA, Finland
Phone +358 10 22 11
Fax +358 10 22 41094
www.abb.com/substationautomation

1MRS756378

Copyright 2008 - ABB