

RELION® 650 SERIES

Transformer protection RET650

Version 2.2

Application manual





Document ID: 1MRK 504 169-UEN
Issued: October 2017
Revision: A
Product version: 2.2.1

© Copyright 2017 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 and hardware described in this document is furnished under a license and may be used or disclosed only in accordance with the terms of such license.

This product includes software developed by the OpenSSL Project for use in the OpenSSL Toolkit. (<http://www.openssl.org/>) This product includes cryptographic software written/developed by: Eric Young (ey@cryptsoft.com) and Tim Hudson (tjh@cryptsoft.com).

Trademarks

ABB and Relion are registered trademarks of the ABB Group. All other brand or product names mentioned in this document may be trademarks or registered trademarks of their respective holders.

Warranty

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

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 Directive 2004/108/EC) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2006/95/EC). This conformity is the result of tests conducted by ABB in accordance with the product standard EN 60255-26 for the EMC directive, and with the product standards EN 60255-1 and EN 60255-27 for the low voltage directive. The product is designed in accordance with the international standards of the IEC 60255 series.

Table of contents

Section 1	Introduction.....	13
	This manual.....	13
	Intended audience.....	13
	Product documentation.....	14
	Product documentation set.....	14
	Document revision history.....	15
	Related documents.....	16
	Document symbols and conventions.....	16
	Symbols.....	16
	Document conventions.....	17
	IEC 61850 edition 1 / edition 2 mapping.....	18
Section 2	Application.....	23
	General IED application.....	23
	Main protection functions.....	24
	Back-up protection functions.....	25
	Control and monitoring functions.....	26
	Communication.....	29
	Basic IED functions.....	30
Section 3	Configuration.....	33
	Description of configuration RET650.....	33
	Introduction.....	33
	Description of A01.....	33
	Description of A05.....	34
Section 4	Analog inputs.....	37
	Introduction.....	37
	Setting guidelines.....	37
	Setting of the phase reference channel.....	38
	Example.....	38
	Setting of current channels.....	38
	Example 1.....	38
	Example 2.....	39
	Example 3.....	40
	Examples on how to connect, configure and set CT inputs for most commonly used CT connections.....	43
	Example on how to connect a star connected three-phase CT set to the IED.....	44

Example how to connect delta connected three-phase CT set to the IED.....	48
Example how to connect single-phase CT to the IED.....	51
Relationships between setting parameter Base Current, CT rated primary current and minimum pickup of a protection IED..	53
Setting of voltage channels.....	53
Example.....	53
Examples how to connect, configure and set VT inputs for most commonly used VT connections.....	54
Examples on how to connect a three phase-to-earth connected VT to the IED.....	55
Example on how to connect a phase-to-phase connected VT to the IED.....	57
Example on how to connect an open delta VT to the IED for high impedance earthed or unearthed networks.....	59
Example how to connect the open delta VT to the IED for low impedance earthed or solidly earthed power systems.....	62
Section 5 Local HMI.....	65
Display.....	66
LEDs.....	68
Keypad.....	69
Local HMI functionality.....	71
Protection and alarm indication.....	71
Parameter management	72
Front communication.....	73
Section 6 Differential protection.....	75
Transformer differential protection T2WPDIF and T3WPDIF	75
Identification.....	75
Application.....	75
Setting guidelines.....	76
Restrained and unrestrained differential protection.....	76
Elimination of zero sequence currents.....	79
Inrush restraint methods.....	80
Overexcitation restraint method.....	80
Cross-blocking between phases.....	81
External/Internal fault discriminator.....	81
Differential current alarm.....	83
Open CT detection.....	83
Switch onto fault feature.....	84
Setting example.....	84
Introduction.....	84

Typical main CT connections for transformer differential protection.....	85
Application Examples.....	86
Summary and conclusions.....	91
Low impedance restricted earth fault protection REFPDIF	93
Identification.....	93
Application.....	93
Transformer winding, solidly earthed.....	94
Transformer winding, earthed through zig-zag earthing transformer.....	94
Autotransformer winding, solidly earthed.....	95
Reactor winding, solidly earthed.....	96
Multi-breaker applications.....	97
CT earthing direction.....	98
Setting guidelines.....	98
Setting and configuration.....	98
Settings.....	99
Section 7 Current protection.....	101
Instantaneous phase overcurrent protection PHPIOC	101
Identification.....	101
Application.....	101
Setting guidelines.....	102
Meshed network without parallel line.....	102
Meshed network with parallel line.....	104
Directional phase overcurrent protection, four steps OC4PTOC....	106
Identification.....	106
Application.....	106
Setting guidelines.....	107
Settings for each step.....	109
Setting example.....	112
Instantaneous residual overcurrent protection EFPIOC	117
Identification.....	117
Application.....	117
Setting guidelines.....	117
Directional residual overcurrent protection, four steps EF4PTOC .	120
Identification.....	120
Application.....	120
Setting guidelines.....	122
Common settings for all steps.....	123
2nd harmonic restrain.....	124
Parallel transformer inrush current logic.....	125
Switch onto fault logic.....	126
Settings for each step (x = 1, 2, 3 and 4).....	127

Transformer application example.....	129
Thermal overload protection, two time constants TRPTTR	133
Identification.....	133
Application.....	133
Setting guideline.....	134
Breaker failure protection CCRBRF.....	136
Identification.....	136
Application.....	137
Setting guidelines.....	137
Pole discordance protection CCPDSC.....	140
Identification.....	141
Application.....	141
Setting guidelines.....	141
Section 8 Voltage protection.....	143
Two step undervoltage protection UV2PTUV	143
Identification.....	143
Application.....	143
Setting guidelines.....	144
Equipment protection, such as for motors and generators...	144
Disconnected equipment detection.....	144
Power supply quality	144
Voltage instability mitigation.....	144
Backup protection for power system faults.....	144
Settings for two step undervoltage protection.....	145
Two step overvoltage protection OV2PTOV	146
Identification.....	146
Application.....	147
Setting guidelines.....	147
Equipment protection, such as for motors, generators, reactors and transformers.....	148
Equipment protection, capacitors.....	148
Power supply quality.....	148
High impedance earthed systems.....	148
The following settings can be done for the two step overvoltage protection.....	148
Two step residual overvoltage protection ROV2PTOV	151
Identification.....	151
Application.....	151
Setting guidelines.....	151
Equipment protection, such as for motors, generators, reactors and transformers.....	152
Equipment protection, capacitors.....	152

Power supply quality.....	152
High impedance earthed systems.....	152
Direct earthed system.....	153
Settings for two step residual overvoltage protection.....	154
Overexcitation protection OEXPVPH	156
Identification.....	156
Application.....	156
Setting guidelines.....	158
Recommendations for input and output signals.....	158
Settings.....	159
Service value report.....	160
Setting example.....	160
Section 9 Frequency protection.....	163
Underfrequency protection SAPTUF	163
Identification.....	163
Application.....	163
Setting guidelines.....	163
Overfrequency protection SAPTOF	164
Identification.....	164
Application.....	165
Setting guidelines.....	165
Rate-of-change of frequency protection SAPFRC	166
Identification.....	166
Application.....	166
Setting guidelines.....	166
Section 10 Secondary system supervision.....	169
Current circuit supervision CCSSPVC.....	169
Identification.....	169
Application.....	169
Setting guidelines.....	169
Fuse failure supervision FUFSPVC.....	170
Identification.....	170
Application.....	170
Setting guidelines.....	171
General.....	171
Setting of common parameters.....	171
Negative sequence based.....	172
Zero sequence based.....	173
Delta U and delta I	173
Dead line detection.....	174
Section 11 Control.....	175

Apparatus control APC.....	175
Application.....	175
Bay control QCBAY.....	179
Switch controller SCSWI.....	180
Switches SXCBR.....	181
Proxy for signals from switching device via GOOSE XLNPROXY.....	182
Interaction between modules.....	185
Setting guidelines.....	187
Bay control (QCBAY).....	188
Switch controller (SCSWI).....	188
Switch (SXCBR).....	189
Proxy for signals from switching device via GOOSE XLNPROXY.....	190
Voltage control.....	190
Identification.....	190
Application.....	191
Setting guidelines.....	224
TR1ATCC or TR8ATCC general settings.....	224
TR1ATCC or TR8ATCC Setting group	225
TCMYLTC and TCLYLTC general settings.....	234
Logic rotating switch for function selection and LHMI presentation SLGAPC.....	235
Identification.....	235
Application.....	235
Setting guidelines.....	235
Selector mini switch VSGAPC.....	236
Identification.....	236
Application.....	236
Setting guidelines.....	237
Generic communication function for Double Point indication DPGAPC.....	237
Identification.....	237
Application.....	237
Setting guidelines.....	238
Single point generic control 8 signals SPC8GAPC.....	238
Identification.....	238
Application.....	239
Setting guidelines.....	239
AutomationBits, command function for DNP3.0 AUTOBITS.....	239
Identification.....	239
Application.....	240
Setting guidelines.....	240
Single command, 16 signals SINGLECMD.....	240

Identification.....	240
Application.....	240
Setting guidelines.....	242
Section 12 Logic.....	245
Tripping logic SMPPTRC	245
Identification.....	245
Application.....	245
Three-phase tripping.....	246
Single- and/or three-phase tripping.....	246
Single-, two- or three-phase tripping.....	248
Lock-out.....	248
Example of directional data.....	249
Blocking of the function block.....	251
Setting guidelines.....	251
Trip matrix logic TMAGAPC.....	251
Identification.....	251
Application.....	252
Setting guidelines.....	252
Logic for group alarm ALMCALH.....	252
Identification.....	252
Application.....	252
Setting guidelines.....	253
Logic for group alarm WRNCALH.....	253
Identification.....	253
Application.....	253
Setting guidelines.....	253
Logic for group indication INDCALH.....	253
Identification.....	253
Application.....	253
Setting guidelines.....	254
Configurable logic blocks.....	254
Application.....	254
Setting guidelines.....	254
Configuration.....	254
Fixed signal function block FXDSIGN.....	255
Identification.....	255
Application.....	255
Boolean 16 to Integer conversion B16I.....	256
Identification.....	256
Application.....	257
Boolean to integer conversion with logical node representation, 16 bit BTIGAPC.....	258
Identification.....	258

Application.....	258
Integer to Boolean 16 conversion IB16.....	259
Identification.....	259
Application.....	259
Integer to Boolean 16 conversion with logic node representation ITBGAPC.....	260
Identification.....	260
Application.....	260
Elapsed time integrator with limit transgression and overflow supervision TEIGAPC.....	261
Identification.....	261
Application.....	262
Setting guidelines.....	262
Comparator for integer inputs - INTCOMP.....	262
Identification.....	262
Application.....	263
Setting guidelines.....	263
Setting example.....	263
Comparator for real inputs - REALCOMP.....	264
Identification.....	264
Application.....	264
Setting guidelines.....	264
Setting example.....	265
Section 13 Monitoring.....	267
Measurement.....	267
Identification.....	267
Application.....	267
Zero clamping.....	269
Setting guidelines.....	270
Setting examples.....	272
Gas medium supervision SSIMG.....	277
Identification.....	277
Application.....	277
Setting guidelines.....	278
Liquid medium supervision SSIML.....	279
Identification.....	279
Application.....	279
Setting guidelines.....	279
Breaker monitoring SSCBR.....	280
Identification.....	280
Application.....	280
Setting guidelines.....	283
Setting procedure on the IED.....	283

Event function EVENT.....	284
Identification.....	284
Application.....	284
Setting guidelines.....	285
Disturbance report DRPRDRE.....	285
Identification.....	285
Application.....	286
Setting guidelines.....	286
Recording times.....	289
Binary input signals.....	290
Analog input signals.....	290
Sub-function parameters.....	290
Consideration.....	291
Logical signal status report BINSTATREP.....	292
Identification.....	292
Application.....	292
Setting guidelines.....	293
Limit counter L4UFCNT.....	293
Identification.....	293
Application.....	293
Setting guidelines.....	294
Running hour-meter TEILGAPC.....	294
Identification.....	294
Application.....	294
Setting guidelines.....	294
Section 14 Metering.....	295
Pulse-counter logic PCFCNT.....	295
Identification.....	295
Application.....	295
Setting guidelines.....	295
Function for energy calculation and demand handling ETPMMTR.....	296
Identification.....	296
Application.....	296
Setting guidelines.....	297
Section 15 Ethernet-based communication.....	299
Access point.....	299
Application.....	299
Setting guidelines.....	299
Redundant communication.....	300
Identification.....	300
Application.....	301
Setting guidelines.....	302

Merging unit.....	303
Application.....	303
Setting guidelines.....	304
Routes.....	304
Application.....	304
Setting guidelines.....	304
Section 16 Station communication.....	305
Communication protocols.....	305
IEC 61850-8-1 communication protocol.....	305
Application IEC 61850-8-1.....	305
Setting guidelines.....	307
Horizontal communication via GOOSE.....	307
Sending data.....	307
Receiving data.....	308
IEC/UCA 61850-9-2LE communication protocol.....	309
Introduction.....	309
Setting guidelines.....	311
Specific settings related to the IEC/UCA 61850-9-2LE communication.....	312
Loss of communication when used with LDCM.....	312
Setting examples for IEC/UCA 61850-9-2LE and time synchronization.....	317
IEC 61850 quality expander QUALEXP.....	322
LON communication protocol.....	323
Application.....	323
MULTICMDRCV and MULTICMDSND.....	324
Identification.....	325
Application.....	325
Setting guidelines.....	325
SPA communication protocol.....	325
Application.....	325
Setting guidelines.....	326
IEC 60870-5-103 communication protocol.....	328
Application.....	328
Functionality.....	328
Design.....	329
Settings.....	331
Settings for RS485 and optical serial communication.....	332
Settings from PCM600.....	333
Function and information types.....	335
DNP3 Communication protocol.....	336
Application.....	336

Section 17 Security.....	337
Authority status ATHSTAT.....	337
Application.....	337
Self supervision with internal event list INTERRSIG.....	337
Application.....	337
Change lock CHNGLCK.....	338
Application.....	338
Denial of service SCHLCCH/RCHLCCH	339
Application.....	339
Setting guidelines.....	339
 Section 18 Basic IED functions.....	 341
IED identifiers TERMINALID.....	341
Application.....	341
Product information PRODINF.....	341
Application.....	341
Factory defined settings.....	341
Measured value expander block RANGE_XP.....	342
Identification.....	342
Application.....	343
Setting guidelines.....	343
Parameter setting groups.....	343
Application.....	343
Setting guidelines.....	344
Rated system frequency PRIMVAL.....	344
Identification.....	344
Application.....	344
Setting guidelines.....	344
Summation block 3 phase 3PHSUM.....	344
Application.....	344
Setting guidelines.....	345
Global base values GBASVAL.....	345
Identification.....	345
Application.....	345
Setting guidelines.....	345
Signal matrix for binary inputs SMBI.....	346
Application.....	346
Setting guidelines.....	346
Signal matrix for binary outputs SMBO	346
Application.....	346
Setting guidelines.....	346
Signal matrix for analog inputs SMAI.....	347
Application.....	347

Frequency values.....	347
Setting guidelines.....	348
Test mode functionality TESTMODE.....	353
Application.....	353
IEC 61850 protocol test mode.....	353
Setting guidelines.....	354
Time synchronization TIMESYNCHGEN.....	354
Application.....	354
Setting guidelines.....	355
System time.....	355
Synchronization.....	356
Process bus IEC/UCA 61850-9-2LE synchronization.....	359
Section 19 Requirements.....	361
Current transformer requirements.....	361
Current transformer basic classification and requirements.....	361
Conditions.....	363
Fault current.....	364
Secondary wire resistance and additional load.....	364
General current transformer requirements.....	365
Rated equivalent secondary e.m.f. requirements.....	365
Transformer differential protection.....	365
Distance protection.....	366
Breaker failure protection.....	368
Restricted earth fault protection (low impedance differential).....	368
Current transformer requirements for CTs according to other standards.....	371
Current transformers according to IEC 61869-2, class P, PR.....	371
Current transformers according to IEC 61869-2, class PX, PXR (and old IEC 60044-6, class TPS and old British Standard, class X).....	371
Current transformers according to ANSI/IEEE.....	372
Voltage transformer requirements.....	372
SNTP server requirements.....	373
PTP requirements.....	373
IEC/UCA 61850-9-2LE Merging unit requirements	373
Section 20 Glossary.....	375

Section 1 Introduction

1.1 This manual

The 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 provide assistance for 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 protection schemes and communication principles.

1.3 Product documentation

1.3.1 Product documentation set

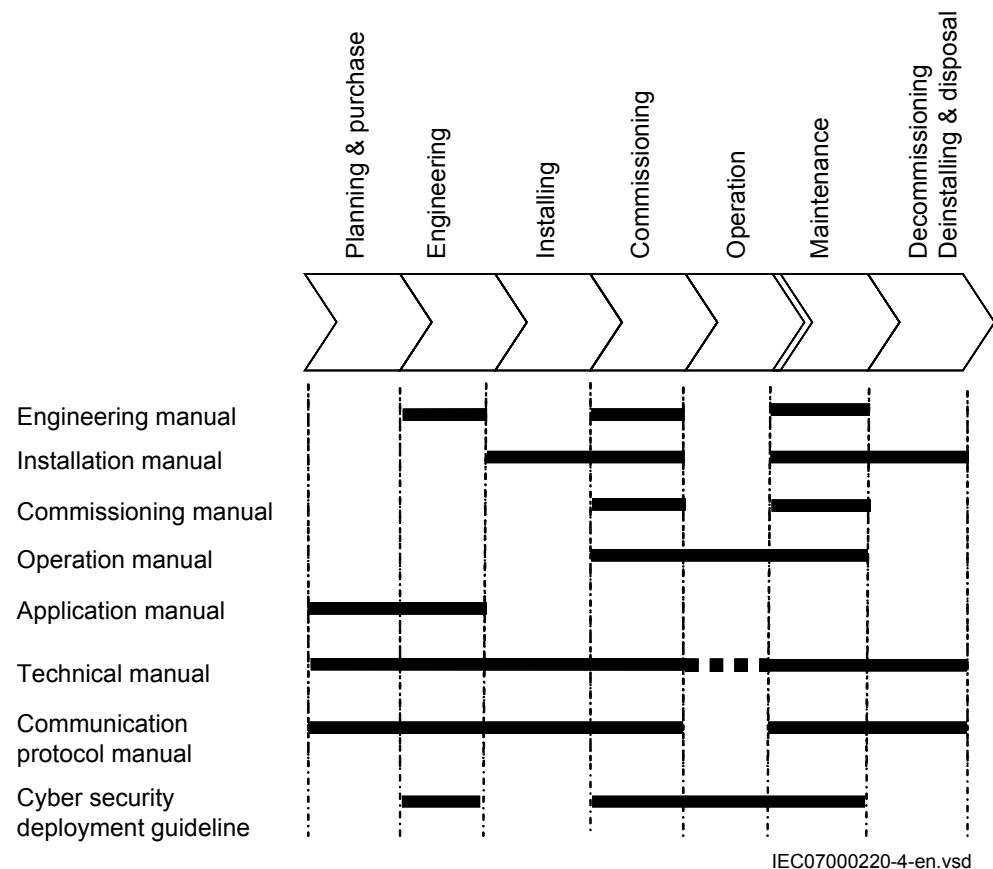


Figure 1: The intended use of manuals throughout the product lifecycle

The engineering manual contains instructions on how to engineer the IEDs using the various tools available within the PCM600 software. The manual provides instructions on how to set up a PCM600 project and insert IEDs to the project structure. The manual also recommends a sequence for the engineering of protection and control functions, LHMI functions as well as communication engineering for IEC 60870-5-103, IEC 61850, DNP3, LON and SPA.

The 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 IED should be installed.

The commissioning manual contains instructions on how to commission the IED. The manual can also be used by system engineers and maintenance personnel for assistance during the testing phase. The manual provides procedures for the checking of external circuitry and energizing the IED, parameter setting and configuration as well as verifying settings by secondary injection. The manual

describes the process of testing an IED in a station which is not in service. The chapters are organized in the chronological order in which the IED should be commissioned. The relevant procedures may be followed also during the service and maintenance activities.

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

The 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 provide assistance for calculating settings.

The technical manual contains operation principle 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 manual describes the communication protocols supported by the IED. The manual concentrates on the vendor-specific implementations.

The point list manual describes the outlook and properties of the data points specific to the IED. The manual should be used in conjunction with the corresponding communication protocol manual.

The cyber security deployment guideline describes the process for handling cyber security when communicating with the IED. Certification, Authorization with role based access control, and product engineering for cyber security related events are described and sorted by function. The guideline can be used as a technical reference during the engineering phase, installation and commissioning phase, and during normal service.

1.3.2

Document revision history

Document revision/date	History
–/May 2017	First release

1.3.3

Related documents

Documents related to RET650	Document numbers
Application manual	1MRK 504 169-UEN
Commissioning manual	1MRK 504 171-UEN
Product guide	1MRK 504 172-BEN
Technical manual	1MRK 504 170-UEN
Type test certificate	1MRK 504 172-TEN

650 series manuals	Document numbers
Operation manual	1MRK 500 128-UEN
Engineering manual	1MRK 511 420-UEN
Installation manual	1MRK 514 027-UEN
Communication protocol manual, DNP3	1MRK 511 413-UUS
Communication protocol manual, IEC 60870-5-103	1MRK 511 416-UEN
Communication protocol manual, IEC 61850 Edition 1	1MRK 511 414-UEN
Communication protocol manual, IEC 61850 Edition 2	1MRK 511 415-UEN
Communication protocol manual, LON	1MRK 511 417-UEN
Communication protocol manual, SPA	1MRK 511 418-UEN
Point list manual, DNP3	1MRK 511 419-UUS
Accessories guide	IEC: 1MRK 514 012-UEN ANSI: 1MRK 514 012-UUS
Cyber security deployment guideline	1MRK 511 421-UEN
Connection and Installation components	1MRK 513 003-BEN
Test system, COMBITEST	1MRK 512 001-BEN
Application guide, Communication set-up	1MRK 505 382-UEN

1.4

Document symbols and conventions

1.4.1

Symbols



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



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



The caution hot surface icon indicates important information or warning about the temperature of product surfaces.



Class 1 Laser product. Take adequate measures to protect the eyes and do not view directly with optical instruments.



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



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



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

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

1.4.2

Document conventions

- Abbreviations and acronyms in this manual are spelled out in the glossary. The glossary also contains definitions of important terms.
- Push button navigation in the LHMI menu structure is presented by using the push button icons.
For example, to navigate between the options, use  and .
- HMI menu paths are presented in bold.
For example, select **Main menu/Settings**.
- LHMI messages are shown in Courier font.
For example, to save the changes in non-volatile memory, select Yes and press .
- Parameter names are shown in italics.
For example, the function can be enabled and disabled with the *Operation* setting.
- Each function block symbol shows the available input/output signal.

- the character ^ in front of an input/output signal name indicates that the signal name may be customized using the PCM600 software.
- the character * after an input signal name indicates that the signal must be connected to another function block in the application configuration to achieve a valid application configuration.
- Logic diagrams describe the signal logic inside the function block and are bordered by dashed lines.
 - Signals in frames with a shaded area on their right hand side represent setting parameter signals that are only settable via the PST, ECT or LHMI.
 - If an internal signal path cannot be drawn with a continuous line, the suffix -int is added to the signal name to indicate where the signal starts and continues.
 - Signal paths that extend beyond the logic diagram and continue in another diagram have the suffix ”-cont.”



Illustrations are used as an example and might show other products than the one the manual describes. The example that is illustrated is still valid.

1.5

IEC 61850 edition 1 / edition 2 mapping

Function block names are used in **ACT** and **PST** to identify functions. Respective function block names of Edition 1 logical nodes and Edition 2 logical nodes are shown in the table below.

Table 1: *IEC 61850 edition 1 / edition 2 mapping*

Function block name	Edition 1 logical nodes	Edition 2 logical nodes
AGSAL	AGSAL SECLLN0	AGSAL
ALMCALH	ALMCALH	ALMCALH
ALTIM	-	ALTIM
ALTMS	-	ALTMS
ALTRK	-	ALTRK
BRCPTOC	BRCPTOC	BRCPTOC
BTIGAPC	B16IFCVI	BTIGAPC
CCPDSC	CCRPLD	CCPDSC
CCRBRF	CCRBRF	CCRBRF
CCSSPVC	CCSRDIF	CCSSPVC
CMMXU	CMMXU	CMMXU
CMSQI	CMSQI	CMSQI
Table continues on next page		

Function block name	Edition 1 logical nodes	Edition 2 logical nodes
CVGAPC	GF2LLN0 GF2MMXN GF2PHAR GF2PTOV GF2PTUC GF2PTUV GF2PVOC PH1PTRC	GF2MMXN GF2PHAR GF2PTOV GF2PTUC GF2PTUV GF2PVOC PH1PTRC
CVMMXN	CVMMXN	CVMMXN
DPGAPC	DPGGIO	DPGAPC
DRPRDRE	DRPRDRE	DRPRDRE
EF4PTOC	EF4LLN0 EF4PTRC EF4RDIR GEN4PHAR PH1PTOC	EF4PTRC EF4RDIR GEN4PHAR PH1PTOC
EFPIOC	EFPIOC	EFPIOC
ETPMMTR	ETPMMTR	ETPMMTR
FUFSPVC	SDDRFUF	FUFSPVC
HZPDIF	HZPDIF	HZPDIF
INDCALH	INDCALH	INDCALH
ITBGAPC	IB16FCVB	ITBGAPC
L4UFCNT	L4UFCNT	L4UFCNT
LCPTTR	LCPTTR	LCPTTR
LD0LLN0	LLN0	LLN0
LDLPSC	LDLPDIF	LDLPSC
LFPTTR	LFPTTR	LFPTTR
LMBRFLO	LMBRFLO	LMBRFLO
LOVPTUV	LOVPTUV	LOVPTUV
LPHD	LPHD	LPHD
LT3CPDIF	LT3CPDIF	LT3CGAPC LT3CPDIF LT3CPHAR LT3CPTRC
MVGAPC	MVGGIO	MVGAPC
NS4PTOC	EF4LLN0 EF4PTRC EF4RDIR GEN4PHAR PH1PTOC	EF4PTRC EF4RDIR PH1PTOC
OC4PTOC	OC4LLN0 GEN4PHAR PH3PTOC PH3PTRC	GEN4PHAR PH3PTOC PH3PTRC
OV2PTOV	GEN2LLN0 OV2PTOV PH1PTRC	OV2PTOV PH1PTRC
PCFCNT	PCGGIO	PCFCNT
Table continues on next page		

Function block name	Edition 1 logical nodes	Edition 2 logical nodes
PHPIOC	PHPIOC	PHPIOC
QCBAY	QCBAY	BAY/LLN0
QCRSV	QCRSV	QCRSV
RCHLCCH	RCHLCCH	RCHLCCH
REFPDIF	REFPDIF	REFPDIF
ROV2PTOV	GEN2LLN0 PH1PTRC ROV2PTOV	PH1PTRC ROV2PTOV
SCHLCCH	SCHLCCH	SCHLCCH
SCILO	SCILO	SCILO
SCSWI	SCSWI	SCSWI
SESRSYN	RSY1LLN0 AUT1RSYN MAN1RSYN SYNRSYN	AUT1RSYN MAN1RSYN SYNRSYN
SLGAPC	SLGGIO	SLGAPC
SMBRREC	SMBRREC	SMBRREC
SMPPTRC	SMPPTRC	SMPPTRC
SP16GAPC	SP16GGIO	SP16GAPC
SPC8GAPC	SPC8GGIO	SPC8GAPC
SPGAPC	SPGGIO	SPGAPC
SSCBR	SSCBR	SSCBR
SSIMG	SSIMG	SSIMG
SSIML	SSIML	SSIML
SXCBR	SXCBR	SXCBR
SXSWI	SXSWI	SXSWI
T3WPDIF	T3WPDIF	T3WGAPC T3WPDIF T3WPHAR T3WPTRC
TEIGAPC	TEIGGIO	TEIGAPC
TEILGAPC	TEILGGIO	TEILGAPC
TMAGAPC	TMAGGIO	TMAGAPC
TRPTTR	TRPTTR	TRPTTR
UV2PTUV	GEN2LLN0 PH1PTRC UV2PTUV	PH1PTRC UV2PTUV
VMMXU	VMMXU	VMMXU
VMSQI	VMSQI	VMSQI
VNMMXU	VNMMXU	VNMMXU
VSGAPC	VSGGIO	VSGAPC
WRNCALH	WRNCALH	WRNCALH
ZCLCPSCH	ZCLCPLAL	ZCLCPSCH
Table continues on next page		

Function block name	Edition 1 logical nodes	Edition 2 logical nodes
ZCPSCH	ZCPSCH	ZCPSCH
ZCRWPSCH	ZCRWPSCH	ZCRWPSCH
ZCVPSOF	ZCVPSOF	ZCVPSOF
ZMFPDIS	ZMFLN0 PSFPDIS ZMFPDIS ZMFPTRC ZMMM XU	PSFPDIS PSFPDIS ZMFPDIS ZMFPTRC ZMMM XU

Section 2 Application

2.1 General IED application

The RET650 provides fast and selective protection, monitoring and control functions for two- and three-winding transformers, autotransformers, generator-transformer units and shunt reactors. The IED is designed to operate correctly over a wide frequency range in order to accommodate power system frequency variations during disturbances and generator startup and shutdown. Apparatus control for 3 circuit breakers is included.

A fast differential protection function with built-in transformer ratio matching and vector group compensation makes this IED the ideal solution even for the most demanding applications. Since RET650 has very low requirements on the main CTs, no interposing CTs are required. The differential protection function is provided with 2nd harmonic and waveform-blocking restraint features to avoid tripping for magnetizing inrush current, and 5th harmonic restraint to avoid tripping for overexcitation.

The differential function offers a high sensitivity for low-level internal faults. The unique and innovative sensitive differential protection feature of the RET650 provides the best possible coverage for internal turn-to-turn winding faults, based on the theory of symmetrical components.

A low impedance restricted earth-fault protection function is available as a complimentary sensitive and fast main protection against winding earth faults. This function includes a directional zero-sequence current criterion for additional security.

Tripping from pressure relief/Buchholz and temperature devices can be implemented through the IED's binary inputs, where trip signal conditioning can be performed (pulsing, lockout, additional logics, etc.). The binary inputs are thoroughly stabilized against disturbances in order to prevent incorrect operations due to DC system capacitive discharges or DC earth faults, for example.

Versatile phase, earth and zero sequence overcurrent functions with directional capability provide further alternative backup protections. Thermal overload with two time-constants and breaker failure protection is also available.

A built-in disturbance and event recorder provides valuable data to the user about status and operation for post-fault disturbance analysis.

Two pre-configured packages have been defined for the following applications:

- Single breaker, 2 winding transformer (A01)
- Single breaker, 2/3 winding transformer (A05)

The package is configured and ready for direct use. Analog and control circuits have been predefined and other signals need to be applied as required for each application. The pre-configured IED can be changed and adapted to suit specific applications with the application configuration tool.

The IED can be used in applications with the IEC/UCA 61850-9-2LE process bus with up to four Merging Units (MU). Each MU has eight analogue channels, four current and four voltages. Conventional input transformer module and Merging Unit channels can be mixed freely in your application.

Forcing of binary inputs and outputs is a convenient way to test wiring in substations as well as testing configuration logic in the IEDs. Basically it means that all binary inputs and outputs on the IED I/O modules (BOM, BIM and IOM) can be forced to arbitrary values.

Central Account Management is an authentication infrastructure that offers a secure solution for enforcing access control to IEDs and other systems within a substation. This incorporates management of user accounts, roles and certificates and the distribution of such, a procedure completely transparent to the user.

The Flexible Product Naming allows the customer to use an IED-vendor independent IEC 61850 model of the IED. This customer model will be used as the IEC 61850 data model, but all other aspects of the IED will remain unchanged (e.g., names on the local HMI and names in the tools). This offers significant flexibility to adapt the IED to the customers' system and standard solution.



The following tables list all the functions available in the IED. Those functions that are not exposed to the user or do not need to be configured are not described in this manual.

2.2

Main protection functions

Table 2: *Example of quantities*

2	= number of basic instances
0-3	= option quantities
3-A03	= optional function included in packages A03 (refer to ordering details)

IEC 61850 or function name	ANSI	Function description	Transformer	
			RET650 (A01)	RET650 (A05)
Differential protection				
T2WPDIF	87T	Transformer differential protection, two winding	1	
T3WPDIF	87T	Transformer differential protection, three winding		1
REFPDIF	87N	Restricted earth fault protection, low impedance	1	2

2.3 Back-up protection functions

IEC 61850 or function name	ANSI	Function description	Transformer	
			RET650 (A01)	RET650 (A05)
Current protection				
PHPIOC	50	Instantaneous phase overcurrent protection	2	3
OC4PTOC	51_67 ¹⁾	Directional phase overcurrent protection, four steps	2	3
EFPIOC	50N	Instantaneous residual overcurrent protection	2	3
EF4PTOC	51N 67N ²⁾	Directional residual overcurrent protection, four steps	2	3
TRPTTR	49	Thermal overload protection, two time constants	1	1
CCRBRF	50BF	Breaker failure protection	2	3
CCPDSC	52PD	Pole discordance protection	2	3
Voltage protection				
UV2PTUV	27	Two step undervoltage protection	1	1
OV2PTOV	59	Two step overvoltage protection	1	1
ROV2PTOV	59N	Two step residual overvoltage protection	1	1
OEXPVPH	24	Overexcitation protection	1	1
Frequency protection				
SAPTUF	81	Underfrequency protection	1	1
SAPTOF	81	Overfrequency protection	1	1
SAPFRC	81	Rate-of-change of frequency protection	1	1

1) 67 requires voltage

2) 67N requires voltage

2.4 Control and monitoring functions

IEC 61850 or function name	ANSI	Function description	Transformer	
			RET650 (A01)	RET650 (A05)
Control				
QCBAY		Bay control	1	1
LOCREM		Handling of LR-switch positions	1	1
LOCREMCTRL		LHMI control of PSTO	1	1
SXCBR		Circuit breaker	3	3
SCILO		Interlocking	2	3
SCSWI		Switch controller	2	3
XLNPROXY		Proxy for signals from switching device via GOOSE	6	9
TR1ATCC	90	Automatic voltage control for tapchanger, single control	1	1
TCMYLTC	84	Tap changer control and supervision, 6 binary inputs	1	1
SLGAPC		Logic rotating switch for function selection and LHMI presentation	15	15
VSGAPC		Selector mini switch	30	30
DPGAPC		Generic communication function for Double Point indication	16	16
SPC8GAPC		Single point generic control function 8 signals	5	5
AUTOBITS		Automation bits, command function for DNP3.0	3	3
SINGLECMD		Single command, 16 signals	4	4
I103CMD		Function commands for IEC 60870-5-103	1	1
I103GENCMD		Function commands generic for IEC 60870-5-103	50	50
I103POSCMD		IED commands with position and select for IEC 60870-5-103	50	50
I103POSCMDV		IED direct commands with position for IEC 60870-5-503	50	50
I103IEDCMD		IED commands for IEC 60870-5-103	1	1
I103USRCMD		Function commands user defined for IEC 60870-5-103	4	4
Secondary system supervision				
CCSSPVC	87	Current circuit supervision	2	3
FUFSPVC		Fuse failure supervision	1	1
Logic				
SMPPTRC	94	Tripping logic	6	6
SMAGAPC		General start matrix block	6	6
STARTCOMB		Start combinator	32	32
TMAGAPC		Trip matrix logic	12	12
ALMCALH		Logic for group alarm	5	5

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Transformer	
			RET650 (A01)	RET650 (A05)
WRNCALH		Logic for group warning	5	5
INDCALH		Logic for group indication	5	5
AND, GATE, INV, LLD, OR, PULSETIMER, RSMEMORY, SRMEMORY, TIMERSET, XOR		Basic configurable logic blocks (see Table 3)	40–420	40–420
FXDSIGN		Fixed signal function block	1	1
B16I		Boolean to integer conversion, 16 bit	18	18
BTIGAPC		Boolean to integer conversion with logical node representation, 16 bit	16	16
IB16		Integer to Boolean 16 conversion	18	18
ITBGAPC		Integer to Boolean 16 conversion with Logic Node representation	16	16
TEIGAPC		Elapsed time integrator with limit transgression and overflow supervision	12	12
INTCOMP		Comparator for integer inputs	30	30
REALCOMP		Comparator for real inputs	30	30

Table 3: *Total number of instances for basic configurable logic blocks*

Basic configurable logic block	Total number of instances
AND	280
GATE	40
INV	420
LLD	40
OR	298
PULSETIMER	40
RSMEMORY	40
SRMEMORY	40
TIMERSET	60
XOR	40

IEC 61850 or function name	ANSI	Function description	Transformer	
			RET650 (A01)	RET650 (A05)
Monitoring				
CVMMXN		Power system measurement	6	6
CMMXU		Current measurement	10	10
VMMXU		Voltage measurement phase-phase	6	6
CMSQI		Current sequence measurement	6	6

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Transformer	
			RET650 (A01)	RET650 (A05)
VMSQI		Voltage sequence measurement	6	6
VNMMXU		Voltage measurement phase-earth	6	6
AISVBAS		General service value presentation of analog inputs	1	1
SSIMG	63	Insulation supervision for gas medium	21	21
SSIML	71	Insulation supervision for liquid medium	3	3
SSCBR		Circuit breaker condition monitoring	6	9
EVENT		Event function	20	20
DRPRDRE, A1RADR- A4RADR, B1RBDR- B22RBDR		Disturbance report	1	1
SPGAPC		Generic communication function for single point indication	64	64
SP16GAPC		Generic communication function for single point indication 16 inputs	16	16
MVGAPC		Generic communication function for measured values	24	24
BINSTATREP		Logical signal status report	3	3
RANGE_XP		Measured value expander block	66	66
I103MEAS		Measurands for IEC 60870-5-103	1	1
I103MEASUSR		Measurands user defined signals for IEC 60870-5-103	3	3
I103AR		Function status auto-recloser for IEC 60870-5-103	1	1
I103EF		Function status earth-fault for IEC 60870-5-103	1	1
I103FLTPROT		Function status fault protection for IEC 60870-5-103	1	1
I103IED		IED status for IEC 60870-5-103	1	1
I103SUPERV		Supervision status for IEC 60870-5-103	1	1
I103USRDEF		Status for user defined signals for IEC 60870-5-103	20	20
L4UFCNT		Event counter with limit supervision	30	30
TEILGAPC		Running hour meter	6	6
Metering				
PCFCNT		Pulse-counter logic	16	16
ETPMTR		Function for energy calculation and demand handling	6	6

2.5 Communication

IEC 61850 or function name	ANSI	Function description	Transformer	
			RET650 (A01)	RET650 (A05)
Station communication				
LONSPA, SPA		SPA communication protocol	1	1
ADE		LON communciation protocol	1	1
HORZCOMM		Network variables via LON	1	1
PROTOCOL		Operation selection between SPA and IEC 60870-5-103 for SLM	1	1
RS485PROT		Operation selection for RS485	1	1
RS485GEN		RS485	1	1
DNPGEN		DNP3.0 communication general protocol	1	1
CHSERRS485		DNP3.0 for EIA-485 communication protocol	1	1
CH1TCP, CH2TCP, CH3TCP, CH4TCP		DNP3.0 for TCP/IP communication protocol	1	1
CHSEROPT		DNP3.0 for TCP/IP and EIA-485 communication protocol	1	1
MSTSER		DNP3.0 serial master	1	1
MST1TCP, MST2TCP, MST3TCP, MST4TCP		DNP3.0 for TCP/IP communication protocol	1	1
DNPFREC		DNP3.0 fault records for TCP/IP and EIA-485 communication protocol	1	1
IEC 61850-8-1		IEC 61850	1	1
GOOSEINTLKRCV		Horizontal communication via GOOSE for interlocking	59	59
GOOSEBINRCV		GOOSE binary receive	16	16
GOOSEDPRCV		GOOSE function block to receive a double point value	64	64
GOOSEINTRCV		GOOSE function block to receive an integer value	32	32
GOOSEMVRCV		GOOSE function block to receive a measurand value	60	60
GOOESPRCV		GOOSE function block to receive a single point value	64	64
GOOSEXLNRCV		GOOSE function block to receive a switching device	6	9
MULTICMDRCV/ MULTICMDSND		Multiple command and transmit	60/10	60/10
OPTICAL103		IEC 60870-5-103 Optical serial communication	1	1
RS485103		IEC 60870-5-103 serial communication for RS485	1	1

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Transformer	
			RET650 (A01)	RET650 (A05)
AGSAL		Generic security application component	1	1
LD0LLN0		IEC 61850 LD0 LLN0	1	1
SYSLLN0		IEC 61850 SYS LLN0	1	1
LPHD		Physical device information	1	1
PCMACCS		IED configuration protocol	1	1
SECALARM		Component for mapping security events on protocols such as DNP3 and IEC103	1	1
FSTACCS		Field service tool access	1	1
		IEC 61850-9-2 Process bus communication, 4 merging units	1-P31	1-P31
ACTIVLOG		Activity logging	1	1
ALTRK		Service tracking	1	1
PRP		IEC 62439-3 Parallel redundancy protocol	1-P23	1-P23
HSR		IEC 62439-3 High-availability seamless redundancy	1-P24	1-P24
PTP		Precision time protocol	1	1
FRONTSTATUS		Access point diagnostic for front Ethernet port	1	1
SCHLCCH		Access point diagnostic for non-redundant Ethernet port	4	4
RCHLCCH		Access point diagnostic for redundant Ethernet ports	2	2
DHCP		DHCP configuration for front access point	1	1
QUALEXP		IEC 61850 quality expander	32	32

2.6 Basic IED functions

Table 4: Basic IED functions

IEC 61850 or function name	Description
INTERRSIG	Self supervision with internal event list
TIMESYNCHGEN	Time synchronization module
BININPUT, SYNCHCAN, SYNCHGPS, SYNCHCMPPS, SYNCHLON, SYNCHPPH, SYNCHPPS, SNTP, SYNCHSPA	Time synchronization
PTP	Precision time protocol
TIMEZONE	Time synchronization
IRIG-B	Time synchronization
Table continues on next page	

IEC 61850 or function name	Description
SETGRPS	Number of setting groups
ACTVGRP	Parameter setting groups
TESTMODE	Test mode functionality
CHNGLCK	Change lock function
SMBI	Signal matrix for binary inputs
SMBO	Signal matrix for binary outputs
SMAI1 - SMAI12	Signal matrix for analog inputs
3PHSUM	Summation block 3 phase
ATHSTAT	Authority status
ATHCHK	Authority check
AUTHMAN	Authority management
FTPACCS	FTP access with password
GBASVAL	Global base values for settings
ALTMS	Time master supervision
ALTIM	Time management
COMSTATUS	Protocol diagnostic

Table 5: *Local HMI functions*

IEC 61850 or function name	ANSI	Description
LHMICTRL		Local HMI signals
LANGUAGE		Local human machine language
SCREEN		Local HMI Local human machine screen behavior
FNKEYTY1–FNKEYTY5 FNKEYMD1– FNKEYMD5		Parameter setting function for HMI in PCM600
LEDGEN		General LED indication part for LHMI
OPENCLOSE_LED		LHMI LEDs for open and close keys
GRP1_LED1– GRP1_LED15 GRP2_LED1– GRP2_LED15 GRP3_LED1– GRP3_LED15		Basic part for CP HW LED indication module

Section 3 Configuration

3.1 Description of configuration RET650

3.1.1 Introduction

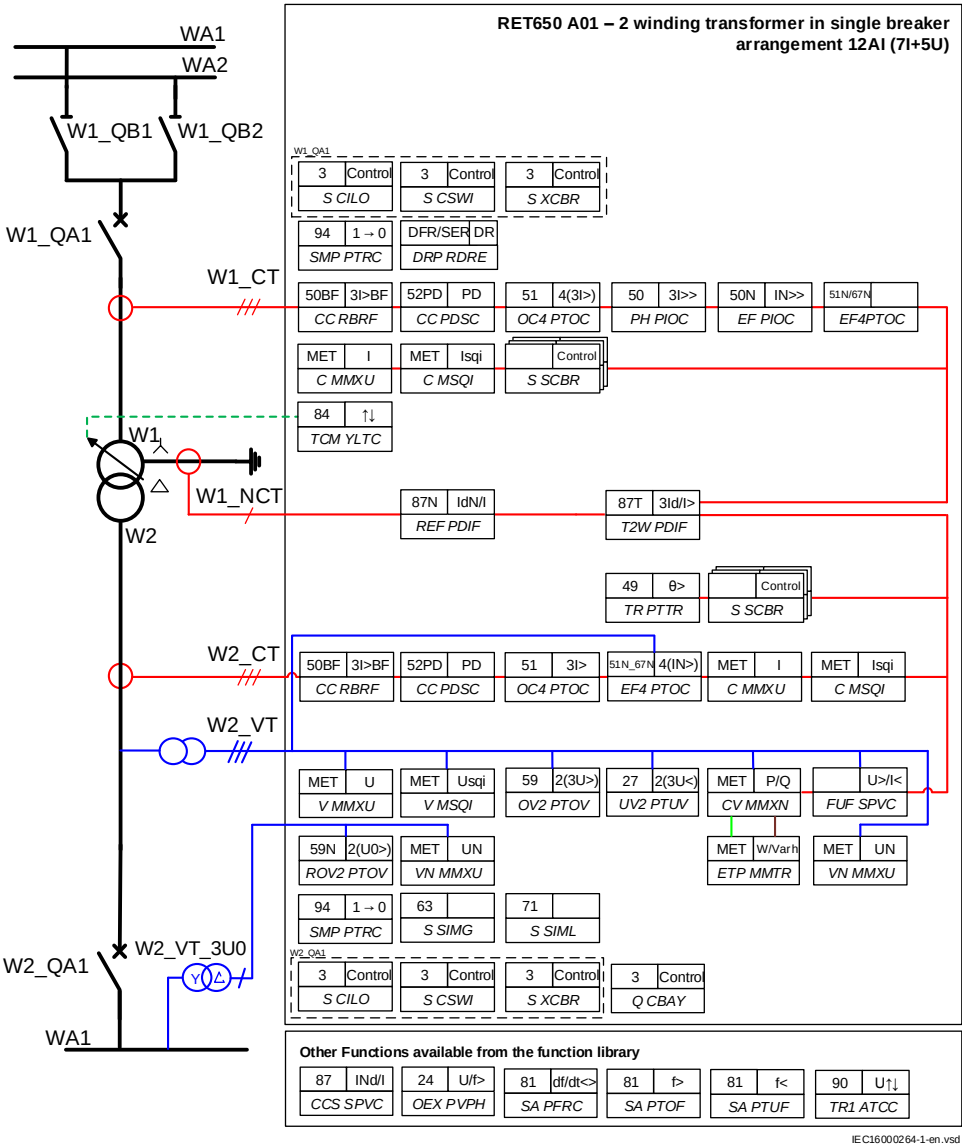
The basic delivery includes one binary input module and one binary output module, which is sufficient for the default configured IO to trip and close circuit breaker. All IEDs can be reconfigured with the help of the application configuration tool in PCM600. The IED can be adapted to special applications and special logic can be developed, such as logic for automatic opening of disconnectors and closing of ring bays, automatic load transfer from one busbar to the other, and so on.

The basic IED configuration is provided with the signal matrix, single line diagram and the application configuration prepared for the functions included in the product by default. All parameters should be verified by the customer, since these are specific to the system, object or application. Optional functions and optional IO ordered will not be configured at delivery. It should be noted that the standard only includes one binary input and one binary output module and only the key functions such as tripping are connected to the outputs in the signal matrix tool. The required total IO must be calculated and specified at ordering.

The configurations are as far as found necessary provided with application comments to explain why the signals have been connected in the special way. On request, ABB is available to support the re-configuration work, either directly or to do the design checking.

3.1.1.1 Description of A01

Two-winding transformer in single breaker arrangements:



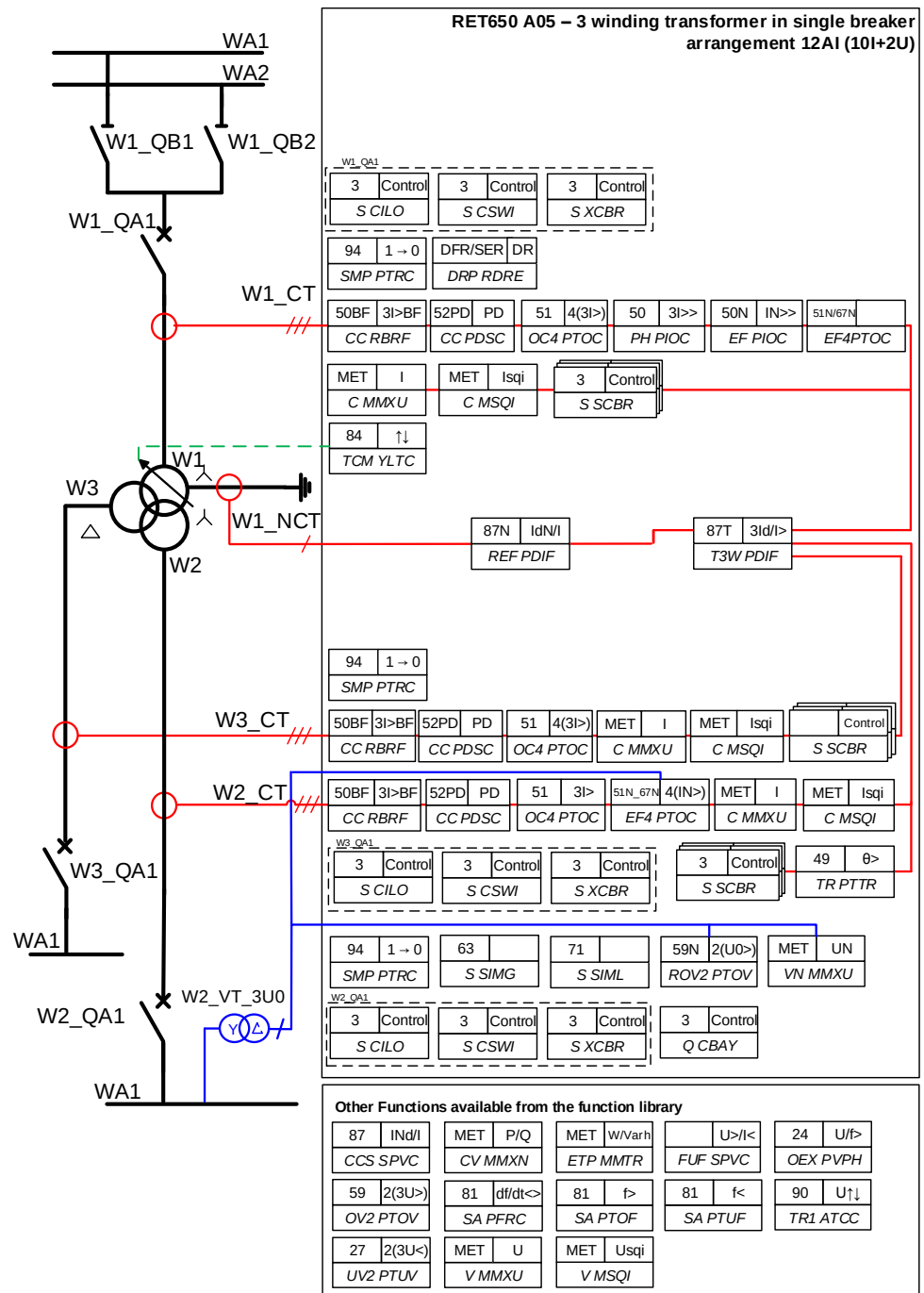
IEC16000264-1-en.vsd

Figure 2: Configuration diagram for configuration A01

3.1.1.2

Description of A05

Three-winding transformer in single breaker arrangements.



IEC15000405-3-en.vsd

Figure 3: Configuration diagram for configuration A05

Section 4 Analog inputs

4.1 Introduction

Analog input channels must be configured and set properly in order to get correct measurement results and correct protection operations. For power measuring, all directional and differential functions, the directions of the input currents must be defined in order to reflect the way the current transformers are installed/connected in the field (primary and secondary connections). Measuring and protection algorithms in the IED use primary system quantities. Setting values are in primary quantities as well and it is important to set the data about the connected current and voltage transformers properly.

An AISVBAS reference *PhaseAngleRef* can be defined to facilitate service values reading. This analog channel's phase angle will always be fixed to zero degrees and remaining analog channel's phase angle information will be shown in relation to this analog input. During testing and commissioning of the IED, the reference channel can be changed to facilitate testing and service values reading.



The IED has the ability to receive analog values from primary equipment, that are sampled by Merging units (MU) connected to a process bus, via the IEC 61850-9-2 LE protocol.



The availability of VT inputs depends on the ordered transformer input module (TRM) type.

4.2 Setting guidelines



The available setting parameters related to analog inputs are depending on the actual hardware (TRM) and the logic configuration made in PCM600.

4.2.1 Setting of the phase reference channel

All phase angles are calculated in relation to a defined reference. An appropriate analog input channel is selected and used as phase reference. The parameter *PhaseAngleRef* defines the analog channel that is used as phase angle reference.

4.2.1.1 Example

4.2.2 Setting of current channels

The direction of a current to the IED is depending on the connection of the CT. Unless indicated otherwise, the main CTs are supposed to be star connected and can be connected with the earthing point to the object or from the object. This information must be set in the IED. The convention of the directionality is defined as follows: A positive value of current, power, and so on means that the quantity has the direction into the object and a negative value means direction out from the object. For directional functions the direction into the object is defined as Forward and the direction out from the object is defined as Reverse. See Figure 4

A positive value of current, power, and so on (forward) means that the quantity flows towards the object. A negative value of current, power, and so on (reverse) means that the quantity flows away from the object. See Figure 4.

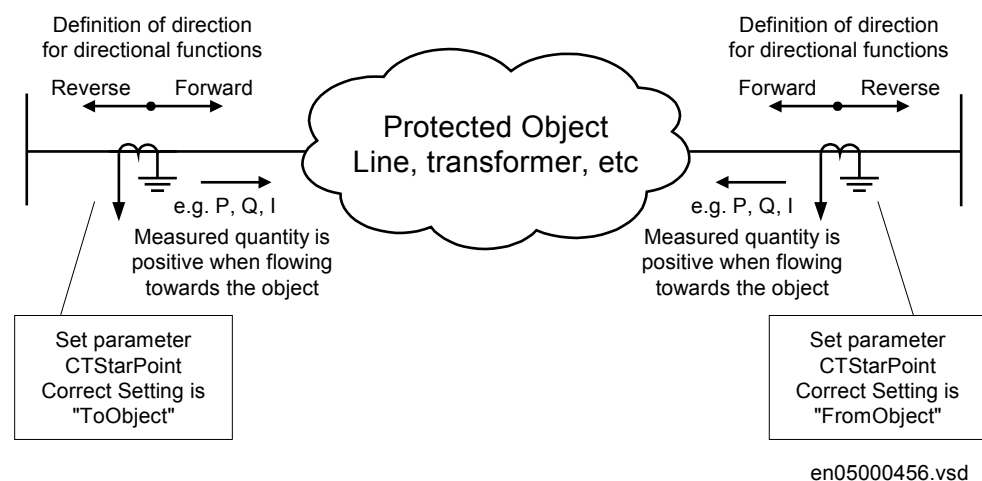


Figure 4: Internal convention of the directionality in the IED

With correct setting of the primary CT direction, *CTStarPoint* set to *FromObject* or *ToObject*, a positive quantities always flowing towards the protected object and a direction defined as Forward always is looking towards the protected object. The following examples show the principle.

4.2.2.1 Example 1

Two IEDs used for protection of two objects.

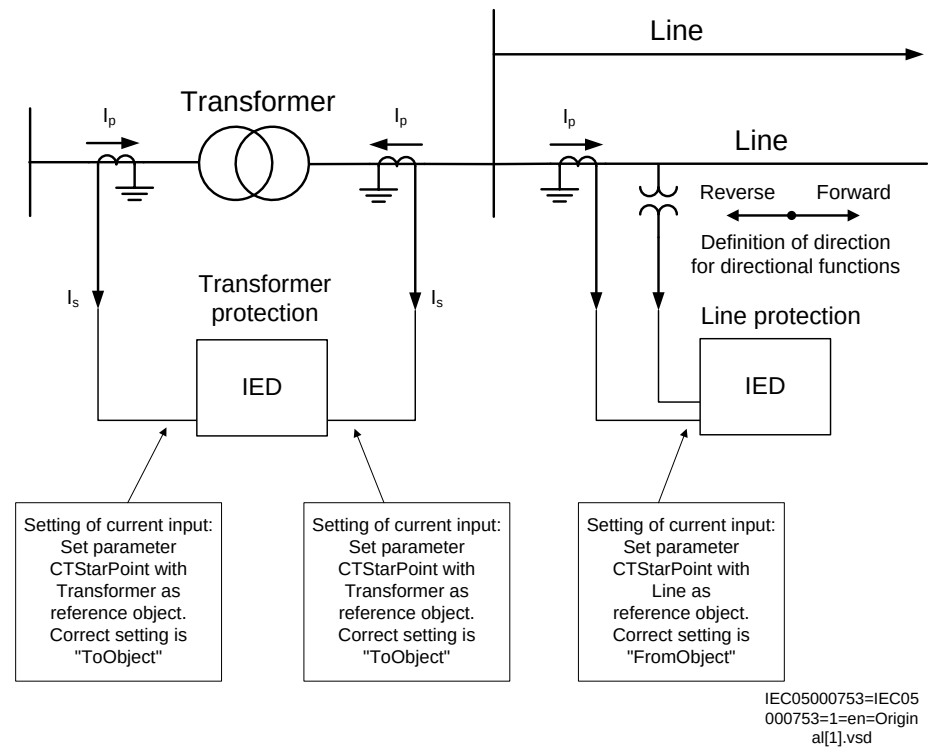


Figure 5: Example how to set CTStarPoint parameters in the IED

Figure 5 shows the normal case where the objects have their own CTs. The settings for CT direction shall be done according to the figure. To protect the line, direction of the directional functions of the line protection shall be set to *Forward*. This means that the protection is looking towards the line.

4.2.2.2

Example 2

Two IEDs used for protection of two objects and sharing a CT.

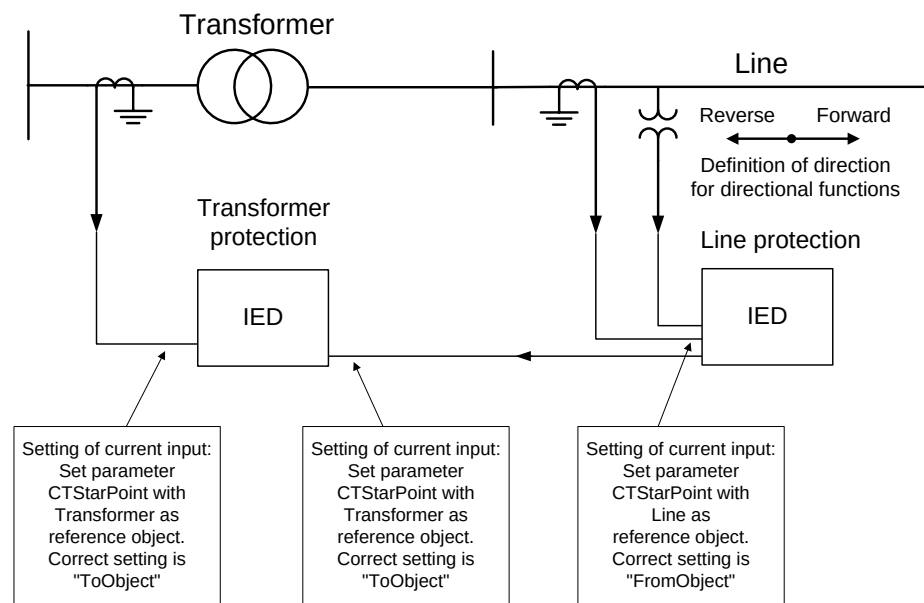


Figure 6: Example how to set CTStarPoint parameters in the IED

This example is similar to example 1, but here the transformer is feeding just one line and the line protection uses the same CT as the transformer protection does. The CT direction is set with different reference objects for the two IEDs though it is the same current from the same CT that is feeding the two IEDs. With these settings, the directional functions of the line protection shall be set to *Forward* to look towards the line.

4.2.2.3

Example 3

One IED used to protect two objects.

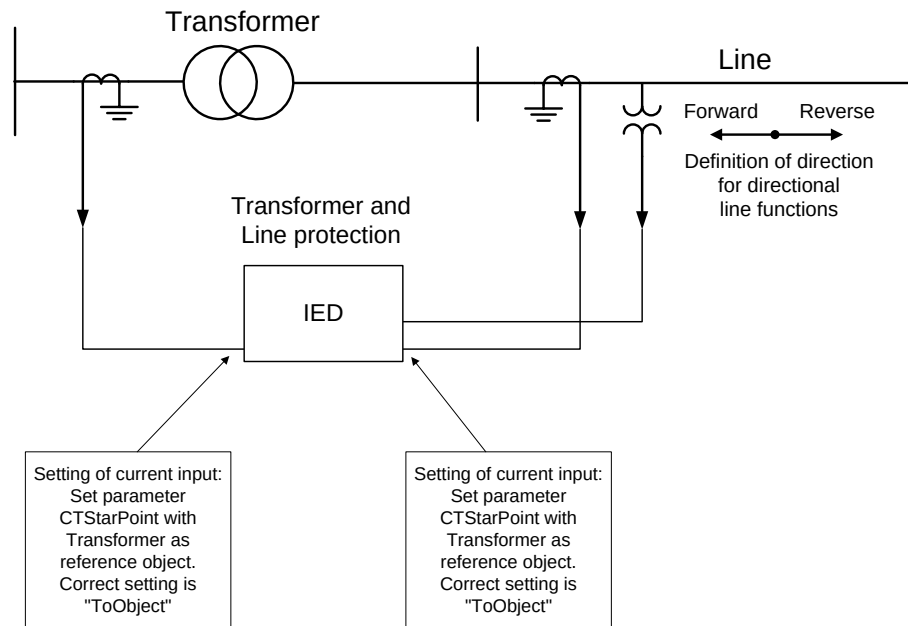


Figure 7: Example how to set CTStarPoint parameters in the IED

In this example, one IED includes both transformer and line protections and the line protection uses the same CT as the transformer protection does. For both current input channels, the CT direction is set with the transformer as reference object. This means that the direction *Forward* for the line protection is towards the transformer. To look towards the line, the direction of the directional functions of the line protection must be set to *Reverse*. The direction *Forward/Reverse* is related to the reference object that is the transformer in this case.

When a function is set to *Reverse* and shall protect an object in reverse direction, it shall be noted that some directional functions are not symmetrical regarding the reach in forward and reverse direction. It is in first hand the reach of the directional criteria that can differ. Normally it is not any limitation but it is advisable to have it in mind and check if it is acceptable for the application in question.

If the IED has sufficient number of analog current inputs, an alternative solution is shown in Figure 8. The same currents are fed to two separate groups of inputs and the line and transformer protection functions are configured to the different inputs. The CT direction for the current channels to the line protection is set with the line as reference object and the directional functions of the line protection shall be set to *Forward* to protect the line.

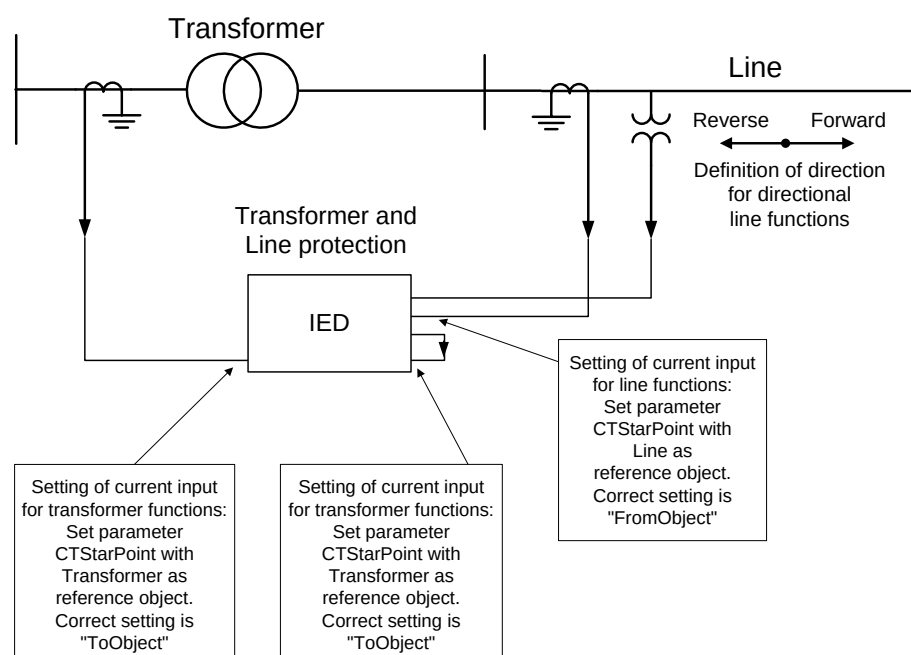


Figure 8: Example how to set CTStarPoint parameters in the IED

Figure 9:

For busbar protection, it is possible to set the *CTStarPoint* parameters in two ways.

The first solution will be to use busbar as a reference object. In that case for all CT inputs marked with 1 in Figure 9, set *CTStarPoint* = *ToObject*, and for all CT inputs marked with 2 in Figure 9, set *CTStarPoint* = *FromObject*.

The second solution will be to use all connected bays as reference objects. In that case for all CT inputs marked with 1 in Figure 9, set *CTStarPoint* = *FromObject*, and for all CT inputs marked with 2 in Figure 9, set *CTStarPoint* = *ToObject*.

Regardless which one of the above two options is selected, busbar differential protection will behave correctly.

The main CT ratios must also be set. This is done by setting the two parameters *CTsec* and *CTprim* for each current channel. For a 1000/1 A CT, the following settings shall be used:

- *CTprim* = 1000 (value in A)
- *CTsec* = 1 (value in A).

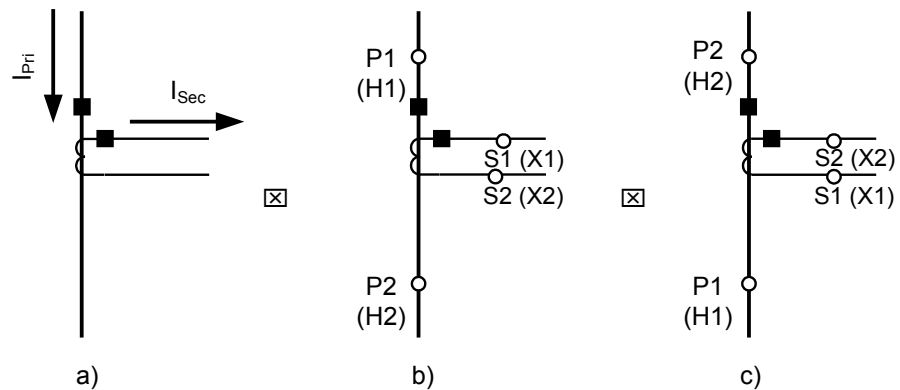
4.2.2.4

Examples on how to connect, configure and set CT inputs for most commonly used CT connections

Figure 10 defines the marking of current transformer terminals commonly used around the world:



In the SMAI function block, you have to set if the SMAI block is measuring current or voltage. This is done with the parameter: *AnalogInputType*: Current/Voltage. The *ConnectionType*: phase - phase/phase-earth and *GlobalBaseSel*.



en06000641.vsd

Figure 10: Commonly used markings of CT terminals

Where:

- a) is symbol and terminal marking used in this document. Terminals marked with a square indicates the primary and secondary winding terminals with the same (that is, positive) polarity
- b) and c) are equivalent symbols and terminal marking used by IEC (ANSI) standard for CTs. Note that for these two cases the CT polarity marking is correct!

It shall be noted that depending on national standard and utility practices, the rated secondary current of a CT has typically one of the following values:

- 1A
- 5A

However, in some cases, the following rated secondary currents are used as well:

- 2A
- 10A

The IED fully supports all of these rated secondary values.



It is recommended to:

- use 1A rated CT input into the IED in order to connect CTs with 1A and 2A secondary rating
- use 5A rated CT input into the IED in order to connect CTs with 5A and 10A secondary rating

4.2.2.5

Example on how to connect a star connected three-phase CT set to the IED

Figure 11 gives an example about the wiring of a star connected two-phase CT set to the IED. It gives an overview of the actions which are needed to make this measurement available to the built-in protection and control functions within the IED as well.



For correct terminal designations, see the connection diagrams valid for the delivered IED.

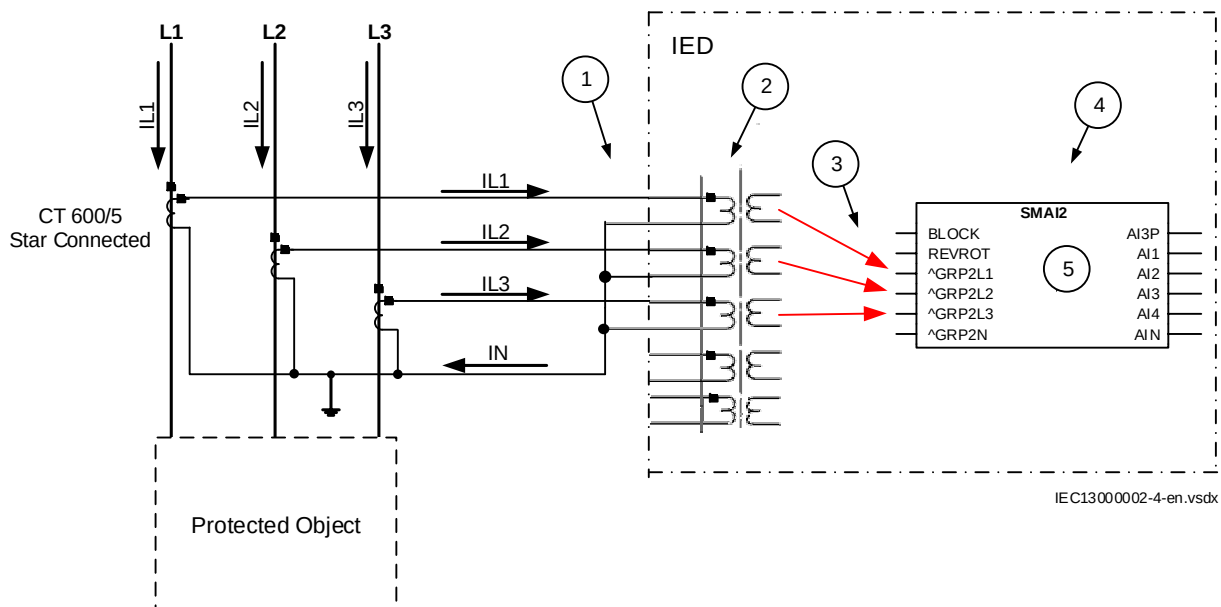


Figure 11: Star connected three-phase CT set with star point towards the protected object

Where:

- 1) The drawing shows how to connect three individual phase currents from a star connected three-phase CT set to the three CT inputs of the IED.
- 2) The current inputs are located in the TRM. It shall be noted that for all these current inputs the following setting values shall be entered for the example shown in Figure 11.
 - *CTprim=600A*
 - *CTsec=5A*
 - *CTStarPoint=ToObject*

Ratio of the first two parameters is only used inside the IED. The third parameter (CTStarPoint=ToObject) as set in this example causes no change on the measured currents. In other words, currents are already measured towards the protected object.
- 3) These three connections are the links between the three current inputs and the three input channels of the preprocessing function block 4). Depending on the type of functions, which need this current information, more than one preprocessing block might be connected in parallel to the same three physical CT inputs.
- 4) The preprocessing block that has the task to digitally filter the connected analog inputs and calculate:
 - fundamental frequency phasors for all three input channels
 - harmonic content for all three input channels
 - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block. For this application most of the preprocessing settings can be left to the default values. If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in power plants), then the setting parameters DFTRreference shall be set accordingly.

Section SMAI in this manual provides information on adaptive frequency tracking for the signal matrix for analogue inputs (SMAI).

- 5) AI3P in the SMAI function block is a grouped signal which contains all the data about the phases L1, L2, L3 and neutral quantity; in particular the data about fundamental frequency phasors, harmonic content and positive sequence, negative and zero sequence quantities are available.
AI1, AI2, AI3, AI4 are the output signals from the SMAI function block which contain the fundamental frequency phasors and the harmonic content of the corresponding input channels of the preprocessing function block.
AIN is the signal which contains the fundamental frequency phasors and the harmonic content of the neutral quantity. In this example, GRP2N is not connected so this data is calculated by the preprocessing function block on the basis of the inputs GRPL1, GRPL2 and GRPL3. If GRP2N is connected, the data reflects the measured value of GRP2N.

Another alternative is to have the star point of the three-phase CT set as shown in Figure 12:

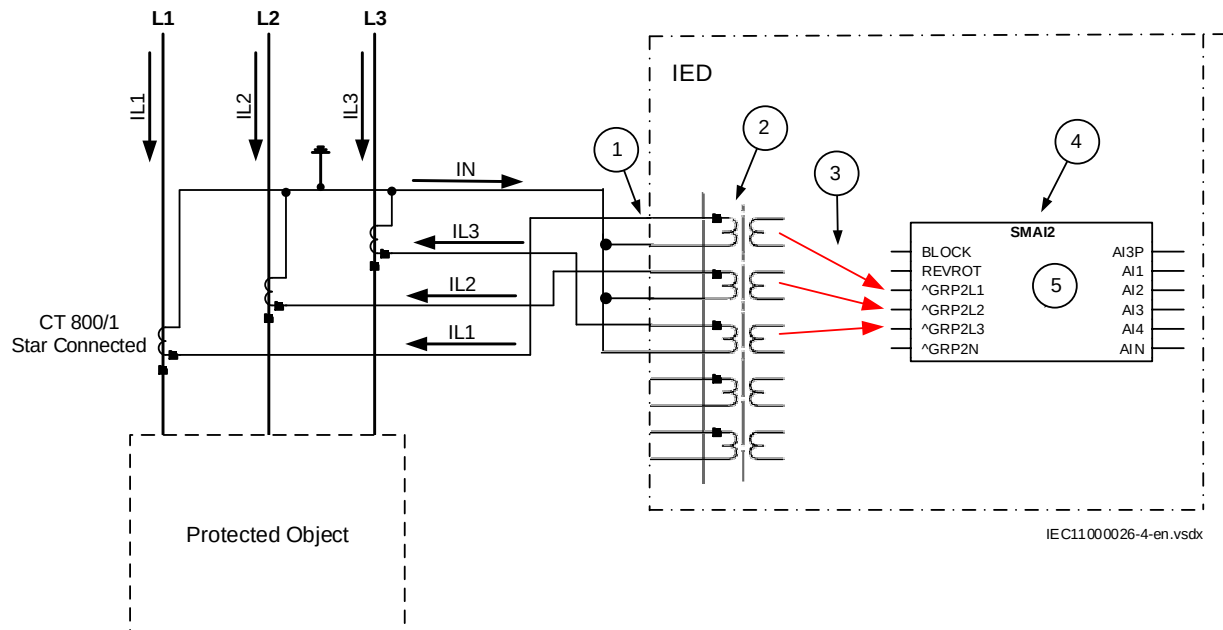


Figure 12: Star connected three-phase CT set with its star point away from the protected object

In the example, everything is done in a similar way as in the above described example (Figure 11). The only difference is the setting of the parameter *CTStarPoint* of the used current inputs on the TRM (item 2 in Figure 12 and 11):

- $CT_{prim}=600A$
- $CT_{sec}=5A$
- $CT_{StarPoint}=FromObject$

The ratio of the first two parameters is only used inside the IED. The third parameter as set in this example will negate the measured currents in order to ensure that the currents are measured towards the protected object within the IED.

A third alternative is to have the residual/neutral current from the three-phase CT set connected to the IED as shown in Figure 12.

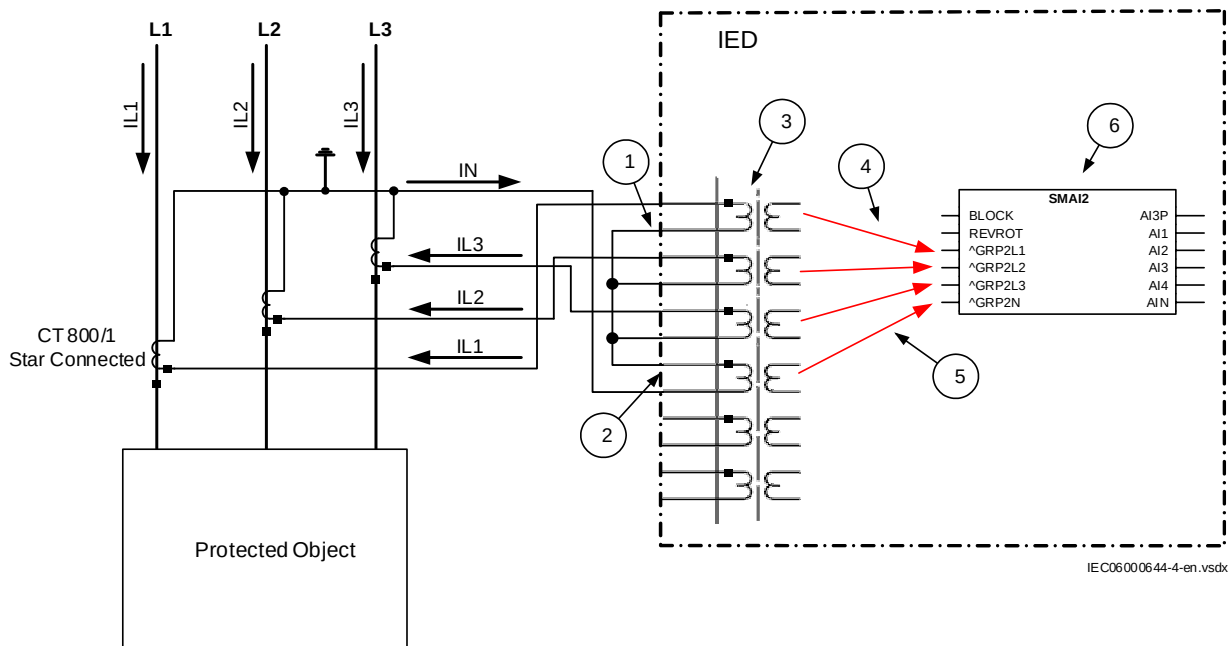


Figure 13: Star connected three-phase CT set with its star point away from the protected object and the residual/neutral current connected to the IED

Where:

- 1) Shows how to connect three individual phase currents from a star connected three-phase CT set to the three CT inputs of the IED.
- 2) Shows how to connect residual/neutral current from the three-phase CT set to the fourth input in the IED. It shall be noted that if this connection is not made, the IED will still calculate this current internally by vectorial summation of the three individual phase currents.
- 3) Is the TRM where these current inputs are located. It shall be noted that for all these current inputs the following setting values shall be entered.
 - $CT_{prim}=800A$
 - $CT_{sec}=1A$
 - $CT_{StarPoint}=FromObject$
 - $ConnectionType=Ph-N$

The ratio of the first two parameters is only used inside the IED. The third parameter as set in this example will have no influence on measured currents (that is, currents are already measured towards the protected object).

- 4) Are three connections made in the Signal Matrix tool (SMT) and Application configuration tool (ACT), which connects these three current inputs to the first three input channels on the preprocessing function block 6). Depending on the type of functions, which need this current information, more than one preprocessing block might be connected in parallel to these three CT inputs.

Table continues on next page

-
- 5) Is a connection made in the Signal Matrix tool (SMT) and Application configuration tool (ACT), which connects the residual/neutral current input to the fourth input channel of the preprocessing function block 6). Note that this connection in SMT shall not be done if the residual/neutral current is not connected to the IED.
- 6) Is a Preprocessing block that has the task to digitally filter the connected analog inputs and calculate:
- fundamental frequency phasors for all input channels
 - harmonic content for all input channels
 - positive, negative and zero sequence quantities by using the fundamental frequency phasors of the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application, most of the preprocessing settings can be left to the default values.

If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations), then the setting parameters DFTReference shall be set accordingly.

4.2.2.6

Example how to connect delta connected three-phase CT set to the IED

Figure 14 gives an example how to connect a delta connected three-phase CT set to the IED. It gives an overview of the required actions by the user in order to make this measurement available to the built-in protection and control functions in the IED as well.



For correct terminal designations, see the connection diagrams valid for the delivered IED.

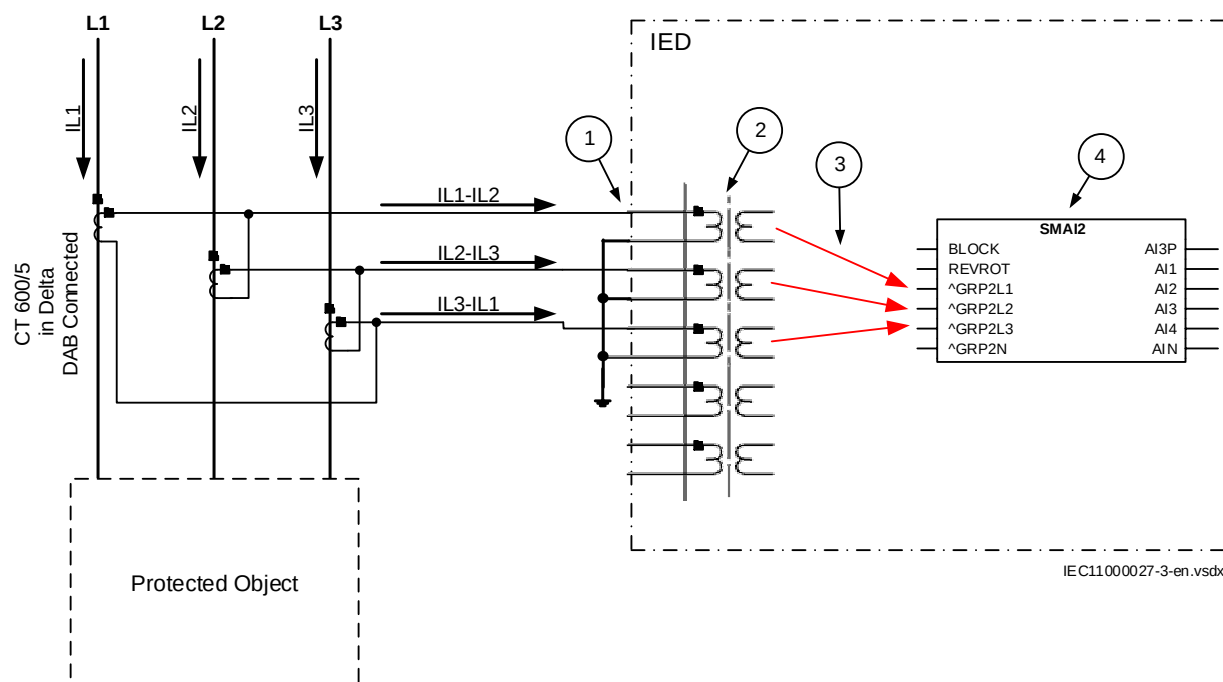


Figure 14: Delta DAB connected three-phase CT set

Where:

- 1) shows how to connect three individual phase currents from a delta connected three-phase CT set to three CT inputs of the IED.
- 2) is the TRM where these current inputs are located. It shall be noted that for all these current inputs the following setting values shall be entered.
 $CT_{prim}=600A$
 $CT_{sec}=5A$
 - $CTStarPoint=ToObject$
 - $ConnectionType=Ph-Ph$
- 3) are three connections made in Signal Matrix Tool (SMT), Application configuration tool (ACT), which connect these three current inputs to first three input channels of the preprocessing function block 4). Depending on the type of functions which need this current information, more than one preprocessing block might be connected in parallel to these three CT inputs.
- 4) is a Preprocessing block that has the task to digitally filter the connected analog inputs and calculate:
 - fundamental frequency phasors for all three input channels
 - harmonic content for all three input channels
 - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block. For this application most of the preprocessing settings can be left to the default values. If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters *DFTReference* shall be set accordingly.

Another alternative is to have the delta connected CT set as shown in figure [15](#):

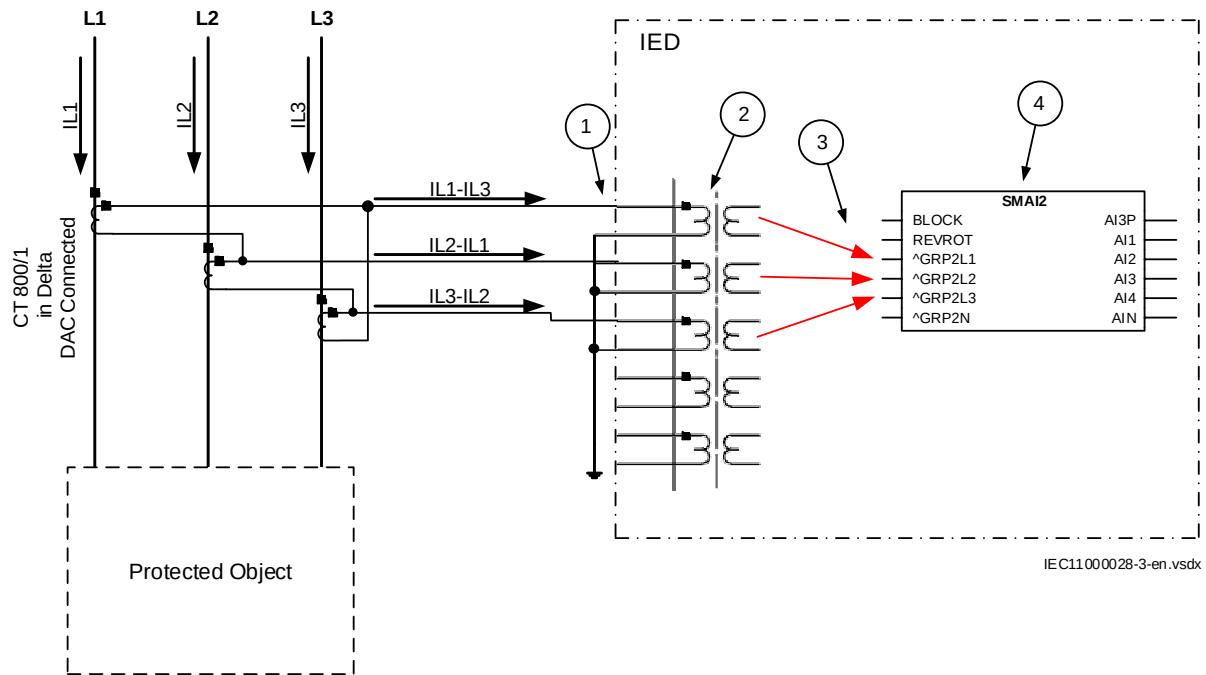


Figure 15: Delta DAC connected three-phase CT set

In this case, everything is done in a similar way as in the above described example, except that for all used current inputs on the TRM the following setting parameters shall be entered:

$$CT_{\text{prim}}=800\text{A}$$

$$CT_{\text{sec}}=1\text{A}$$

- $CTStarPoint=ToObject$
- $ConnectionType=Ph-Ph$

It is important to notice the references in SMAI. As inputs at *Ph-Ph* are expected to be L1L2, L2L3 respectively L3L1 we need to tilt 180° by setting *ToObject*.

4.2.2.7

Example how to connect single-phase CT to the IED

Figure 16 gives an example how to connect the single-phase CT to the IED. It gives an overview of the required actions by the user in order to make this measurement available to the built-in protection and control functions within the IED as well.



For correct terminal designations, see the connection diagrams valid for the delivered IED.

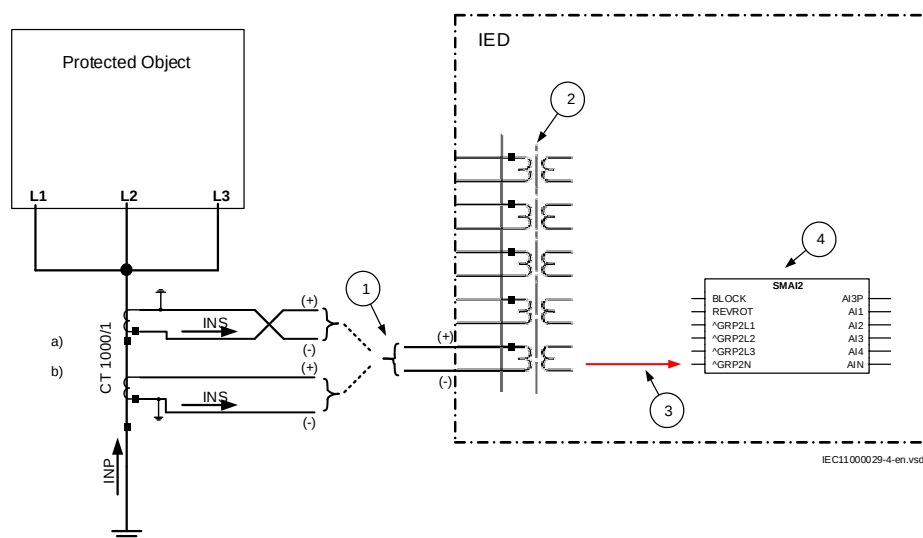


Figure 16: Connections for single-phase CT input

Where:

- 1) shows how to connect single-phase CT input in the IED.
- 2) is TRM where these current inputs are located. It shall be noted that for all these current inputs the following setting values shall be entered.
For connection (a) shown in Figure 16:
 $CT_{prim} = 1000\text{ A}$
 $CT_{sec} = 1\text{ A}$
 $CT_{StarPoint} = ToObject$
 For connection (b) shown in Figure 16:
 $CT_{prim} = 1000\text{ A}$
 $CT_{sec} = 1\text{ A}$
 $CT_{StarPoint} = FromObject$
- 3) shows the connection made in SMT tool, which connect this CT input to the fourth input channel of the preprocessing function block 4).
- 4) is a Preprocessing block that has the task to digitally filter the connected analog inputs and calculate values. The calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block.
If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the power plants) then the setting parameters $DFTR_{Reference}$ shall be set accordingly.

4.2.3 Relationships between setting parameter Base Current, CT rated primary current and minimum pickup of a protection IED

Note that for all line protection applications (e.g. distance protection or line differential protection) the parameter Base Current (i.e. *IBase* setting in the IED) used by the relevant protection function, shall always be set equal to the largest rated CT primary current among all CTs involved in the protection scheme. The rated CT primary current value is set as parameter *CTPrim* under the IED TRM settings.

For all other protection applications (e.g. generator, shunt reactor, shunt capacitor and transformer protection) it is typically desirable to set *IBase* parameter equal to the rated current of the protected object. However this is only recommended to do if the rated current of the protected object is within the range of 40% to 120% of the selected CT rated primary current. If for any reason (e.g. high maximum short circuit current) the rated current of the protected object is less than 40% of the rated CT primary current, it is strongly recommended to set the parameter *IBase* in the IED to be equal to the largest rated CT primary current among all CTs involved in the protection scheme and installed on the same voltage level. This will effectively make the protection scheme less sensitive; however, such measures are necessary in order to avoid possible problems with loss of the measurement accuracy in the IED.

Regardless of the applied relationship between the *IBase* parameter and the rated CT primary current, the corresponding minimum pickup of the function on the CT secondary side must always be verified. It is strongly recommended that the minimum pickup of any instantaneous protection function (e.g. differential, restricted earth fault, distance, instantaneous overcurrent, etc.) shall under no circumstances be less than 4% of the used IED CT input rating (i.e. 1A or 5A). This corresponds to 40mA secondary for IED 1A rated inputs and to 200mA secondary for IED 5A rated inputs used by the function. This shall be individually verified for all current inputs involved in the protection scheme.

Note that exceptions from the above 4% rule may be acceptable for very special applications (e.g. when Multipurpose filter SMAIHPAC is involved in the protection scheme).

4.2.4 Setting of voltage channels

As the IED uses primary system quantities, the main VT ratios must be known to the IED. This is done by setting the two parameters *VTsec* and *VTprim* for each voltage channel. The phase-to-phase value can be used even if each channel is connected to a phase-to-earth voltage from the VT.

4.2.4.1 Example

Consider a VT with the following data:

$$\frac{132kV}{\sqrt{3}} / \frac{110V}{\sqrt{3}}$$

(Equation 1)

The following setting should be used: $VT_{prim}=132$ (value in kV) $VT_{sec}=110$ (value in V)

4.2.4.2

Examples how to connect, configure and set VT inputs for most commonly used VT connections

Figure 17 defines the marking of voltage transformer terminals commonly used around the world.

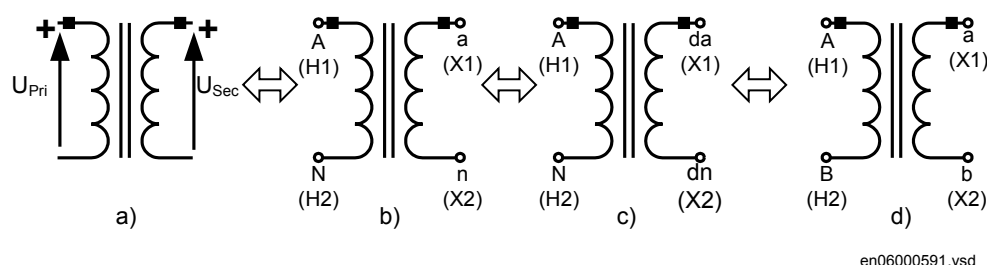


Figure 17: Commonly used markings of VT terminals

Where:

- a) is the symbol and terminal marking used in this document. Terminals marked with a square indicate the primary and secondary winding terminals with the same (positive) polarity
- b) is the equivalent symbol and terminal marking used by IEC (ANSI) standard for phase-to-earth connected VTs
- c) is the equivalent symbol and terminal marking used by IEC (ANSI) standard for open delta connected VTs
- d) is the equivalent symbol and terminal marking used by IEC (ANSI) standard for phase-to-phase connected VTs

It shall be noted that depending on national standard and utility practices the rated secondary voltage of a VT has typically one of the following values:

- 100 V
- 110 V
- 115 V
- 120 V
- 230 V

The IED fully supports all of these values and most of them will be shown in the following examples.

4.2.4.3

Examples on how to connect a three phase-to-earth connected VT to the IED

Figure 18 gives an example on how to connect a three phase-to-earth connected VT to the IED. It gives an overview of required actions by the user in order to make this measurement available to the built-in protection and control functions within the IED.



For correct terminal designations, see the connection diagrams valid for the delivered IED.

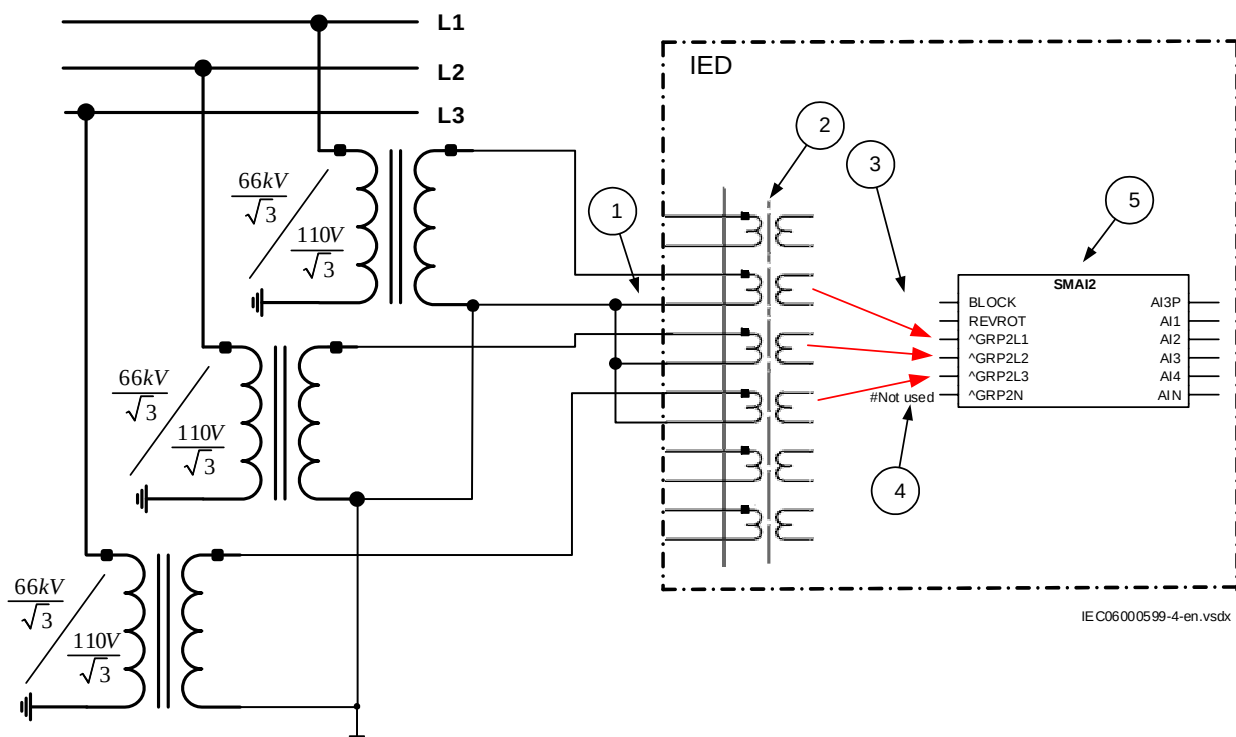


Figure 18: A Three phase-to-earth connected VT

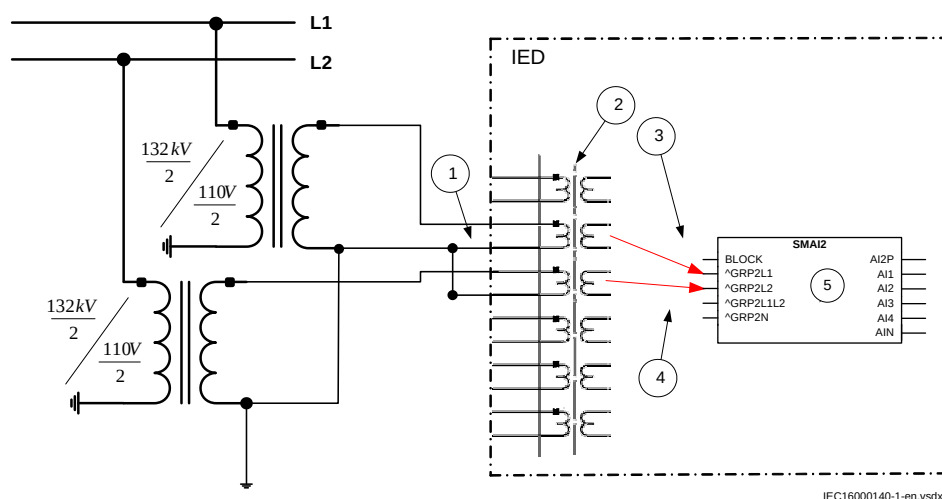


Figure 19: A two phase-to-earth connected VT

Where:

- 1) shows how to connect three secondary phase-to-earth voltages to three VT inputs on the IED
- 2) is the TRM where these three voltage inputs are located. For these three voltage inputs, the following setting values shall be entered:
 $VT_{prim} = 132 \text{ kV}$
 $VT_{sec} = 110 \text{ V}$
 Inside the IED, only the ratio of these two parameters is used. It shall be noted that the ratio of the entered values exactly corresponds to ratio of one individual VT.

$$\frac{66}{110} = \frac{66/\sqrt{3}}{110/\sqrt{3}}$$

(Equation 2)

Table continues on next page

- 3) are three connections made in Signal Matrix Tool (SMT), which connect these three voltage inputs to first three input channels of the preprocessing function block 5). Depending on the type of functions which need this voltage information, more than one preprocessing block might be connected in parallel to these three VT inputs.
- 4) shows that in this example the fourth (that is, residual) input channel of the preprocessing block is not connected in SMT tool. Thus the preprocessing block will automatically calculate $3U_0$ inside by vectorial sum from the three phase to earth voltages connected to the first three input channels of the same preprocessing block. Alternatively, the fourth input channel can be connected to open delta VT input, as shown in Figure 21.
- 5) is a Preprocessing block that has the task to digitally filter the connected analog inputs and calculate:
 - fundamental frequency phasors for all input channels
 - harmonic content for all input channels
 - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application most of the preprocessing settings can be left to the default values. However the following settings shall be set as shown here:
 $U_{Base}=66$ kV (that is, rated Ph-Ph voltage)
 If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters *DFTReference* shall be set accordingly.

4.2.4.4

Example on how to connect a phase-to-phase connected VT to the IED

Figure 20 gives an example how to connect a phase-to-phase connected VT to the IED. It gives an overview of the required actions by the user in order to make this measurement available to the built-in protection and control functions within the IED. It shall be noted that this VT connection is only used on lower voltage levels (that is, rated primary voltage below 40 kV).

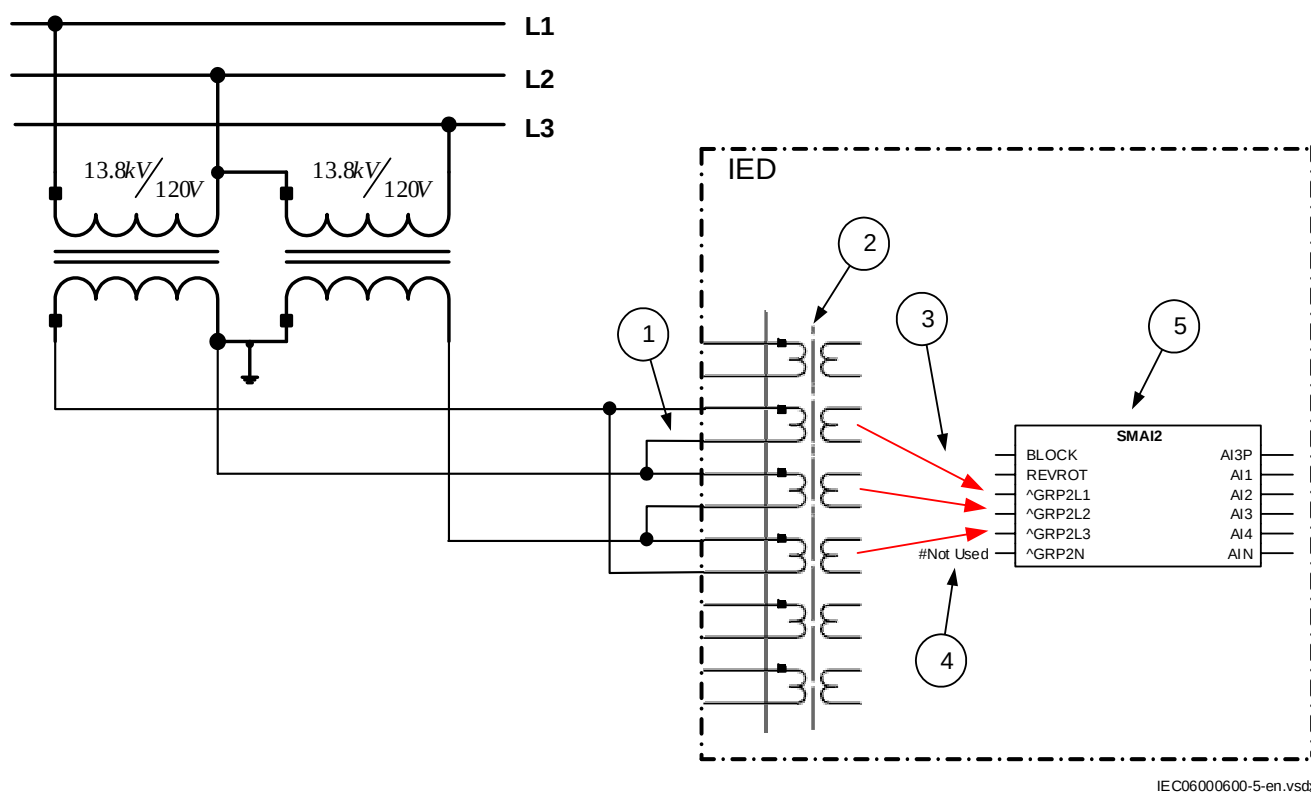


Figure 20: A Two phase-to-phase connected VT

Where:

- 1) shows how to connect the secondary side of a phase-to-phase VT to the VT inputs on the IED
- 2) is the TRM where these three voltage inputs are located. It shall be noted that for these three voltage inputs the following setting values shall be entered:
 $VT_{prim}=13.8\text{ kV}$
 $VT_{sec}=120\text{ V}$
 Please note that inside the IED only ratio of these two parameters is used.

Table continues on next page

- 3) are three connections made in the Signal Matrix tool (SMT), Application configuration tool (ACT), which connects these three voltage inputs to first three input channels of the preprocessing function block 5). Depending on the type of functions, which need this voltage information, more than one preprocessing block might be connected in parallel to these three VT inputs
- 4) shows that in this example the fourth (that is, residual) input channel of the preprocessing block is not connected in SMT. Note. If the parameters U_{L1} , U_{L2} , U_{L3} , U_N should be used the open delta must be connected here.
- 5) Preprocessing block has a task to digitally filter the connected analog inputs and calculate:
 - fundamental frequency phasors for all four input channels
 - harmonic content for all four input channels
 - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application most of the preprocessing settings can be left to the default values. However the following settings shall be set as shown here:

ConnectionType=Ph-Ph

UBase=13.8 kV

If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters *DFTReference* shall be set accordingly.

4.2.4.5

Example on how to connect an open delta VT to the IED for high impedance earthed or unearthen networks

Figure 21 gives an example about the wiring of an open delta VT to the IED for high impedance earthed or unearthen power systems. It shall be noted that this type of VT connection presents a secondary voltage proportional to $3U_0$ to the IED.

In case of a solid earth fault close to the VT location the primary value of $3U_0$ will be equal to:

$$3U_0 = \sqrt{3} \cdot U_{Ph-Ph} = 3 \cdot U_{Ph-N}$$

(Equation 3)

The primary rated voltage of an open Delta VT is always equal to U_{Ph-E} . Three series connected VT secondary windings gives a secondary voltage equal to three times the individual VT secondary winding rating. Thus the secondary windings of open delta VTs quite often have a secondary rated voltage equal to one third of the rated phase-to-phase VT secondary voltage (110/3V in this particular example).

Figure 21 gives overview of required actions by the user in order to make this measurement available to the built-in protection and control functions within the IED as well.

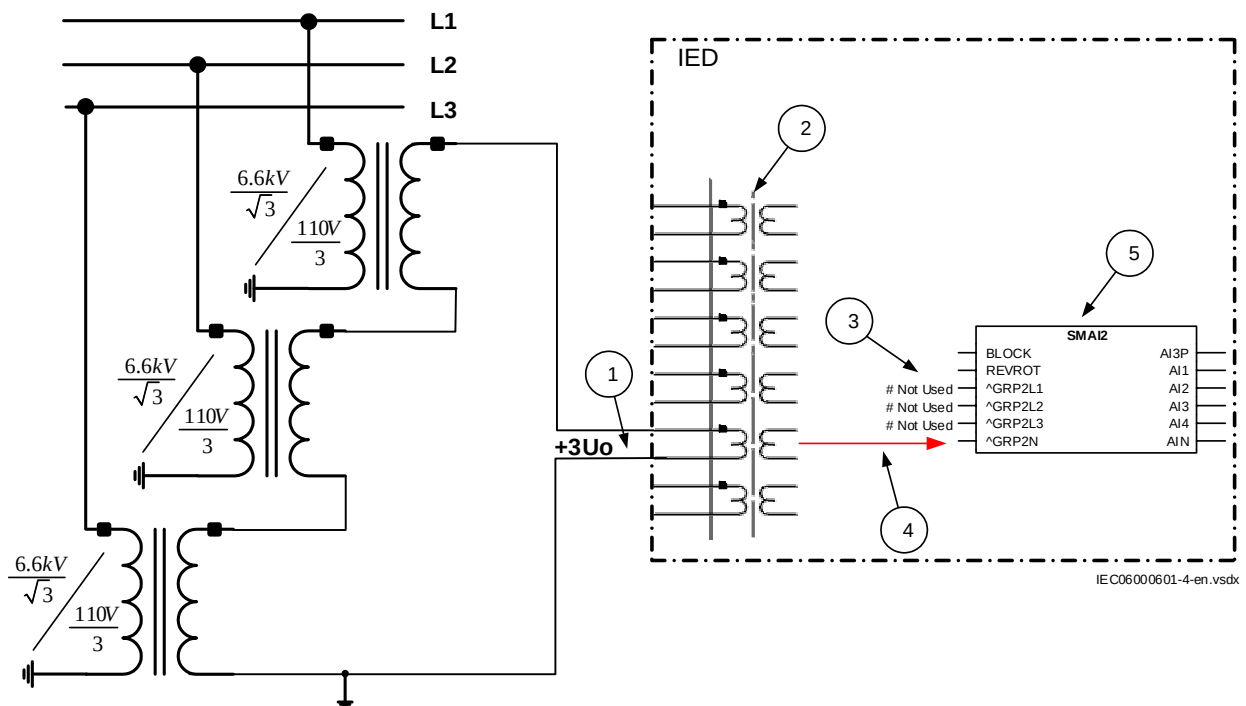


Figure 21: Open delta connected VT in high impedance earthed power system

Where:

- 1) shows how to connect the secondary side of the open delta VT to one VT input on the IED.



+3U0 shall be connected to the IED

- 2) is the TRM where this voltage input is located. It shall be noted that for this voltage input the following setting values shall be entered:

$$VT_{prim} = \sqrt{3} \cdot 6.6 = 11.43kV$$

(Equation 4)

$$VT_{sec} = 3 \cdot \frac{110}{3} = 110V$$

(Equation 5)

Inside the IED, only the ratio of these two parameters is used. It shall be noted that the ratio of the entered values exactly corresponds to ratio of one individual open delta VT.

$$\frac{\sqrt{3} \cdot 6.6}{110} = \frac{6.6/\sqrt{3}}{110/3}$$

(Equation 6)

- 3) shows that in this example the first three input channel of the preprocessing block is not connected in SMT tool or ACT tool.
- 4) shows the connection made in Signal Matrix Tool (SMT), Application configuration tool (ACT), which connect this voltage input to the fourth input channel of the preprocessing function block 5).
- 5) is a Preprocessing block that has the task to digitally filter the connected analog input and calculate:
- fundamental frequency phasors for all four input channels
 - harmonic content for all four input channels
 - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application most of the preprocessing settings can be left to the default values.

If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters *DFTR* shall be set accordingly.

4.2.4.6

Example how to connect the open delta VT to the IED for low impedance earthed or solidly earthed power systems

Figure 22 gives an example about the connection of an open delta VT to the IED for low impedance earthed or solidly earthed power systems. It shall be noted that this type of VT connection presents secondary voltage proportional to $3U_0$ to the IED.

In case of a solid earth fault close to the VT location the primary value of $3U_0$ will be equal to:

$$3U_0 = \frac{U_{Ph-Ph}}{\sqrt{3}} = U_{Ph-E}$$

(Equation 7)

The primary rated voltage of such VT is always equal to U_{Ph-E} . Therefore, three series connected VT secondary windings will give the secondary voltage equal only to one individual VT secondary winding rating. Thus the secondary windings of such open delta VTs quite often has a secondary rated voltage close to rated phase-to-phase VT secondary voltage, that is, 115V or $115/\sqrt{3}$ V as in this particular example. Figure 22 gives an overview of the actions which are needed to make this measurement available to the built-in protection and control functions within the IED.

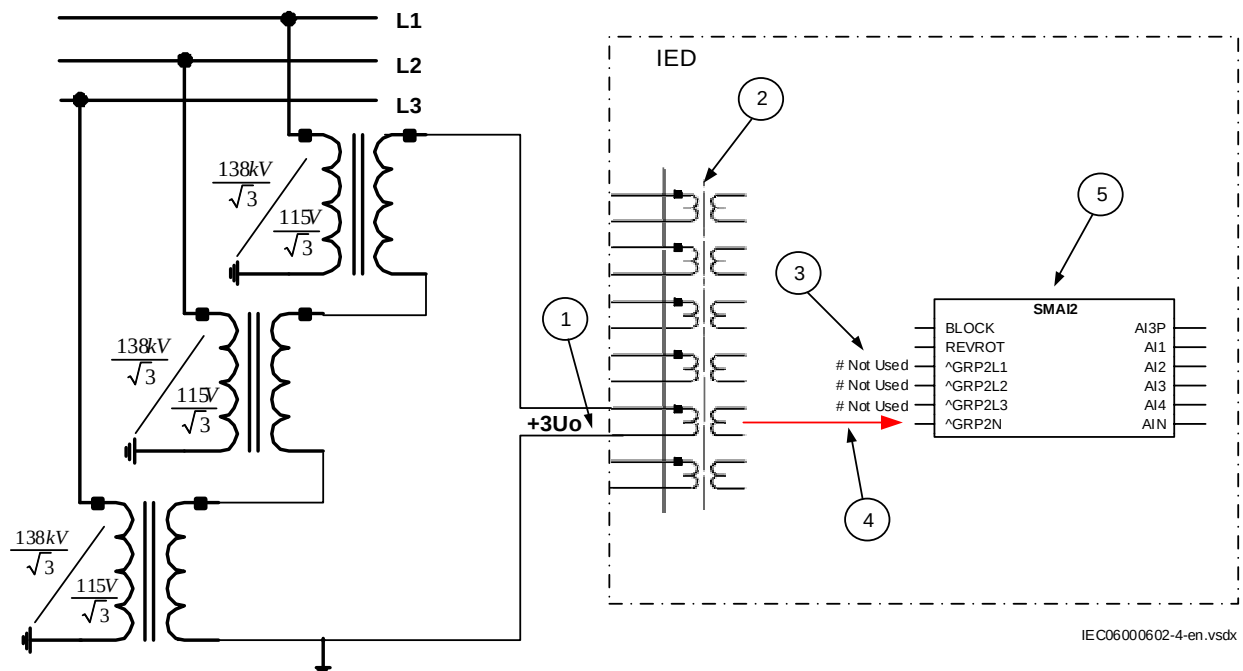


Figure 22: Open delta connected VT in low impedance or solidly earthed power system

Where:

- 1) shows how to connect the secondary side of open delta VT to one VT input in the IED.



+3U₀ shall be connected to the IED.

- 2) is TRM where this voltage input is located. It shall be noted that for this voltage input the following setting values shall be entered:

$$VT_{prim} = \sqrt{3} \cdot \frac{138}{\sqrt{3}} = 138kV$$

(Equation 8)

$$VT_{sec} = \sqrt{3} \cdot \frac{115}{\sqrt{3}} = 115V$$

(Equation 9)

Inside the IED, only the ratio of these two parameters is used. It shall be noted that the ratio of the entered values exactly corresponds to ratio of one individual open delta VT.

$$\frac{138}{115} = \frac{138/\sqrt{3}}{115/\sqrt{3}}$$

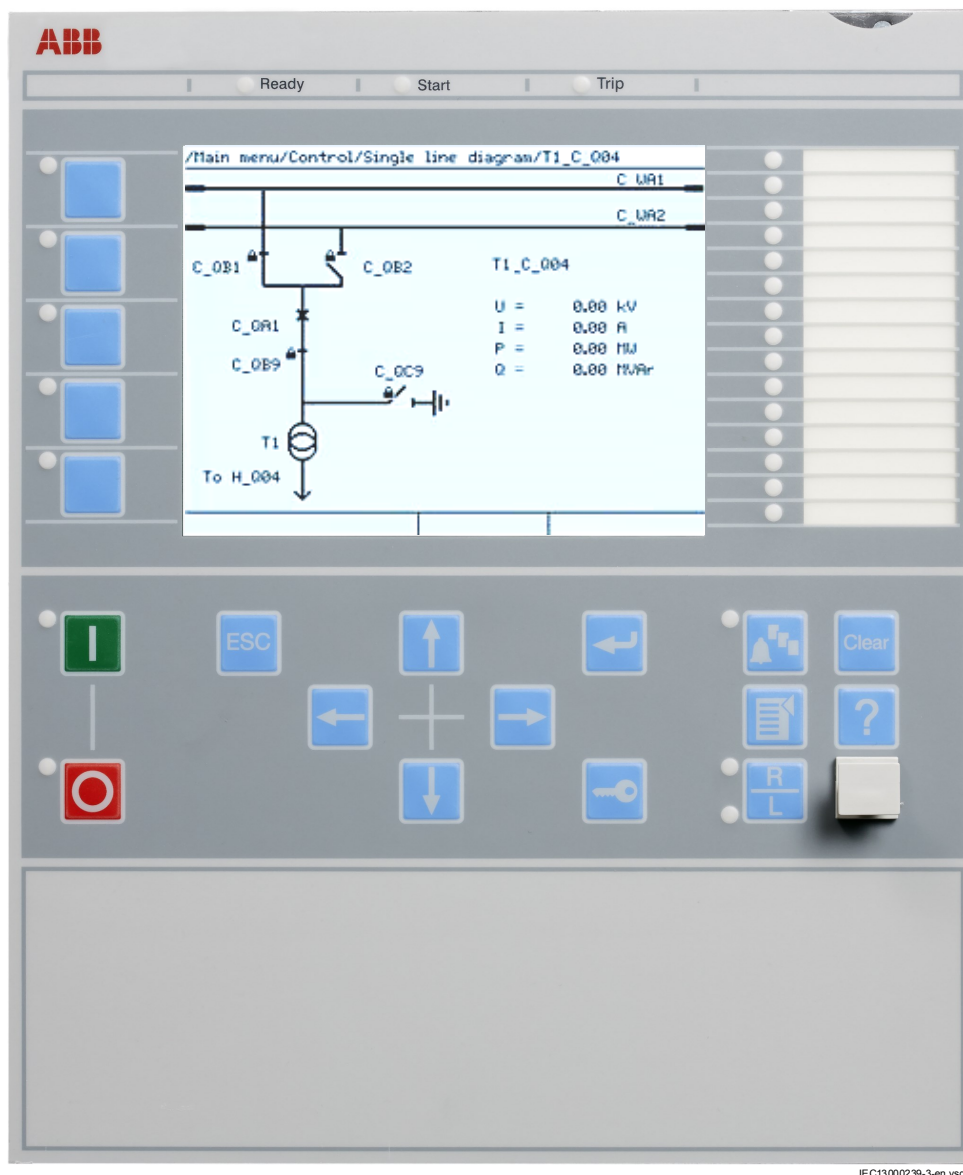
(Equation 10)

- 3) shows that in this example the first three input channel of the preprocessing block is not connected in SMT tool.
- 4) shows the connection made in Signal Matrix Tool (SMT), which connect this voltage input to the fourth input channel of the preprocessing function block 4).
- 5) preprocessing block has a task to digitally filter the connected analog inputs and calculate:
 - fundamental frequency phasors for all four input channels
 - harmonic content for all four input channels
 - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application most of the preprocessing settings can be left to the default values.

If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters *DFTReference* shall be set accordingly.

Section 5 Local HMI



IEC13000239-3-en.vsd

Figure 23: Local human-machine interface

The LHMI of the IED contains the following elements:

- Keypad
- Display (LCD)
- LED indicators
- Communication port for PCM600

The LHMI is used for setting, monitoring and controlling.

5.1 Display

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

The display view is divided into four basic areas.

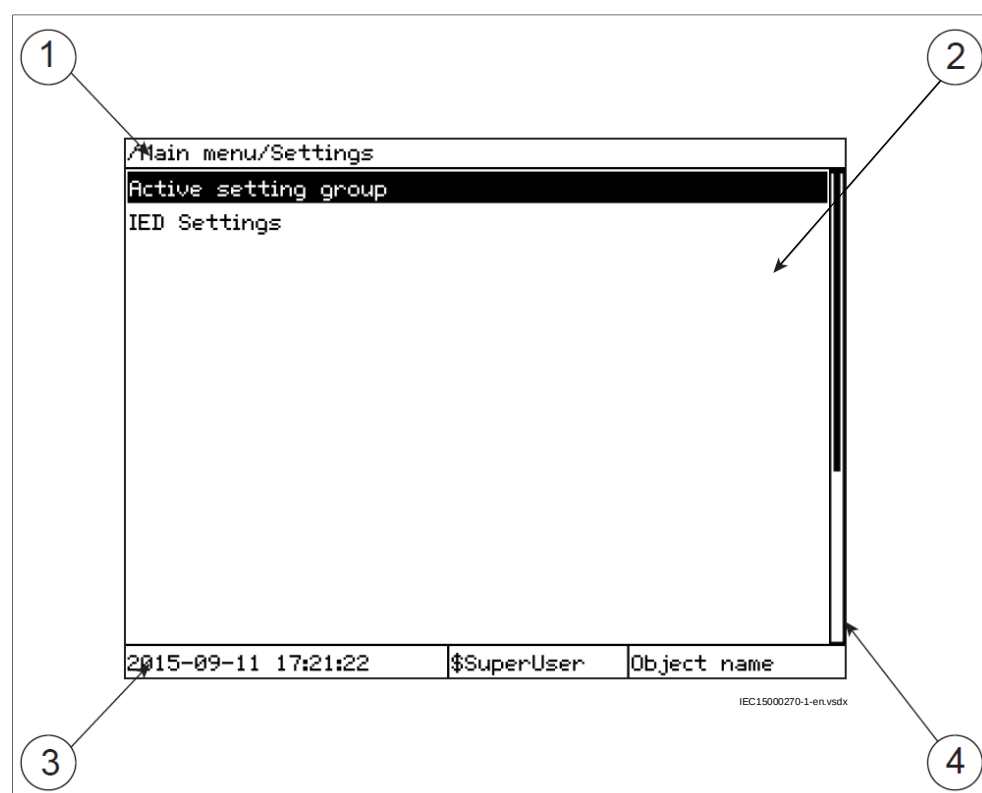
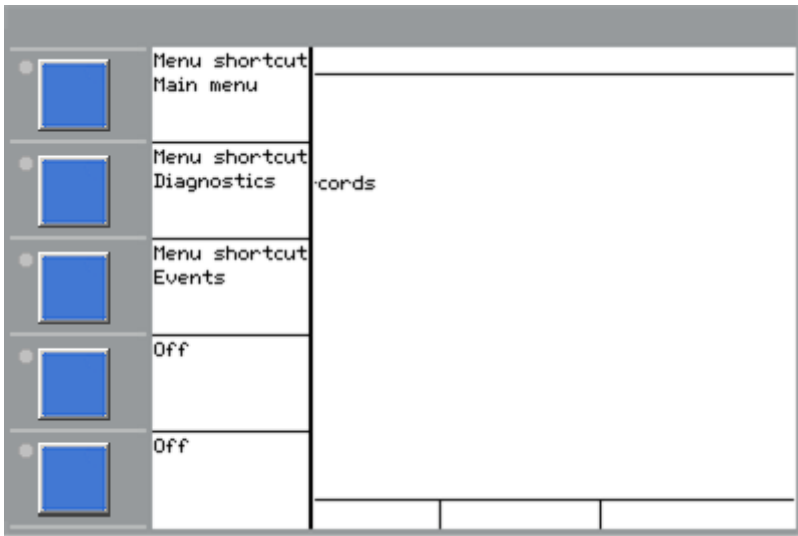


Figure 24: Display layout

- 1 Path
- 2 Content
- 3 Status
- 4 Scroll bar (appears when needed)

The function key button panel shows on request what actions are possible with the function buttons. Each function button has a LED indication that can be used as a

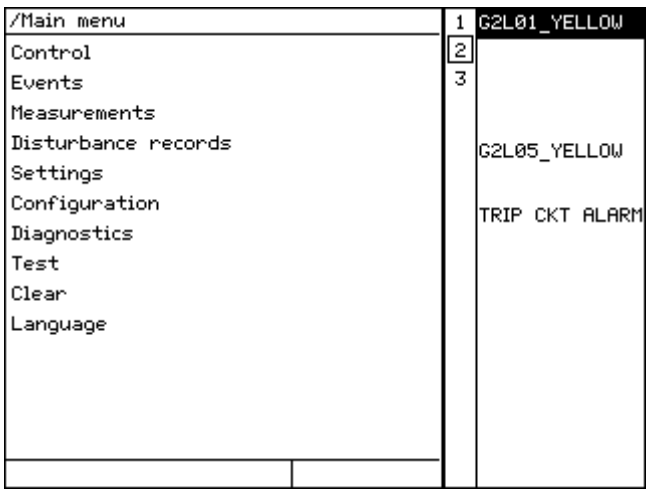
feedback signal for the function button control action. The LED is connected to the required signal with PCM600.



IEC13000281-1-en.vsd

Figure 25: Function button panel

The indication LED panel shows on request the alarm text labels for the indication LEDs. Three indication LED pages are available.



IEC13000240-1-en.vsd

Figure 26: Indication LED panel

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

5.2

LEDs

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

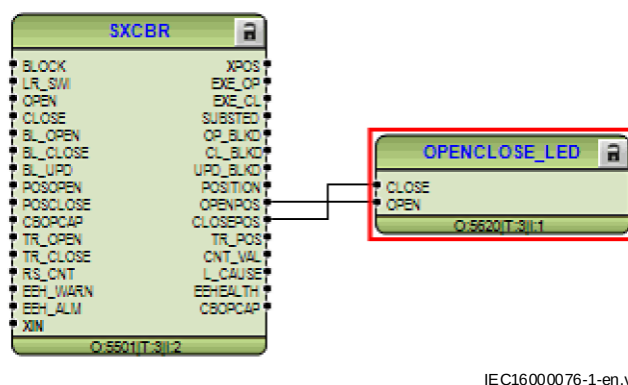
There are 15 programmable indication LEDs on the front of the LHMI. Each LED can indicate three states with the colors: green, yellow and red. The texts related to each three-color LED are divided into three panels.

There are 3 separate panels of LEDs available. The 15 physical three-color LEDs in one LED group can indicate 45 different signals. Altogether, 135 signals can be indicated since there are three LED groups. The LEDs are lit according to priority, with red being the highest and green the lowest priority. For example, if on one panel there is an indication that requires the green LED to be lit, and on another panel there is an indication that requires the red LED to be lit, the red LED takes priority and is lit. The LEDs can be configured with PCM600 and the operation mode can be selected with the LHMI or PCM600.

Information panels for the indication LEDs are shown by pressing the Multipage button. Pressing that button cycles through the three pages. A lit or un-acknowledged LED is indicated with a highlight. Such lines can be selected by using the Up/Down arrow buttons. Pressing the Enter key shows details about the selected LED. Pressing the ESC button exits from information pop-ups as well as from the LED panel as such.

The Multipage button has a LED. This LED is lit whenever any LED on any panel is lit. If there are un-acknowledged indication LEDs, then the Multipage LED blinks. To acknowledge LEDs, press the Clear button to enter the Reset menu (refer to description of this menu for details).

There are two additional LEDs which are next to the control buttons  and . These LEDs can indicate the status of two arbitrary binary signals by configuring the OPENCLOSE_LED function block. For instance, OPENCLOSE_LED can be connected to a circuit breaker to indicate the breaker open/close status on the LEDs.



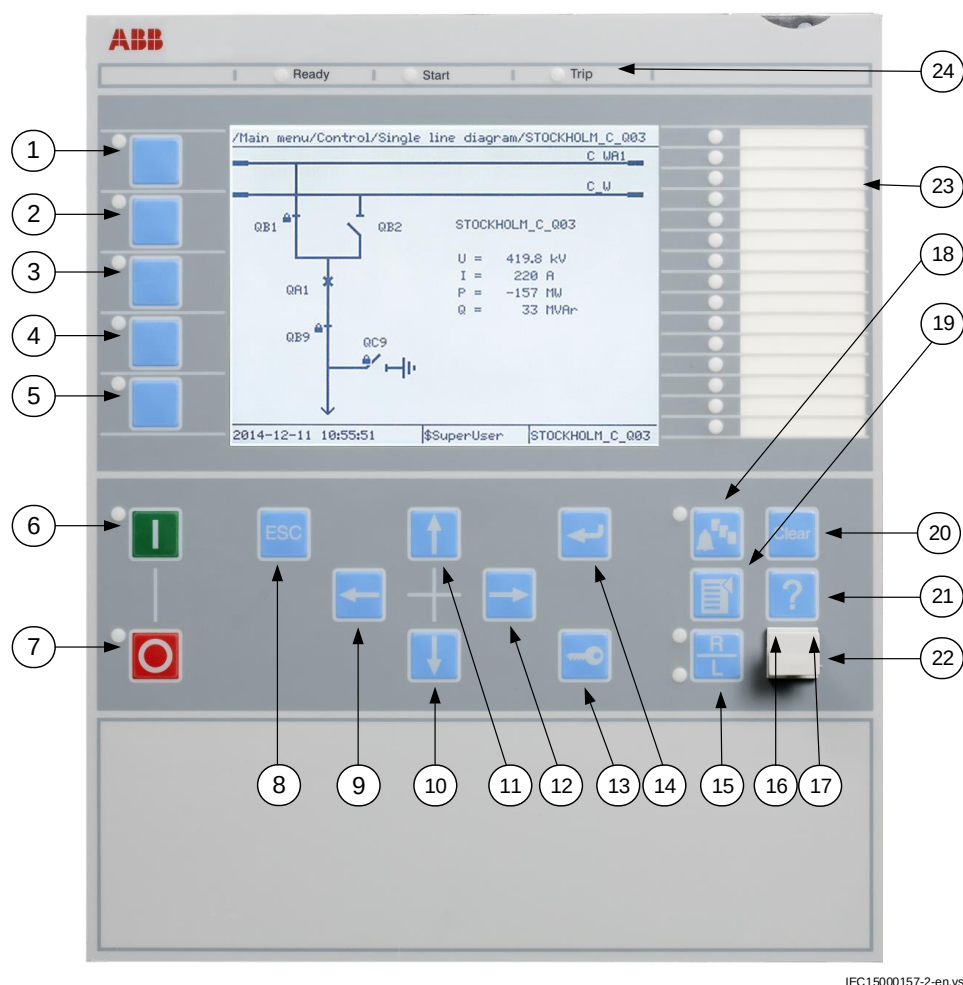
IEC16000076-1-en.vsd

Figure 27: *OPENCLOSE_LED connected to SXCBR*

5.3 Keypad

The LHMI keypad contains push-buttons which are used to navigate in different views or menus. The push-buttons are also used to acknowledge alarms, reset indications, provide help and switch between local and remote control mode.

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



IEC15000157-2-en.vsd

Figure 28: LHM keypad with object control, navigation and command push-buttons and RJ-45 communication port

- 1...5 Function button
- 6 Close
- 7 Open
- 8 Escape
- 9 Left
- 10 Down
- 11 Up
- 12 Right
- 13 Key
- 14 Enter
- 15 Remote/Local
- 16 Uplink LED
- 17 Not in use
- 18 Multipage
- 19 Menu

- 20 Clear
- 21 Help
- 22 Communication port
- 23 Programmable indication LEDs
- 24 IED status LEDs

5.4 Local HMI functionality

5.4.1 Protection and alarm indication

Protection indicators

The protection indicator LEDs are Ready, Start and Trip.



The start and trip LEDs are configured via the disturbance recorder. The yellow and red status LEDs are configured in the disturbance recorder function, DRPRDRE, by connecting a start or trip signal from the actual function to a BxRBDR binary input function block using the PCM600 and configure the setting to *Off*, *Start* or *Trip* for that particular signal.

Table 6: *Ready LED (green)*

LED state	Description
Off	Auxiliary supply voltage is disconnected.
On	Normal operation.
Flashing	Internal fault has occurred.

Table 7: *Start LED (yellow)*

LED state	Description
Off	Normal operation.
On	A protection function has started and an indication message is displayed. The start indication is latching and must be reset via communication, LHMI or binary input on the LEDGEN component. To open the reset menu on the LHMI, press  .
Flashing	The IED is in test mode and protection functions are blocked, or the IEC61850 protocol is blocking one or more functions. The indication disappears when the IED is no longer in test mode and blocking is removed. The blocking of functions through the IEC61850 protocol can be reset in Main menu/Test/Reset IEC61850 Mod . The yellow LED changes to either On or Off state depending on the state of operation.

Table 8: *Trip LED (red)*

LED state	Description
Off	Normal operation.
On	A protection function has tripped. An indication message is displayed if the auto-indication feature is enabled in the local HMI. The trip indication is latching and must be reset via communication, LHMI or binary input on the LEDGEN component. To open the reset menu on the LHMI, press  .
Flashing	Configuration mode.

Alarm indicators

The 15 programmable three-color LEDs are used for alarm indication. An individual alarm/status signal, connected to any of the LED function blocks, can be assigned to one of the three LED colors when configuring the IED.

Table 9: *Alarm indications*

LED state	Description
Off	Normal operation. All activation signals are off.
On	- Follow-S sequence: The activation signal is on. - LatchedColl-S sequence: The activation signal is on, or it is off but the indication has not been acknowledged. - LatchedAck-F-S sequence: The indication has been acknowledged, but the activation signal is still on. - LatchedAck-S-F sequence: The activation signal is on, or it is off but the indication has not been acknowledged. - LatchedReset-S sequence: The activation signal is on, or it is off but the indication has not been acknowledged.
Flashing	- Follow-F sequence: The activation signal is on. - LatchedAck-F-S sequence: The activation signal is on, or it is off but the indication has not been acknowledged. - LatchedAck-S-F sequence: The indication has been acknowledged, but the activation signal is still on.

5.4.2

Parameter management

The LHMI is used to access the relay parameters. Three types of parameters can be read and written.

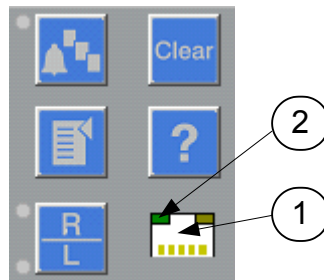
- Numerical values
- String values
- Enumerated values

Numerical values are presented either in integer or in decimal format with minimum and maximum values. Character strings can be edited character by character. Enumerated values have a predefined set of selectable values.

5.4.3 Front communication

The RJ-45 port in the LHMI enables front communication.

- The green uplink LED on the left is lit when the cable is successfully connected to the port.
- The yellow LED is not used; it is always off.



IEC13000280-1-en.vsd

Figure 29: RJ-45 communication port and green indicator LED

- 1 RJ-45 connector
- 2 Green indicator LED

The default IP address for the IED front port is 10.1.150.3 and the corresponding subnetwork mask is 255.255.254.0. It can be set through the local HMI path **Main menu/Configuration/Communication/Ethernet configuration/FRONT port/AP_FRONT**.

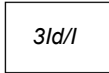
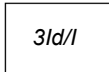


Do not connect the IED front port to a LAN. Connect only a single local PC with PCM600 to the front port. It is only intended for temporary use, such as commissioning and testing.

Section 6 Differential protection

6.1 Transformer differential protection T2WPDIF and T3WPDIF

6.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Transformer differential protection, two-winding	T2WPDIF		87T
Transformer differential protection, three-winding	T3WPDIF		87T

6.1.2 Application

The transformer differential protection is a unit protection. It serves as the main protection of transformers in case of winding failure. The protective zone of a differential protection includes the transformer itself, the bus-work or cables between the current transformers and the power transformer. When bushing current transformers are used for the differential IED, the protective zone does not include the bus-work or cables between the circuit breaker and the power transformer.

In some substations there is a current differential protection relay for the busbar. Such a busbar protection will include the bus-work or cables between the circuit breaker and the power transformer. Internal electrical faults are very serious and will cause immediate damage. Short circuits and earth faults in windings and terminals will normally be detected by the differential protection. Interturn faults are flashovers between conductors within the same physical winding. It is possible to detect interturn faults if sufficient number of turns are short-circuited. Interturn faults are the most difficult transformer winding fault to detect with electrical protections. A small interturn fault including just a few turns will result in an undetectable amount of current until it develops into an earth or phase fault. For this reason it is important that the differential protection has a high level of sensitivity and that it is possible to use a sensitive setting without causing unwanted operations during external faults.

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

A transformer differential protection compares the current flowing into the transformer with the current leaving the transformer. A correct analysis of fault conditions by the differential protection must take into consideration changes due to the voltage, current and phase angle caused by the protected transformer. Traditional transformer differential protection functions required auxiliary transformers for correction of the phase shift and ratio. The numerical microprocessor based differential algorithm as implemented in the IED compensates for both the turn-ratio and the phase shift internally in the software. No auxiliary current transformers are necessary.

The differential current should theoretically be zero during normal load or external faults if the turn-ratio and the phase shift are correctly compensated. However, there are several different phenomena other than internal faults that will cause unwanted and false differential currents. The main reasons for unwanted differential currents may be:

- mismatch due to varying tap changer positions
- different characteristics, loads and operating conditions of the current transformers
- zero sequence currents that only flow on one side of the power transformer
- normal magnetizing currents
- magnetizing inrush currents
- overexcitation magnetizing currents



The three winding transformer differential protection function can be also used in variety of application for two winding transformer protection. In such application, it is suggested to set the tertiary winding (W3) rated current and rated voltage to the exact same rating as secondary winding (W2).

6.1.3

Setting guidelines

The parameters for the Transformer differential protection function are set via the local HMI or Protection and Control IED Manager (PCM600).

6.1.3.1

Restrained and unrestrained differential protection

To make a differential IED as sensitive and stable as possible, restrained differential protections have been developed and are now adopted as the general practice in the protection of power transformers. The protection should be provided with a proportional bias, which makes the protection operate for a certain

percentage differential current related to the current through the transformer. This stabilizes the protection under through fault conditions while still permitting the system to have good basic sensitivity. The bias current can be defined in many different ways. One classical way of defining the bias current has been $I_{bias} = (I_1 + I_2) / 2$, where I_1 is the magnitude of the power transformer primary current, and I_2 the magnitude of the power transformer secondary current. However, it has been found that if the bias current is defined as the highest power transformer current this will reflect the difficulties met by the current transformers much better. The differential protection function uses the highest current of all restrain inputs as bias current. For applications where the power transformer rated current and the CT primary rated current can differ considerably, (applications with T-connections), measured currents in the T connections are converted to pu value using the rated primary current of the CT, but one additional "measuring" point is introduced as sum of this two T currents. This summed current is converted to pu value using the power transformer winding rated currents. After that the highest pu value is taken as bias current in pu. In this way the best possible combination between sensitivity and security for differential protection function with T connection is obtained. The main philosophy behind the principle with the operate bias characteristic is to increase the pickup level when the current transformers have difficult operating conditions. This bias quantity gives the best stability against an unwanted operation during external faults.

The usual practice for transformer protection is to set the bias characteristic to a value of at least twice the value of the expected spill current under through faults conditions. These criteria can vary considerably from application to application and are often a matter of judgment. The second slope is increased to ensure stability under heavy through fault conditions which could lead to increased differential current due to saturation of current transformers. Default settings for the operating characteristic with $I_{dMin} = 0.3pu$ of the power transformer rated current can be recommended as a default setting in normal applications. If the conditions are known more in detail, higher or lower sensitivity can be chosen. The selection of suitable characteristic should in such cases be based on the knowledge of the class of the current transformers, availability of information on the load tap changer position, short circuit power of the systems, and so on.

The second section of the restrain characteristic has an increased slope in order to deal with increased differential current due to additional power transformer losses during heavy loading of the transformer and external fault currents. The third section of the restrain characteristic decreases the sensitivity of the restrained differential function further in order to cope with CT saturation and transformer losses during heavy through faults. A default setting for the operating characteristic with $I_{dMin} = 0.3 * I_{Base}$ is recommended in normal applications. If the conditions are known in more detail, higher or lower sensitivity can be chosen. The selection of suitable characteristic should in such cases be based on the knowledge of the class of the current transformers, availability of information on the tap changer position, short circuit power of the systems, and so on.

Transformers can be connected to buses in such ways that the current transformers used for the differential protection will be either in series with the power

transformer windings or the current transformers will be in breakers that are part of the bus, such as a breaker-and-a-half or a ring bus scheme. For current transformers with primaries in series with the power transformer winding, the current transformer primary current for external faults will be limited by the transformer impedance. When the current transformers are part of the bus scheme, as in the breaker-and-a-half or the ring bus scheme, the current transformer primary current is not limited by the power transformer impedance. High primary currents may be expected. In either case, any deficiency of current output caused by saturation of one current transformer that is not matched by a similar deficiency of another current transformer will cause a false differential current to appear. Differential protection can overcome this problem if the bias is obtained separately from each set of current transformer circuits. It is therefore important to avoid paralleling of two or more current transformers for connection to a single restraint input. Each current connected to the IED is available for biasing the differential protection function.

The unrestrained operation level has a default value of $IdUnre = 10pu$, which is typically acceptable for most of the standard power transformer applications. In the following case, this setting need to be changed accordingly:

- When CT from "T-connection" are connected to IED, as in the breaker-and-a-half or the ring bus scheme, special care shall be taken in order to prevent unwanted operation of transformer differential IED for through-faults due to different CT saturation of "T-connected" CTs. Thus if such uneven saturation is a possibility it is typically required to increase unrestrained operational level to $IdUnre = 20-25pu$
- For differential applications on HV shunt reactors, due to the fact that there is no heavy through-fault condition, the unrestrained differential operation level can be set to $IdUnre = 1.75pu$

The overall operating characteristic of the transformer differential protection is shown in figure [30](#).

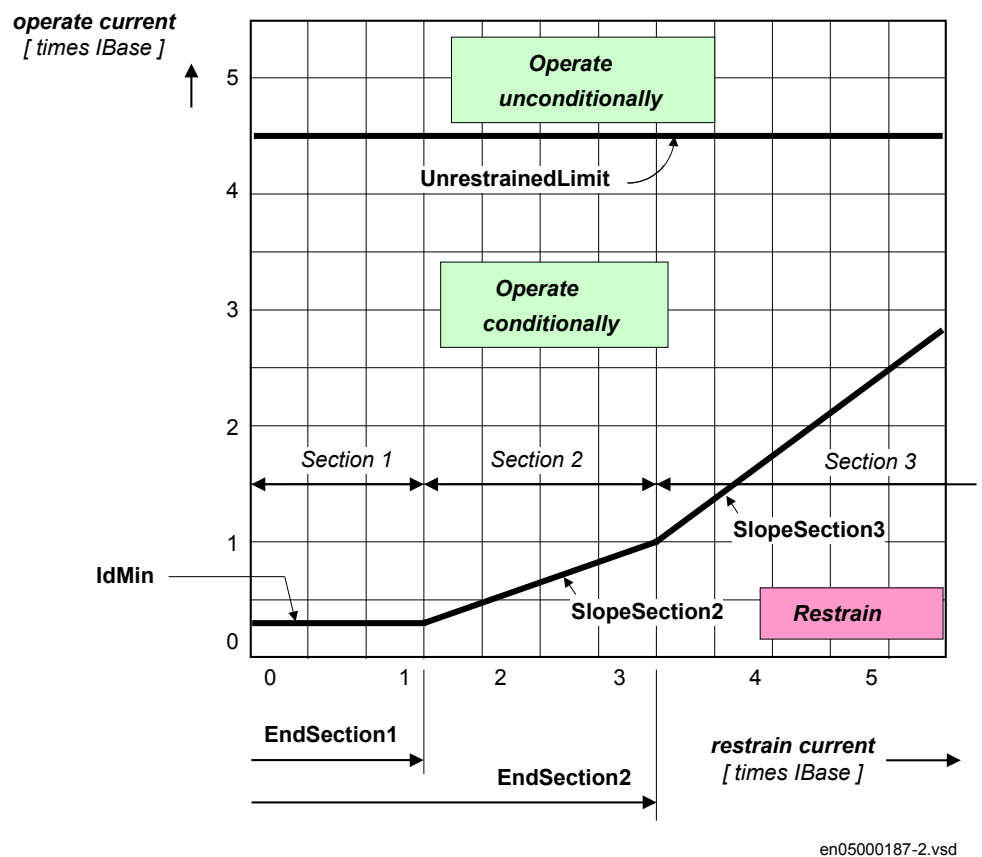


Figure 30: Representation of the restrained, and the unrestrained operate characteristics

$$\text{slope} = \frac{\Delta I_{\text{operate}}}{\Delta I_{\text{restrain}}} \cdot 100\%$$

(Equation 11)

and where the restrained characteristic is defined by the settings:

1. I_{dMin}
2. $EndSection1$
3. $EndSection2$
4. $SlopeSection2$
5. $SlopeSection3$

6.1.3.2

Elimination of zero sequence currents

A differential protection may operate undesirably due to external earth-faults in cases where the zero sequence current can flow on only one side of the power transformer, but not on the other side. This is the case when zero sequence current cannot be properly transformed to the other side of the power transformer. Power

transformer connection groups of the Yd or Dy type cannot transform zero sequence current. If a delta winding of a power transformer is earthed via an earthing transformer inside the zone protected by the differential protection there will be an unwanted differential current in case of an external earth-fault. The same is true for an earthed star winding. Even if both the star and delta winding are earthed, the zero sequence current is usually limited by the earthing transformer on the delta side of the power transformer, which may result in differential current as well. To make the overall differential protection insensitive to external earth-faults in these situations the zero sequence currents must be eliminated from the power transformer IED currents on the earthed windings, so that they do not appear as differential currents. This had once been achieved by means of interposing auxiliary current transformers. The elimination of zero sequence current is done numerically by setting *ZSCurrSubtrWx=Off* or *On* and doesn't require any auxiliary transformers or zero sequence traps. Instead it is necessary to eliminate the zero sequence current from every individual winding by proper setting of setting parameters *ZSCurrSubtrWx=Off* or *On*

6.1.3.3

Inrush restraint methods

With a combination of the second harmonic restraint and the waveform restraint methods it is possible to get a protection with high security and stability against inrush effects and at the same time maintain high performance in case of heavy internal faults even if the current transformers are saturated. Both these restraint methods are used by the IED. The second harmonic restraint function has a settable level. If the ratio of the second harmonic to the fundamental in the differential current is above the settable limit, the operation of the differential protection is restrained. It is recommended to set parameter *I2/I1Ratio = 15%* as default value in case no special reasons exist to choose another value.

6.1.3.4

Overexcitation restraint method

In case of an overexcited transformer, the winding currents contain odd harmonic components because the currents waveform are symmetrical relative to the time axis. As the third harmonic currents cannot flow into a delta winding, the fifth harmonic is the lowest harmonic which can serve as a criterion for overexcitation. The differential protection function is provided with a fifth harmonic restraint to prevent the protection from operation during an overexcitation condition of a power transformer. If the ratio of the fifth harmonic to the fundamental in the differential current is above a settable limit the operation is restrained. It is recommended to use *I5/I1Ratio = 25%* as default value in case no special reasons exist to choose another setting.

Transformers likely to be exposed to overvoltage or underfrequency conditions (that is, generator step-up transformers in power stations) should be provided with a dedicated overexcitation protection based on V/Hz to achieve a trip before the core thermal limit is reached.

6.1.3.5**Cross-blocking between phases**

Basic definition of the cross-blocking is that one of the three phases can block operation (that is, tripping) of the other two phases due to the harmonic pollution of the differential current in that phase (waveform, 2nd or 5th harmonic content). In the algorithm the user can control the cross-blocking between the phases via the setting parameter *CrossBlockEn*. When parameter *CrossBlockEn* is set to *On*, cross blocking between phases will be introduced. There are no time related settings involved, but the phase with the operating point above the set bias characteristic will be able to cross-block the other two phases if it is self-blocked by any of the previously explained restrained criteria. As soon as the operating point for this phase is below the set bias characteristic cross blocking from that phase will be inhibited. In this way cross-blocking of the temporary nature is achieved. It should be noted that this is the default (recommended) setting value for this parameter. When parameter *CrossBlockEn* is set to *Off*, any cross blocking between phases will be disabled.

6.1.3.6**External/Internal fault discriminator**

The external/internal fault discriminator operation is based on the relative position of the two phasors (in case of a two-winding transformer) representing the W1 and W2 negative sequence current contributions, defined by matrix expression see the technical reference manual. It practically performs a directional comparison between these two phasors.

In order to perform a directional comparison of the two phasors their magnitudes must be high enough so that one can be sure that they are due to a fault. On the other hand, in order to guarantee a good sensitivity of the internal/external fault discriminator, the value of this minimum limit must not be too high. Therefore this limit value (*IMinNegSeq*) is settable in the range from 1% to 20% of the differential protections IBasecurrent, which is in our case the power transformer HV side rated current. The default value is 4%. Only if the magnitude of both negative sequence current contributions are above the set limit, the relative position between these two phasors is checked. If either of the negative sequence current contributions, which should be compared, is too small (less than the set value for *IMinNegSeq*), no directional comparison is made in order to avoid the possibility to produce a wrong decision.

This magnitude check, guarantees stability of the algorithm when the power transformer is energized. In cases where the protected transformer can be energized with a load connected on the LV side (e.g. a step-up transformer in a power station with directly connected auxiliary transformer on its LV side) the value for this setting shall be increased to at least 12%. This is necessary in order to prevent unwanted operation due to LV side currents during the transformer inrush.

The setting *NegSeqROA* represents the so-called Relay Operate Angle, which determines the boundary between the internal and external fault regions. It can be selected in the range from 30 degrees to 90 degrees, with a step of 1 degree. The default value is 60 degrees. The default setting 60 degrees somewhat favors

security in comparison to dependability. If the user has no well-justified reason for another value, 60 degrees shall be applied.

If the above conditions concerning magnitudes are fulfilled, the internal/external fault discriminator compares the relative phase angle between the negative sequence current contributions from the HV side and LV side of the power transformer using the following two rules :

- If the negative sequence currents contributions from HV and LV sides are in phase or at least in the internal fault region, the fault is internal.
- If the negative sequence currents contributions from HV and LV sides are 180 degrees out of phase or at least in the external fault region, the fault is external.

Under external fault condition and with no current transformer saturation, the relative angle is theoretically equal to 180 degrees. During internal fault and with no current transformer saturation, the angle shall ideally be 0 degrees, but due to possible different negative sequence source impedance angles on HV and LV side of power transformer, it may differ somewhat from the ideal zero value.

The internal/external fault discriminator has proved to be very reliable. If a fault is detected, that is, START signals set by ordinary differential protection, and at the same time the internal/external fault discriminator characterizes this fault as an internal, any eventual blocking signals produced by either the harmonic or the waveform restraints are ignored.

If the bias current is more than 110% of I_{Base} , the negative sequence threshold ($I_{MinNegSeq}$) is increased internally.. This assures response times of the differential protection below one power system cycle (below 20 ms for 50 Hz system) for all more severe internal faults. Even for heavy internal faults with severely saturated current transformers this differential protection operates well below one cycle, since the harmonic distortions in the differential currents do not slow down the differential protection operation. Practically, an unrestrained operation is achieved for all internal faults.

External faults happen ten to hundred times more often than internal ones as far as the power transformers are concerned. If a disturbance is detected and the internal/external fault discriminator characterizes this fault as an external fault, the conventional additional criteria are posed on the differential algorithm before its trip is allowed. This assures high algorithm stability during external faults. However, at the same time the differential function is still capable of tripping quickly for evolving faults.

The principle of the internal/external fault discriminator can be extended to autotransformers and transformers with three windings. If all three windings are connected to their respective networks then three directional comparisons are made, but only two comparisons are necessary in order to positively determine the position of the fault with respect to the protected zone. The directional comparisons which are possible, are: $W1 - (W2+W3)$ and $W2 - (W1+W3)$. The rule applied by the internal/external fault discriminator in case of three-winding power transformers is:

- If any comparison indicates an internal fault, then it is an internal fault.
- If any comparison indicates an external fault, then it is an external fault

If one of the windings is not connected, the algorithm automatically reduces to the two-winding version. Nevertheless, the whole power transformer is protected, including the non-connected winding.

6.1.3.7

Differential current alarm

Differential protection continuously monitors the level of the fundamental frequency differential currents and gives an alarm if the pre-set value is simultaneously exceeded in all three phases. This feature can be used to monitor the integrity of on-load tap-changer compensation within the differential function. The threshold for the alarm pickup level is defined by setting parameter *IDiffAlarm*. This threshold should be typically set in such way to obtain operation when on-load tap-changer measured value within differential function differs for more than two steps from the actual on-load tap-changer position. To obtain such operation set parameter *IDiffAlarm* equal to two times the on-load tap-changer step size (For example, typical setting value is 5% to 10% of base current). Set the time delay defined by parameter *tAlarmDelay* two times longer than the on-load tap-changer mechanical operating time (For example, typical setting value 10s).

6.1.3.8

Open CT detection

The Transformer differential function has a built-in, advanced open CT detection feature. This feature can block the unexpected operation created by the Transformer differential function in case of open CT secondary circuit under normal load condition. An alarm signal can also be issued to station operational personnel to make remedy action once the open CT condition is detected.

The following setting parameters are related to this feature:

- Setting parameter *OpenCTEnable* enables/disables this feature
- Setting parameter *tOCTAlarmDelay* defines the time delay after which the alarm signal will be given
- Setting parameter *tOCTReset* defines the time delay after which the open CT condition will reset once the defective CT circuits have been rectified
- Once the open CT condition has been detected, then all the differential protection functions are blocked except the unrestraint (instantaneous) differential protection

The outputs of open CT condition related parameters are listed below:

- *OpenCT*: Open CT detected
- *OpenCTAlarm*: Alarm issued after the setting delay
- *OpenCTIN*: Open CT in CT group inputs (1 for input 1 and 2 for input 2)
- *OpenCTPH*: Open CT with phase information (1 for phase L1, 2 for phase L2, 3 for phase L3)

6.1.3.9 Switch onto fault feature

The Transformer differential function in the IED has a built-in, advanced switch onto fault feature. This feature can be enabled or disabled by the setting parameter *SOTFMode*. When *SOTFMode* = *On* this feature is enabled. It shall be noted that when this feature is enabled it is not possible to test the 2nd harmonic blocking feature by simply injecting one current with superimposed second harmonic. In that case the switch on to fault feature will operate and the differential protection will trip. However for a real inrush case the differential protection function will properly restrain from operation.

For more information about the operating principles of the switch onto fault feature please read the Technical Manual.

6.1.4 Setting example

6.1.4.1 Introduction

Differential protection for power transformers has been used for decades. In order to correctly apply transformer differential protection proper compensation is needed for:

- power transformer phase shift (vector group compensation)
- CT secondary currents magnitude difference on different sides of the protected transformer (ratio compensation)
- zero sequence current elimination (zero sequence current reduction) shall be done. In the past this was performed with help of interposing CTs or special connection of main CTs (delta connected CTs). With numerical technology all these compensations are done in IED software.

The Differential transformer protection is capable to provide differential protection for all standard three-phase power transformers without any interposing CTs. It has been designed with assumption that all main CTs will be star connected. For such applications it is then only necessary to enter directly CT rated data and power transformer data as they are given on the power transformer nameplate and differential protection will automatically balance itself.



These are internal compensations within the differential function. The protected power transformer data are always entered as they are given on the nameplate. Differential function will by itself correlate nameplate data and properly select the reference windings.

However the IED can also be used in applications where some of the main CTs are connected in delta. In such cases the ratio for the main CT connected in delta shall be intentionally set for $\sqrt{3}=1.732$ times smaller than actual ratio of individual phase CTs (for example, instead of 800/5 set 462/5) In case the ratio is 800/2.88A,

often designed for such typical delta connections, set the ratio as 800/5 in the IED. At the same time the power transformer vector group shall be set as Yy0 because the IED shall not internally provide any phase angle shift compensation. The necessary phase angle shift compensation will be provided externally by delta connected main CT. All other settings should have the same values irrespective of main CT connections.

6.1.4.2

Typical main CT connections for transformer differential protection

Three most typical main CT connections used for transformer differential protection are shown in figure 31. It is assumed that the primary phase sequence is L1-L2-L3.

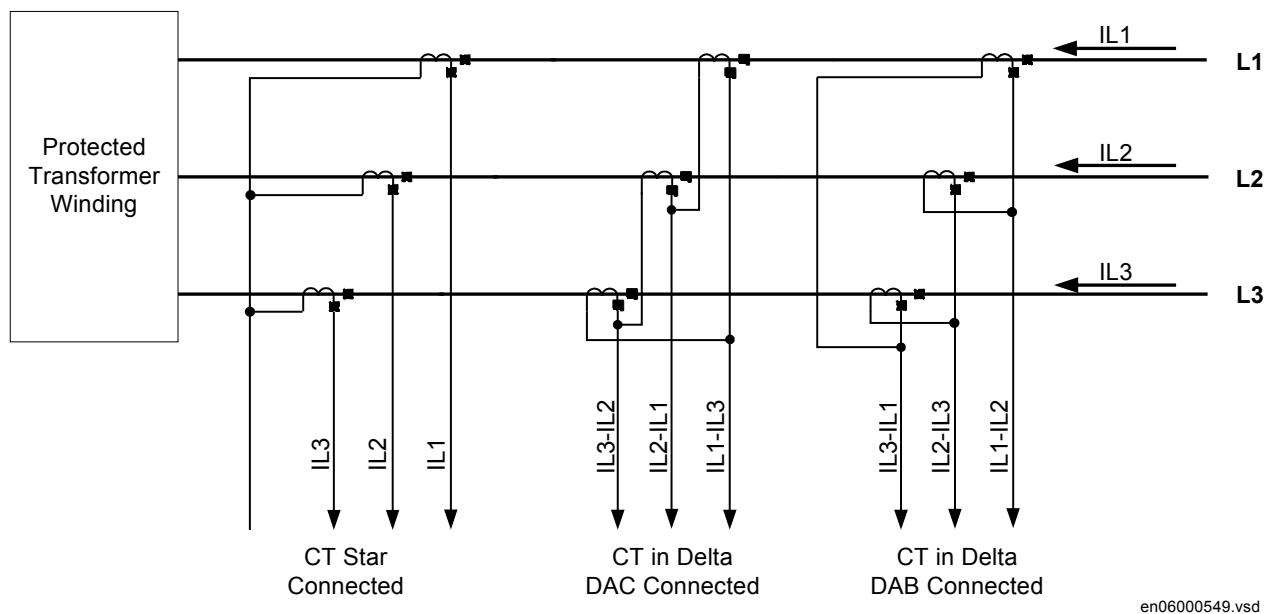


Figure 31: Commonly used main CT connections for Transformer differential protection.

For star connected main CTs, secondary currents fed to the IED:

- are directly proportional to the measured primary currents
- are in phase with the measured primary currents
- contain all sequence components including zero sequence current component

For star connected main CTs, the main CT ratio shall be set as it is in actual application. The “StarPoint” parameter, for the particular star connection shown in figure 31, shall be set *ToObject*. If star connected main CTs have their star point away from the protected transformer this parameter should be set *FromObject*.

For delta DAC connected main CTs, secondary currents fed to the IED:

- are increased $\sqrt{3}$ times (1.732 times) in comparison with star connected CTs
- lag by 30° the primary winding currents (this CT connection rotates currents by 30° in clockwise direction)
- do not contain zero sequence current component

For DAC delta connected main CTs, ratio shall be set for $\sqrt{3}$ times smaller than the actual ratio of individual phase CTs. The “StarPoint” parameter, for this particular connection shall be set *ToObject*. It shall be noted that delta DAC connected main CTs must be connected exactly as shown in figure [31](#).

For delta DAB connected main CTs, secondary currents fed to the IED:

- are increased $\sqrt{3}$ times (1.732 times) in comparison with star connected CTs
- lead by 30° the primary winding currents (this CT connection rotates currents by 30° in anti-clockwise direction)
- do not contain zero sequence current component

For DAB delta connected main CT ratio shall be set for $\sqrt{3}$ times smaller in RET 670 then the actual ratio of individual phase CTs. The “StarPoint” parameter, for this particular connection shall be set *ToObject*. It shall be noted that delta DAB connected main CTs must be connected exactly as shown in figure [31](#).

For more detailed info regarding CT data settings please refer to the three application examples presented in section ["Application Examples"](#).

6.1.4.3

Application Examples

Three application examples will be given here. For each example two differential protection solutions will be presented:

- First solution will be with all main CTs star connected.
- Second solution will be with delta connected main CT on Y (that is, star) connected sides of the protected power transformer.

For each differential protection solution the following settings will be given:

1. Input CT channels on the transformer input modules.
2. General settings for the transformer differential protection where specific data about protected power transformer shall be entered.

Finally the setting for the differential protection characteristic will be given for all presented applications.

Example 1: Star-delta connected power transformer without on-load tap-changer

Single line diagrams for two possible solutions for such type of power transformer with all relevant application data are given in figure [32](#).

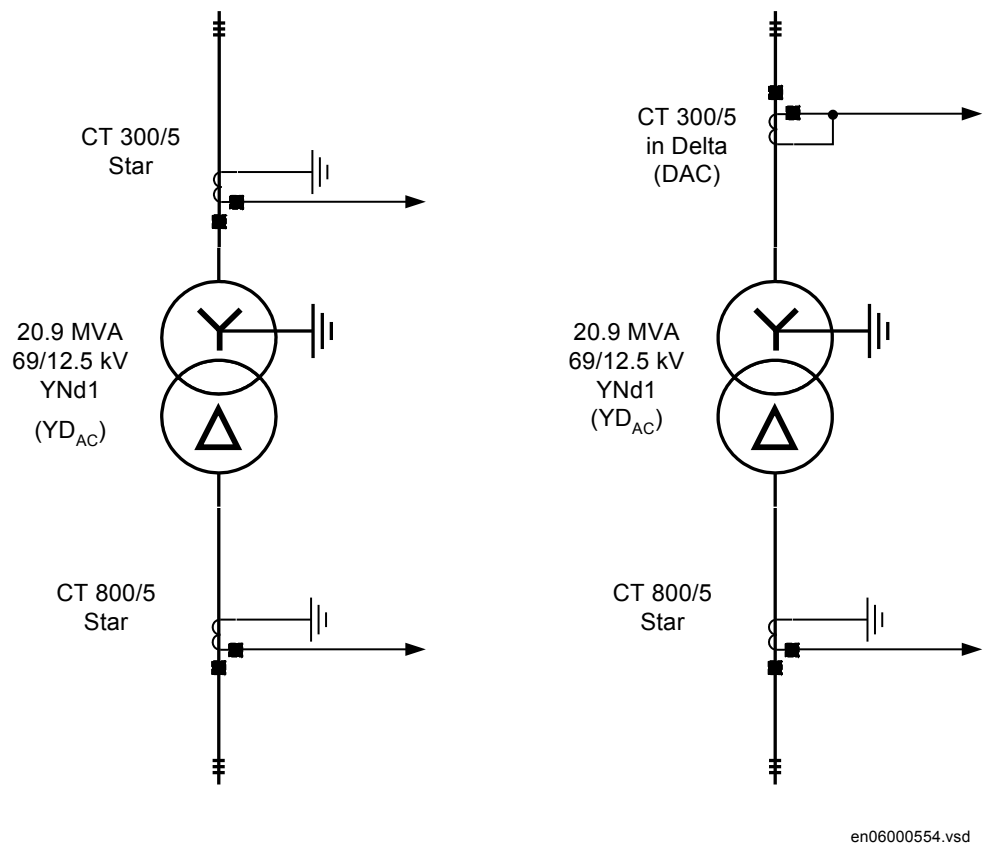


Figure 32: Two differential protection solutions for star-delta connected power transformer

For this particular power transformer the 69 kV side phase-to-earth no-load voltages lead by 30 degrees the 12.5 kV side phase-to-earth no-load voltages. Thus when external phase angle shift compensation is done by connecting main HV CTs in delta, as shown in the right-hand side in figure 32, it must be ensured that the HV currents are rotated by 30° in clockwise direction. Thus the DAC delta CT connection must be used for 69 kV CTs in order to put 69 kV & 12.5 kV currents in phase.

To ensure proper application of the IED for this power transformer it is necessary to do the following:

1. Check that HV & LV CTs are connected to 5 A CT inputs in the IED.
2. For second solution make sure that HV delta connected CTs are DAC connected.
3. For star connected CTs make sure how they are starred (that is, earthed) to/from protected transformer.
4. Enter the following settings for all three CT input channels used for the LV side CTs see table 10.

Table 10: *CT input channels used for the LV side CTs*

Setting parameter	Selected value for both solutions
CTprim	800
CTsec	5
CTStarPoint	ToObject

5. Enter the following settings for all three CT input channels used for the HV side CTs, see table 11.

Table 11: *CT input channels used for the HV side CTs*

Setting parameter	Selected value for solution 1 (star connected CT)	Selected value for solution 2 (delta connected CT)
CTprim	300	$\frac{300}{\sqrt{3}} = 173$ (Equation 12)
CTsec	5	5
CTStarPoint	From Object	ToObject

To compensate for delta connected CTs, see equation 12.

6. Enter the following values for the general settings of the Transformer differential protection function, see table 12.

Table 12: *General settings of the differential protection function*

Setting parameter	Select value for solution 1 (star connected CT)	Selected value for solution 2 (delta connected CT)
GlobalBaseSelW1	CTPrim / GlobalBaseSelW1	(CTPrim / GlobalBaseSelW1) / sqrt(3)
GlobalBaseSelW2	CTPrim / GlobalBaseSelW2	(CTPrim / GlobalBaseSelW2) / sqrt(3)
GlobalBaseSelW3	CTPrim / GlobalBaseSelW3	(CTPrim / GlobalBaseSelW3) / sqrt(3)
ConnectTypeW1	STAR (Y)	STAR (Y)
ConnectTypeW2	delta=d	star=y ¹⁾
ClockNumberW2	1 [30 deg lag]	0 [0 deg] ¹⁾
ZSCurrSubtrW1	On	Off ²⁾
ZSCurrSubtrW2	Off	Off
TconfigForW1	No	No
TconfigForW2	No	No
Table continues on next page		

Setting parameter	Select value for solution 1 (star connected CT)	Selected value for solution 2 (delta connected CT)
LocationOLTC1	Not used	Not used
Other Parameters	Not relevant for this application. Use default value.	Not relevant for this application. Use default value.
1) To compensate for delta connected CTs 2) Zero-sequence current is already removed by connecting main CTs in delta		

Delta-star connected power transformer without tap charger

Single line diagrams for two possible solutions for such type of power transformer with all relevant application data are given in figure 33.

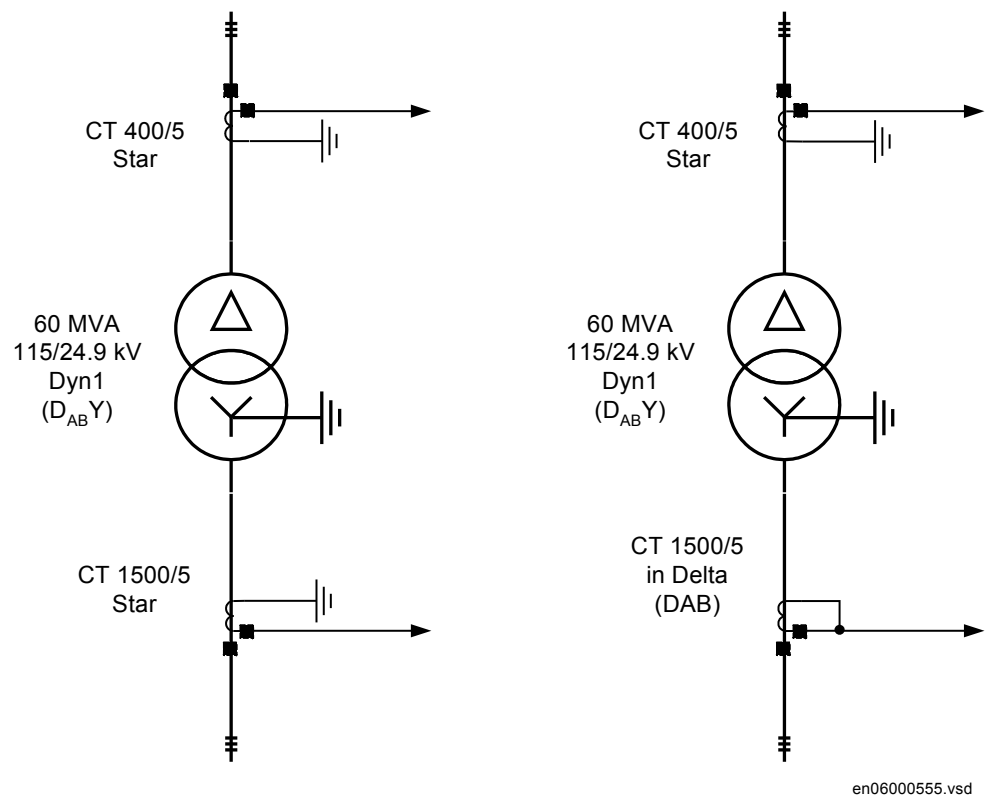


Figure 33: Two differential protection solutions for delta-star connected power transformer

For this particular power transformer the 115 kV side phase-to-earth no-load voltages lead by 30° the 24.9 kV side phase-to-earth no-load voltages. Thus when external phase angle shift compensation is done by connecting main 24.9 kV CTs in delta, as shown in the right-hand side in figure 33, it must be ensured that the 24.9 kV currents are rotated by 30° in anti-clockwise direction. Thus, the DAB CT delta connection (see figure 33) must be used for 24.9 kV CTs in order to put 115 kV & 24.9 kV currents in phase.

To ensure proper application of the IED for this power transformer it is necessary to do the following:

1. Check that HV & LV CTs are connected to 5 A CT inputs in the IED.
2. For second solution make sure that LV delta connected CTs are DAB connected.
3. For star connected CTs make sure how they are 'star'ed (that is, earthed) to/from protected transformer.
4. Enter the following settings for all three CT input channels used for the HV side CTs, see table [13](#).

Table 13: *CT input channels used for the HV side CTs*

Setting parameter	Selected value for both solutions
CTprim	400
CTsec	5
CTStarPoint	ToObject

5. Enter the following settings for all three CT input channels used for the LV side CTs, see table ["CT input channels used for the LV side CTs"](#).

CT input channels used for the LV side CTs

Setting parameter	Selected value for Solution 1 (star connected CT)	Selected value for Solution 2 (delta connected CT)
CTprim	1500	$\frac{1500}{\sqrt{3}} = 866$ (Equation 13)
CTsec	5	5
CTStarPoint	ToObject	ToObject

To compensate for delta connected CTs, see equation [13](#).

6. Enter the following values for the general settings of the differential protection function, see table [14](#).

Table 14: *General settings of the differential protection*

Setting parameter	selected value for both Solution 1 (star connected CT)	Selected value for both Solution 2 (delta connected CT)
RatedVoltageW1	115 kV	115 kV
Rated VoltageW2	24.9 kV	24.9 kV
RatedCurrentW1	301 A	301 A
RatedCurrentW2	1391 A	1391 A
Table continues on next page		

Setting parameter	selected value for both Solution 1 (star connected CT)	Selected value for both Solution 2 (delta connected CT)
ConnectTypeW1	Delta (D)	STAR (Y) ¹⁾
ConnectTypeW2	star=y	star=y
ClockNumberW2	1 [30 deg lag]	0 [0 deg] ¹⁾
ZSCurrSubtrW1	Off	Off
ZSCurrSubtrW2	On	On ²⁾
TconfigForW1	No	No
TconfigForW2	No	No
LocationOLTC1	Not Used	Not Used
Other parameters	Not relevant for this application. Use default value.	Not relevant for this application. Use default value.
¹⁾ To compensate for delta connected CTs. ²⁾ Zero-sequence current is already removed by connecting main CTs in delta.		

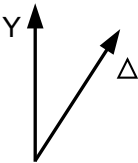
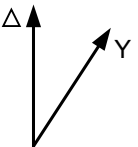
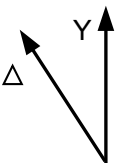
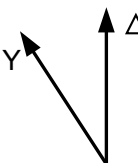
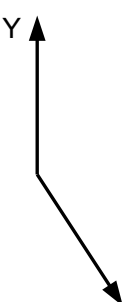
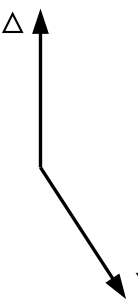
6.1.4.4

Summary and conclusions

The IED can be used for differential protection of three-phase power transformers with main CTs either star or delta connected. However the IED has been designed with the assumption that all main CTS are star connected. The IED can be used in applications where the main CTs are delta connected. For such applications the following shall be kept in mind:

1. The ratio for delta connected CTs shall be set $\sqrt{3}=1.732$ times smaller than the actual individual phase CT ratio.
2. The power transformer vector group shall typically be set as Yy0 because the compensation for power transformer the actual phase shift is provided by the external delta CT connection.
3. The zero sequence current is eliminated by the main CT delta connections. Thus on sides where CTs are connected in delta the zero sequence current elimination shall be set to Off in the IED.

The following table summarizes the most commonly used star-delta vector groups around the world and provides information about the required type of main CT delta connection on the star side of the protected transformer.

IEC vector group	Positive sequence no-load voltage phasor diagram	Required delta CT connection type on star side of the protected power transformer and internal vector group setting in the IED
YNd1		DAC/Yy0
Dyn1		DAB/Yy0
YNd11		DAB/Yy0
Dyn11		DAC/Yy0
YNd5		DAB/Yy6
Dyn5		DAC/Yy6

6.2 Low impedance restricted earth fault protection REFPDIF

6.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Restricted earth fault protection, low impedance	REFPDIF	<i>IdN/I</i>	87N

6.2.2 Application

A breakdown of the insulation between a transformer winding and the core or the tank may result in a large fault current which causes severe damage to the windings and the transformer core. A high gas pressure may develop, damaging the transformer tank.

Fast and sensitive detection of earth faults in a power transformer winding can be obtained in solidly earthed or low impedance earthed networks by the restricted earth fault protection. The only requirement is that the power transformer winding is connected to earth in the star point (in case of star-connected windings) or through a separate earthing transformer (in case of delta-connected windings).

The low impedance restricted earth fault protection REFPDIF is a winding protection function. It protects the power transformer winding against faults involving earth. Observe that single phase-to-earth faults are the most common fault types in transformers. Therefore, a sensitive earth fault protection is desirable.

A restricted earth fault protection is the fastest and the most sensitive protection, a power transformer winding can have and will detect faults such as:

- earth faults in the transformer winding when the network is earthed through an impedance
- earth faults in the transformer winding in solidly earthed network when the point of the fault is close to the winding star point.

The restricted earth fault protection is not affected, as a differential protection, with the following power transformer related phenomena:

- Due to its features, REFPDIF is often used as a main protection of the transformer winding for all faults involving earth.

Transformer winding, solidly earthed

REFPDIF

I3PW1CT1

IdN/I

I3P

Protected winding

IEC09000109-4-EN.vsd

Figure 34: Connection of the low impedance Restricted earth fault function REFPDIF for a directly (solidly) earthed transformer winding

Transformer winding, earthed through zig-zag earthing transformer

A common application is for low reactance earthed transformer where the earthing is through separate zig-zag earthing transformers. The fault current is then limited to typical 800 to 2000 A for each transformer. The connection for this application is shown in figure 35.

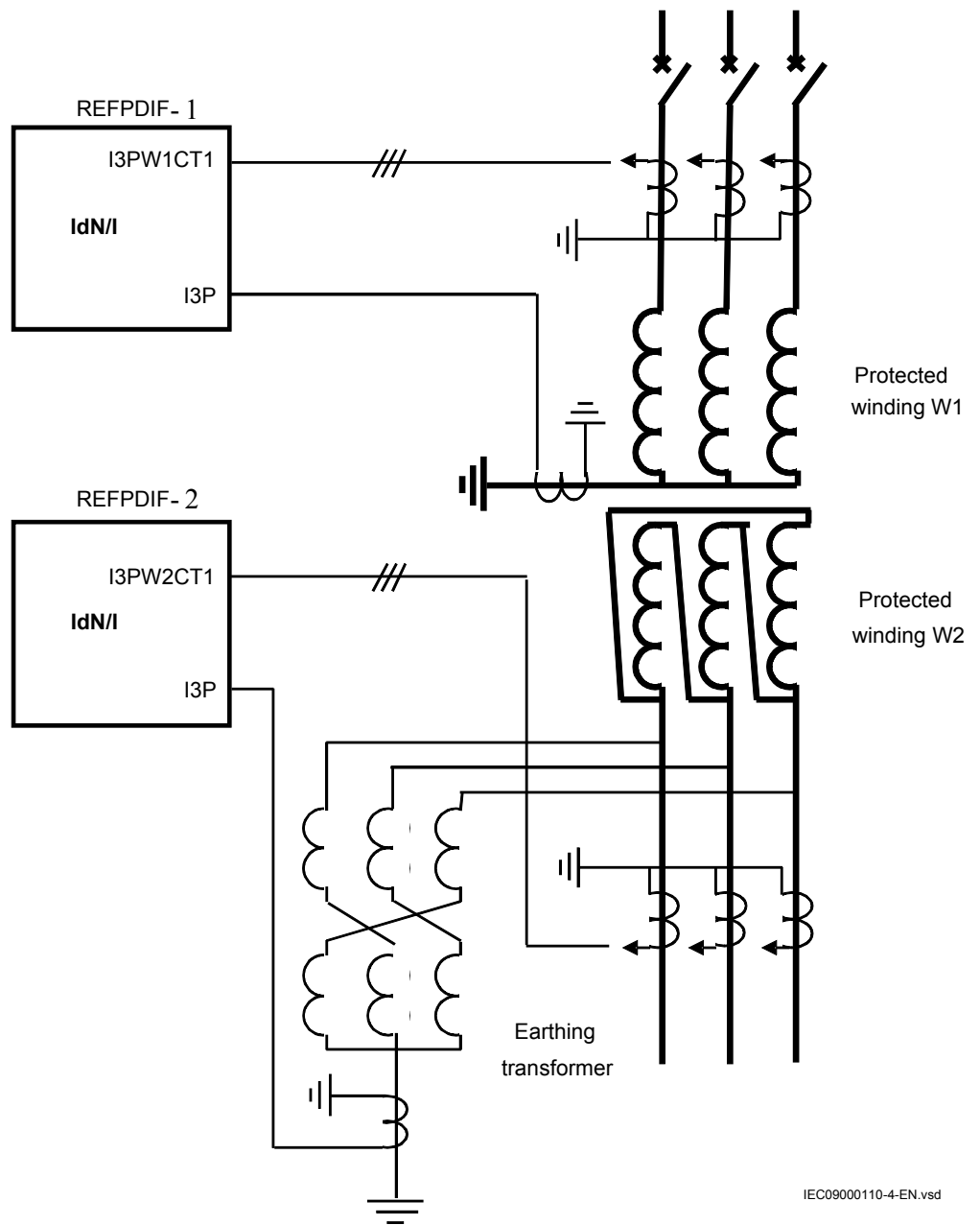


Figure 35: Connection of the low impedance Restricted earth-fault function REFPDIF for a zig-zag earthing transformer

6.2.2.3

Autotransformer winding, solidly earthed

Autotransformers can be protected with the low impedance restricted earth-fault protection function REFPDIF. The complete transformer will then be protected including the HV side, the neutral connection and the LV side. The connection of REFPDIF for this application is shown in figure 36.

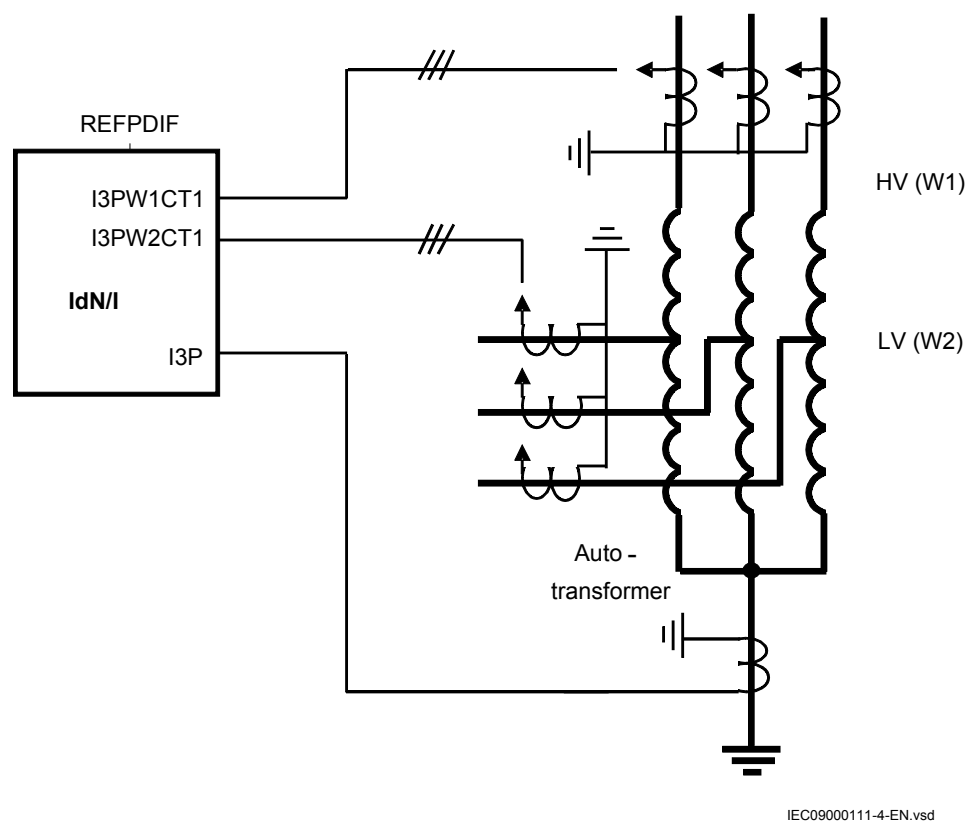


Figure 36: Connection of restricted earth fault, low impedance function REFPDIF for an autotransformer, solidly earthed

6.2.2.4

Reactor winding, solidly earthed

Reactors can be protected with restricted earth-fault protection, low impedance function REFPDIF. The connection of REFPDIF for this application is shown in figure 37.

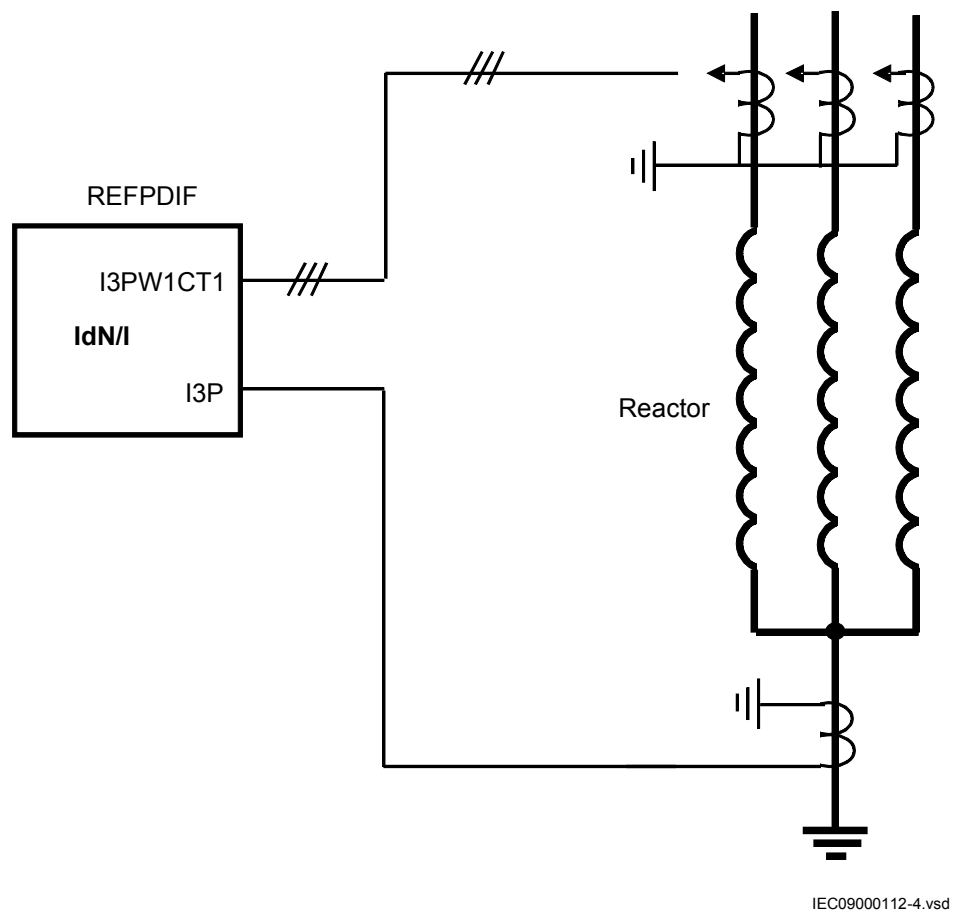


Figure 37: Connection of restricted earth-fault, low impedance function REFPDIF for a solidly earthed reactor

6.2.2.5

Multi-breaker applications

Multi-breaker arrangements including ring, one and a half breaker, double breaker and mesh corner arrangements have two sets of current transformers on the phase side. The restricted earth-fault protection, low impedance function REFPDIF has inputs to allow two current inputs from each side of the transformer. The second winding set is only applicable for autotransformers.

A typical connection for a star-delta transformer is shown in figure [38](#).

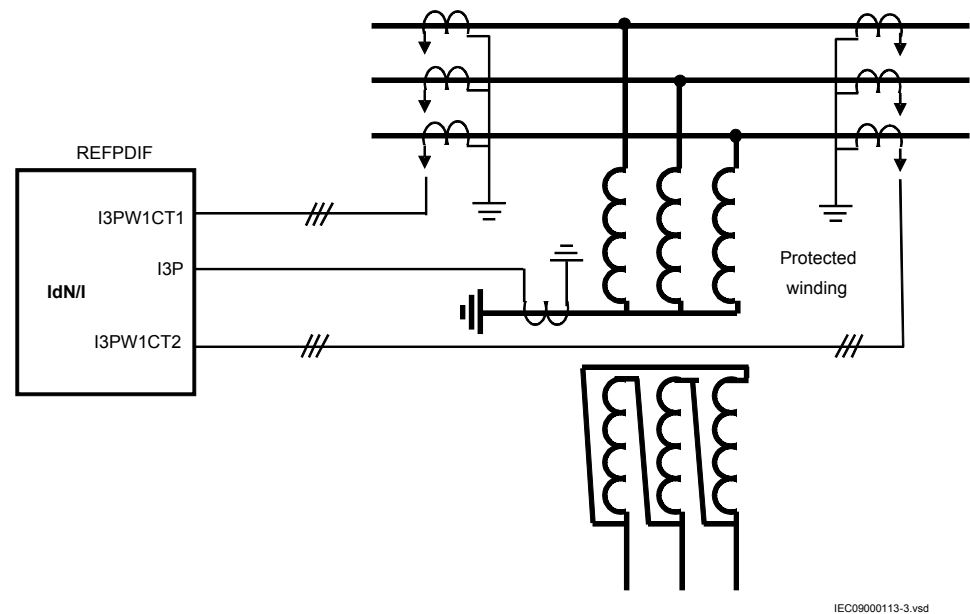


Figure 38: Connection of Restricted earth fault, low impedance function REFPDIF in multi-breaker arrangements

6.2.2.6

CT earthing direction

To make the restricted earth fault protection REFPDIF operate correctly, the main CTs are always supposed to be star-connected. The main CT's neutral (star) formation can be positioned in either way, *ToObject* or *FromObject*. However, internally REFPDIF always uses reference directions towards the protected transformers, as shown in Figure 38. Thus the IED always measures the primary currents on all sides and in the neutral of the power transformer with the same reference direction towards the power transformer windings.

The earthing can be freely selected for each of the involved current transformers.

6.2.3

Setting guidelines

6.2.3.1

Setting and configuration

Recommendation for analog inputs

I3P: Neutral point current (All analog inputs connected as 3Ph groups in ACT).

I3PW1CT1: Phase currents for winding 1 first current transformer set.

I3PW1CT2: Phase currents for winding1 second current transformer set for multi-breaker arrangements. When not required configure input to "GRP-OFF".

I3PW2CT1: Phase currents for winding 2 first current transformer set. Used for autotransformers.

I3PW2CT2: Phase currents for winding 2 second current transformer set for multi-breaker arrangements. Used when protecting an autotransformer. When not required, configure input to "GRP-OFF".

Recommendation for Binary input signals

Refer to the pre-configured configurations for details.

BLOCK: The input will block the operation of the function. It can be used, for example, to block the operation during special service conditions for a limited time.

Recommendation for output signals

Refer to pre-configured configurations for details.

START: The start output indicates that *Idiff* is in the operate region of the characteristic.

TRIP: The trip output is activated when all operating criteria are fulfilled.

DIROK: The output is activated when the directional criteria has been fulfilled.

BLK2H: The output is activated when the function is blocked due to high level of second harmonic.

6.2.3.2

Settings

The parameters for the restricted earth fault protection, low impedance function REFPDIF are set via the local HMI or PCM600.

Common base IED values for primary current (*IBase*), primary voltage (*UBase*) and primary power (*SBase*) are set in a Global base values for settings function GBASVAL.

GlobalBaseSel: It is used to select a GBASVAL function for reference of base values.

Operation: The operation of REFPDIF can be switched *On/Off*.

IdMin: The setting gives the minimum operation value. The setting is in percent of the *IBase* value of the chosen *GlobalBaseSel*. For function operation, the neutral current must be larger than half of this value. A recommended setting is 30% of power transformer-winding rated current for a solidly earthed winding.

ROA: Relay operate angle for zero sequence directional feature. It is used to differentiate an internal fault and an external fault based on measured zero sequence current and neutral current.

CTFactorPri1: A factor to allow a sensitive function also at multi-breaker arrangement where the rating in the bay is much higher than the rated current of the transformer winding. The stabilizing can then be high so an unnecessary high fault level can be required. The setting is normally 1.0 but in multi-breaker arrangement the setting shall be CT primary rating/*IBase*.

CTFactorPri2: A factor to allow a sensitive function also at multi-breaker arrangement where the rating in the bay is much higher than the rated current of the transformer winding. The stabilizing can then be high so an unnecessary high fault level can be required. The setting is normally 1.0 but in multi-breaker arrangement the setting shall be CT primary rating/*IBase*.

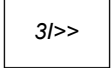
CTFactorSec1: See setting *CTFactorPri1*. Only difference is that *CTFactorSec1* is related to W2 side.

CTFactorSec2: See setting *CTFactorPri2*. Only difference is that *CTFactorSec2* is related to W2 side.

Section 7 Current protection

7.1 Instantaneous phase overcurrent protection PHPIOC

7.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Instantaneous phase overcurrent protection	PHPIOC		50

7.1.2 Application

Long transmission lines often transfer great quantities of electric power from generation to consumption areas. The unbalance of the produced and consumed electric power at each end of the transmission line is very large. This means that a fault on the line can easily endanger the stability of a complete system.

The transient stability of a power system depends mostly on three parameters (at constant amount of transmitted electric power):

- The type of the fault. Three-phase faults are the most dangerous, because no power can be transmitted through the fault point during fault conditions.
- The magnitude of the fault current. A high fault current indicates that the decrease of transmitted power is high.
- The total fault clearing time. The phase angles between the EMFs of the generators on both sides of the transmission line increase over the permitted stability limits if the total fault clearing time, which consists of the protection operating time and the breaker opening time, is too long.

The fault current on long transmission lines depends mostly on the fault position and decreases with the distance from the generation point. For this reason the protection must operate very quickly for faults very close to the generation (and relay) point, for which very high fault currents are characteristic.

The instantaneous phase overcurrent protection PHPIOC can operate in 10 ms for faults characterized by very high currents.

7.1.3

Setting guidelines

The parameters for instantaneous phase overcurrent protection PHPIOC are set via the local HMI or PCM600.

This protection function must operate only in a selective way. So check all system and transient conditions that could cause its unwanted operation.

Only detailed network studies can determine the operating conditions under which the highest possible fault current is expected on the line. In most cases, this current appears during three-phase fault conditions. But also examine single-phase-to-earth and two-phase-to-earth conditions.

Also study transients that could cause a high increase of the line current for short times. A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when connected to the network and can thus also cause the operation of the built-in, instantaneous, overcurrent protection.

Common base IED values for primary current ($IBase$), primary voltage ($UBase$) and primary power ($SBase$) are set in the global base values for settings function GBASVAL.

GlobalBaseSel: This is used to select GBASVAL function for reference of base values.

Operation: Set the protection to *On/Off*.

OpMode: This parameter can be set to *2 out of 3* or *1 out of 3*. The setting controls the minimum number of phase currents that must be larger than the set operate current $IP>>$ for operation. Normally this parameter is set to *1 out of 3* and will thus detect all fault types. If the protection is to be used mainly for multi phase faults, *2 out of 3* should be chosen.

$IP>>$: Set operate current in % of IB .

$IP>>Max$ and $IP>>Min$ should only be changed if remote setting of operation current level, $IP>>$, is used. The limits are used for decreasing the used range of the $IP>>$ setting. If $IP>>$ is set outside $IP>>Max$ and $IP>>Min$, the closest of the limits to $IP>>$ is used by the function. If $IP>>Max$ is smaller than $IP>>Min$, the limits are swapped.

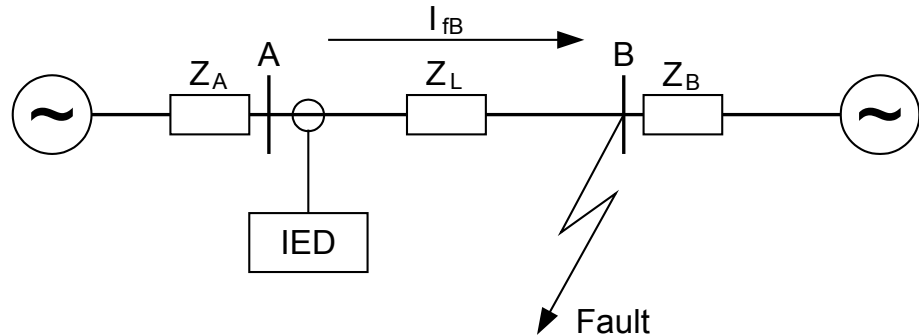
StValMult: The set operate current can be changed by activation of the binary input ENMULT to the set factor *StValMult*.

7.1.3.1

Meshed network without parallel line

The following fault calculations have to be done for three-phase, single-phase-to-earth and two-phase-to-earth faults. With reference to Figure 39, apply a fault in B and then calculate the current through-fault phase current I_{fB} . The calculation

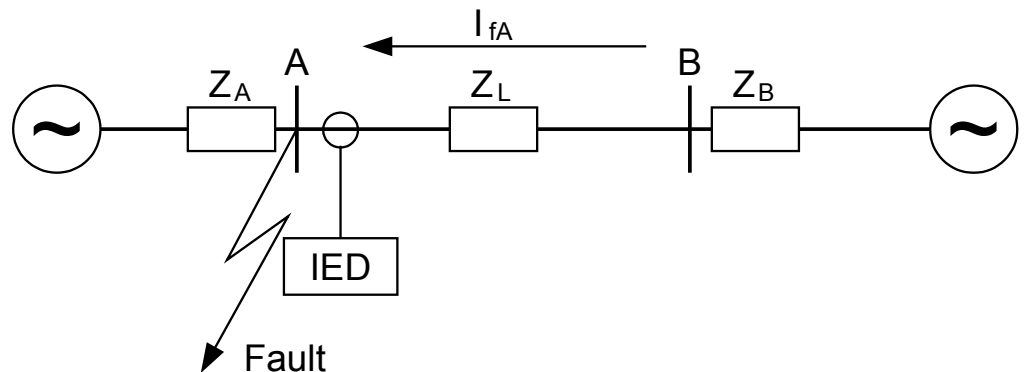
should be done using the minimum source impedance values for Z_A and the maximum source impedance values for Z_B in order to get the maximum through fault current from A to B.



IEC09000022-1-en.vsd

Figure 39: Through fault current from A to B: I_{fB}

Then a fault in A has to be applied and the through fault current I_{fA} has to be calculated, Figure 40. In order to get the maximum through fault current, the minimum value for Z_B and the maximum value for Z_A have to be considered.



IEC09000023-1-en.vsd

Figure 40: Through fault current from B to A: I_{fA}

The IED must not trip for any of the two through-fault currents. Hence the minimum theoretical current setting (I_{min}) will be:

$$I_{min} \geq \text{MAX}(I_{fA}, I_{fB})$$

(Equation 14)

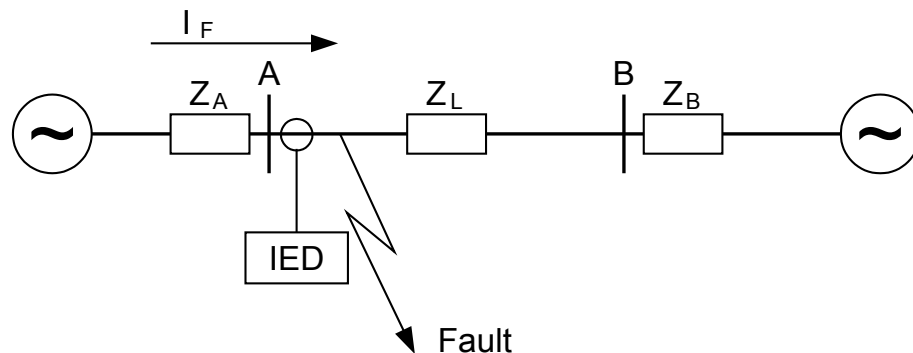
A safety margin of 5% for the maximum protection static inaccuracy and a safety margin of 5% for the maximum possible transient overreach have to be introduced. An additional 20% is suggested due to the inaccuracy of the instrument transformers under transient conditions and inaccuracy in the system data.

The minimum primary setting (I_s) for the instantaneous phase overcurrent protection is then:

$$I_s \geq 1.3 \cdot I_{\min}$$

(Equation 15)

The protection function can be used for the specific application only if this setting value is equal to or less than the maximum fault current that the IED has to clear, I_F in Figure 41.



IEC09000024-1-en.vsd

Figure 41: Fault current: I_F

$$IP \gg \frac{I_s}{I_{Base}} \cdot 100$$

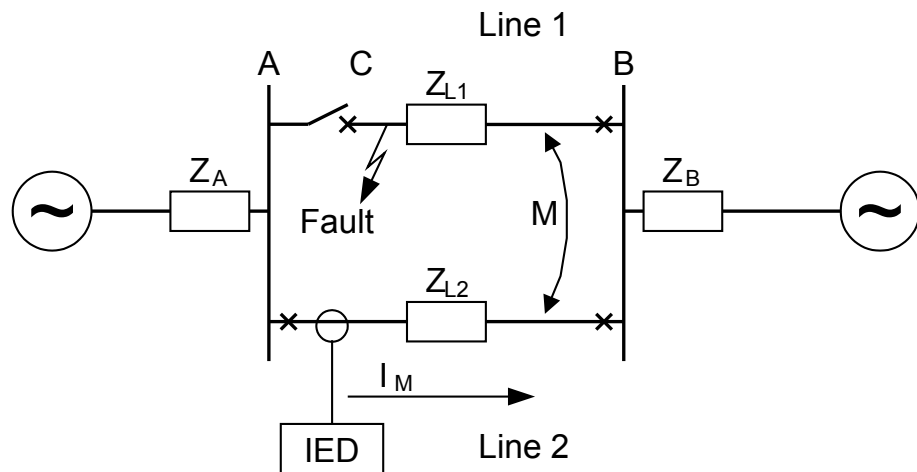
(Equation 16)

7.1.3.2

Meshed network with parallel line

In case of parallel lines, the influence of the induced current from the parallel line to the protected line has to be considered. One example is given in Figure 42, where the two lines are connected to the same busbars. In this case the influence of the induced fault current from the faulty line (line 1) to the healthy line (line 2) is considered together with the two through fault currents I_{fA} and I_{fB} mentioned previously. The maximal influence from the parallel line for the IED in Figure 42 will be with a fault at the C point with the C breaker open.

A fault in C has to be applied, and then the maximum current seen from the IED (I_M) on the healthy line (this applies for single-phase-to-earth and two-phase-to-earth faults) is calculated.



IEC09000025-1-en.vsd

Figure 42: Two parallel lines. Influence from parallel line to the through fault current: I_M

The minimum theoretical current setting for the overcurrent protection function (I_{min}) will be:

$$I_{\min} \geq \text{MAX}(I_{fA}, I_{fB}, I_M)$$

(Equation 17)

Where I_{fA} and I_{fB} have been described in the previous paragraph. Considering the safety margins mentioned previously, the minimum setting (I_s) for the instantaneous phase overcurrent protection 3-phase output is then:

$$I_s \geq 1.3 \cdot I_{min}$$

(Equation 18)

The protection function can be used for the specific application only if this setting value is equal or less than the maximum phase fault current that the IED has to clear.

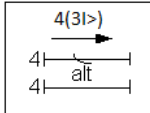
The IED setting value $IP_{>>}$ is given in percentage of the primary base current value, I_{Base} . The value for $IP_{>>}$ is given from this formula:

$$IP \gg = \frac{I_s}{I_{Base}} \cdot 100$$

(Equation 19)

7.2 Directional phase overcurrent protection, four steps OC4PTOC

7.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional phase overcurrent protection, four steps	OC4PTOC		51_67

7.2.2 Application

Directional phase overcurrent protection, four steps OC4PTOC is used in several applications in the power system. Some applications are:

- Short circuit protection of feeders in distribution and subtransmission systems. Normally these feeders have a radial structure.
- Back-up short circuit protection of transmission lines.
- Back-up short circuit protection of power transformers.
- Short circuit protection of different kinds of equipment connected to the power system such as; shunt capacitor banks, shunt reactors, motors and others.
- Back-up short circuit protection of power generators.

In many applications several steps with different current pickup levels and time delays are needed. OC4PTOC can have up to four different, individually settable steps. The following options are possible:

Non-directional / Directional function: In most applications the non-directional functionality is used. This is mostly the case when no fault current can be fed from the protected object itself. In order to achieve both selectivity and fast fault clearance, the directional function can be necessary.



If VT inputs are not available or not connected, the setting parameter *DirModex* ($x = \text{step } 1, 2, 3 \text{ or } 4$) shall be left to the default value *Non-directional*.

Choice of time delay characteristics: There are several types of time delay characteristics available such as definite time delay and different types of inverse time delay characteristics. The selectivity between different overcurrent protections is normally enabled by co-ordination between the function time delays of the different protections. To enable optimal co-ordination between all overcurrent

protections, they should have the same time delay characteristic. Therefore, a wide range of standardized inverse time characteristics are available for IEC and ANSI. It is also possible to tailor make the inverse time characteristic.

Normally, it is required that the phase overcurrent protection shall reset as fast as possible when the current level gets lower than the operation level. In some cases some sort of delayed reset is required. Therefore, different kinds of reset characteristics can be used.

For some protection applications, there can be a need to change the current pick-up level for some time. A typical case is when the protection will measure the current to a large motor. At the start up sequence of a motor the start current can be significantly larger than the rated current of the motor. Therefore, there is a possibility to give a setting of a multiplication factor to the current pick-up level. This multiplication factor is activated from a binary input signal to the function.

Power transformers can have a large inrush current, when being energized. This phenomenon is due to saturation of the transformer magnetic core during parts of the period. There is a risk that inrush current will reach levels above the pick-up current of the phase overcurrent protection. The inrush current has a large 2nd harmonic content. This can be used to avoid unwanted operation of the protection function. Therefore, OC4PTOC has a possibility of 2nd harmonic restrain if the level of 2nd harmonic current reaches a value above a set percent of the fundamental current.

The phase overcurrent protection is often used as a protection for two and three phase short circuits. In some cases, it is not wanted to detect single-phase earth faults by the phase overcurrent protection. This fault type is detected and cleared after operation of earth fault protection. Therefore, it is possible to make a choice how many phases, at minimum, that have to have current above the pick-up level, to enable operation. If set 1 of 3 it is sufficient to have high current in one phase only. If set 2 of 3 or 3 of 3 single-phase earth faults are not detected.

7.2.3

Setting guidelines



When inverse time overcurrent characteristic is selected, the operate time of the stage will be the sum of the inverse time delay and the set definite time delay. Thus, if only the inverse time delay is required, it is important to set the definite time delay for that stage to zero.

The parameters for the directional phase overcurrent protection, four steps OC4PTOC are set via the local HMI or PCM600.

The following settings can be done for OC4PTOC.

Common base IED values for primary current ($IBase$), primary voltage ($UBase$) and primary power ($SBase$) are set in the global base values for settings function GBASVAL.

GlobalBaseSel: This is used to select GBASVAL function for reference of base values.

MeasType: Selection of discrete Fourier filtered (*DFT*) or true RMS filtered (*RMS*) signals. *RMS* is used when the harmonic contents are to be considered, for example in applications with shunt capacitors.

Operation: The protection can be set to *On* or *Off*.

AngleRCA: Protection characteristic angle set in degrees. If the angle of the fault loop current has the angle RCA, the direction to the fault is forward.

AngleROA: Angle value, given in degrees, to define the angle sector of the directional function, shown in Figure [43](#).

StartPhSel: Number of phases, with high current, required for operation. The setting possibilities are: *1 out of 3*, *2 out of 3* and *3 out of 3*. The default setting is *1 out of 3*.

IMinOpPhSel: Minimum current setting level for releasing the directional start signals in % of IB . This setting should be less than the lowest step setting. The default setting is 7% of IB .

2ndHarmStab: Operate level of 2nd harmonic current restrain set in % of the fundamental current. The setting range is 5 - 100% in steps of 1%. The default setting is 20%.

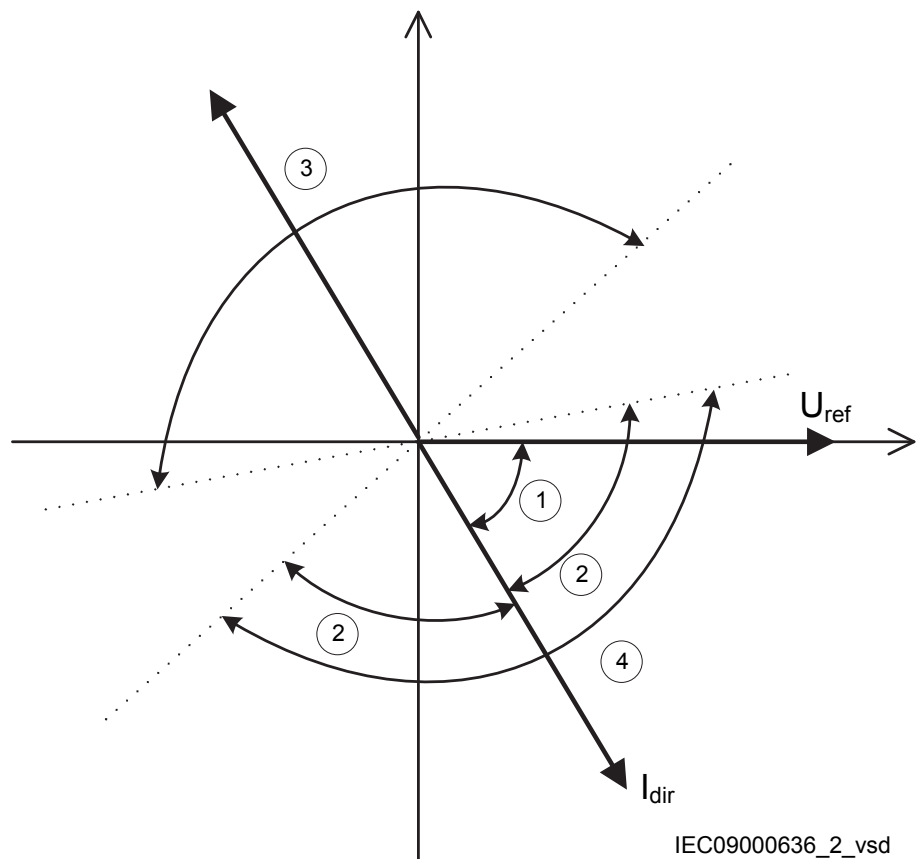


Figure 43: Directional function characteristic

1. RCA = Relay characteristic angle
2. ROA = Relay operating angle
3. Reverse
4. Forward

7.2.3.1

Settings for each step



x means step 1, 2, 3 and 4.

DirMod x : The directional mode of step x . Possible settings are *Off/Non-directional/Forward/Reverse*.

Characterist x : Selection of time characteristic for step x . Definite time delay and different types of inverse time characteristics are available according to Table [15](#).

Table 15: *Inverse time characteristics*

Curve name
ANSI Extremely Inverse
ANSI Very Inverse
ANSI Normal Inverse
ANSI Moderately Inverse
ANSI/IEEE Definite time
ANSI Long Time Extremely Inverse
ANSI Long Time Very Inverse
ANSI Long Time Inverse
IEC Normal Inverse
IEC Very Inverse
IEC Inverse
IEC Extremely Inverse
IEC Short Time Inverse
IEC Long Time Inverse
IEC Definite Time
User Programmable
ASEA RI
RXIDG or RD (logarithmic)

The different characteristics are described in *Technical manual*.

$I_{x>}$: Operate phase current level for step x given in % of I_B .

$I_{x>Max}$ and $I_{x>Min}$ should only be changed if remote setting of operation current level, $I_{x>}$, is used. The limits are used for decreasing the used range of the $I_{x>}$ setting. If $I_{x>}$ is set outside $I_{x>Max}$ and $I_{x>Min}$, the closest of the limits to $I_{x>}$ is used by the function. If $I_{x>Max}$ is smaller than $I_{x>Min}$, the limits are swapped.

t_x : Definite time delay for step x . The definite time t_x is added to the inverse time when inverse time characteristic is selected. Note that the value set is the time between activation of the start and the trip outputs.

k_x : Time multiplier for inverse time delay for step x .

I_{Minx} : Minimum operate current in % of I_B for all inverse time characteristics, below which no operation takes place.

t_{xMin} : Minimum operate time for all inverse time characteristics. At high currents the inverse time characteristic might give a very short operation time. By setting this parameter the operation time of the step can never be shorter than the setting. Setting range: 0.000 - 60.000s in steps of 0.001s.

IxMult: Multiplier for scaling of the current setting value. If a binary input signal ENMULTx (enableMultiplier) is activated the current operation level is increased by this setting constant. Setting range: 1.0-10.0

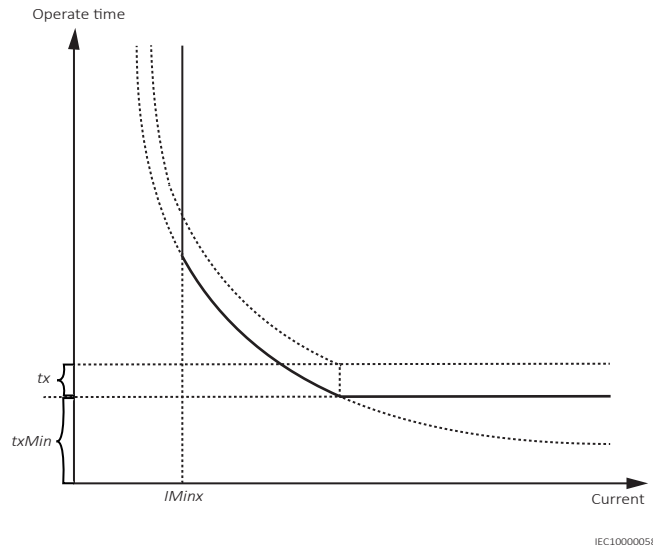


Figure 44: Minimum operate current and operate time for inverse time characteristics

In order to fully comply with the definition of the curve, the setting parameter *txMin* shall be set to a value equal to the operating time of the selected inverse curve for twenty times the set current pickup value. Note that the operate time is dependent on the selected time multiplier setting *kx*.

ResetTypeCrvx: The reset of the delay timer can be made as shown in Table 16.

Table 16: Reset possibilities

Curve name	Curve index no.
Instantaneous	1
IEC Reset (constant time)	2
ANSI Reset (inverse time)	3

The delay characteristics are described in *Technical manual*. There are some restrictions regarding the choice of the reset delay.

For the definite time delay characteristics, the possible delay time setting instantaneous (1) and IEC (2 = set constant time reset).

For ANSI inverse time characteristics, all three types of reset time characteristics are available: instantaneous (1), IEC (2 = set constant time reset) and ANSI (3 = current dependent reset time).

For IEC inverse time characteristics, the possible delay time settings are instantaneous (1) and IEC (2 = set constant time reset).

For the customer tailor-made inverse time delay characteristics (type 17), all three types of reset time characteristics are available: instantaneous (1), IEC (2 = set constant time reset) and ANSI (3 = current dependent reset time). If the current-dependent type is used, settings *pr*, *tr* and *cr* must be given.

tResetx: Constant reset time delay in seconds for step x.

tPCrvx, *tACrvx*, *tBCrvx*, *tCCrvx*: These parameters are used by the customer to create the inverse time characteristic curve. See equation 20 for the time characteristic equation. For more information, refer to *Technical manual*.

$$t[s] = \left(\frac{A}{\left(\frac{i}{in>} \right)^p - C} + B \right) \cdot IxMult$$

(Equation 20)

tPRCrvx, *tTRCrvx*, *tCRCrvx*: These parameters are used by the customer to create the inverse reset time characteristic curve. For more information, refer to *Technical manual*.

HarmRestrinx: Enables the block of step x from the harmonic restrain function (2nd harmonic). This function should be used when there is a risk of an unwanted trip caused by power transformer inrush currents. It can be set to *Off/On*.

7.2.3.2

Setting example

Directional phase overcurrent protection, four steps can be used in different ways, depending on the application where the protection is used. A general description is given below.

The operating current setting of the inverse time protection, or the lowest current step of the definite time protection, must be defined so that the highest possible load current does not cause protection operation. The protection reset current must also be considered so that a short peak of overcurrent does not cause the operation of a protection even when the overcurrent has ceased. This phenomenon is described in Figure 45.

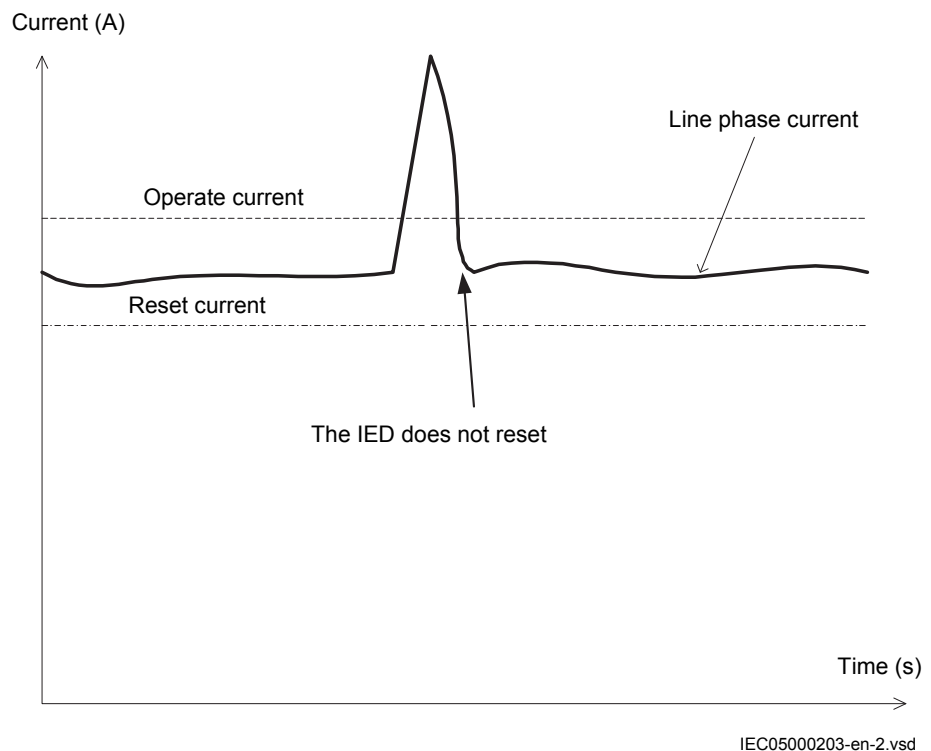


Figure 45: Operate and reset current for an overcurrent protection

The lowest setting value can be written according to Equation 21.

$$I_{pu} \geq 1.2 \cdot \frac{I_{max}}{k}$$

(Equation 21)

where:

- 1.2 is a safety factor
- k is the reset ratio of the protection
- I_{max} is the maximum load current

The load current up to the present situation can be found from operation statistics. The current setting must remain valid for several years. In most cases, the setting values are updated once every five years or less often. Investigate the maximum load current that the equipment on the line can withstand. Study components, such as line conductors, current transformers, circuit breakers, and disconnectors. The manufacturer of the equipment normally gives the maximum thermal load current of the equipment.

The maximum load current on the line has to be estimated. There is also a demand that all faults within the zone that the protection shall cover must be detected by the phase overcurrent protection. The minimum fault current I_{scmin} to be detected by

the protection must be calculated. Taking this value as a base, the highest pickup current setting can be written according to Equation 22.

$$I_{pu} \leq 0.7 \cdot I_{sc \min}$$

(Equation 22)

where:

0.7 is a safety factor

$I_{sc \min}$ is the smallest fault current to be detected by the overcurrent protection.

As a summary, the operating current shall be chosen within the interval stated in Equation 23.

$$1.2 \cdot \frac{I_{\max}}{k} \leq I_{pu} \leq 0.7 \cdot I_{sc \min}$$

(Equation 23)

The high current function of the overcurrent protection, which only has a short-delay trip time, must be given a current setting so that the protection is selective to other protection functions in the power system. It is desirable to have rapid tripping of faults within a large part of the power system to be protected by the protection (primary protected zone). A fault current calculation gives the largest current of faults, $I_{sc \max}$, at the most remote part of the primary protected zone. The risk of transient overreach must be considered, due to a possible DC component of the short circuit current. The lowest current setting of the fastest stage can be written according to

$$I_{high} \geq 1.2 \cdot k_t \cdot I_{sc \max}$$

(Equation 24)

where:

1.2 is a safety factor

k_t is a factor that takes care of the transient overreach due to the DC component of the fault current and can be considered to be less than 1.05

$I_{sc \max}$ is the largest fault current at a fault at the most remote point of the primary protection zone.

The operate time of the phase overcurrent protection has to be chosen so that the fault time is short enough that the protected equipment will not be destroyed due to thermal overload while, at the same time, selectivity is assured. For overcurrent protection in a radial fed network, the time setting can be chosen in a graphical way. This is mostly used in the case of inverse time overcurrent protection. Figure 46 shows how the time-versus-current curves are plotted in a diagram. The time setting is chosen to get the shortest fault time with maintained selectivity.

Selectivity is assured if the time difference between the curves is larger than a critical time difference.

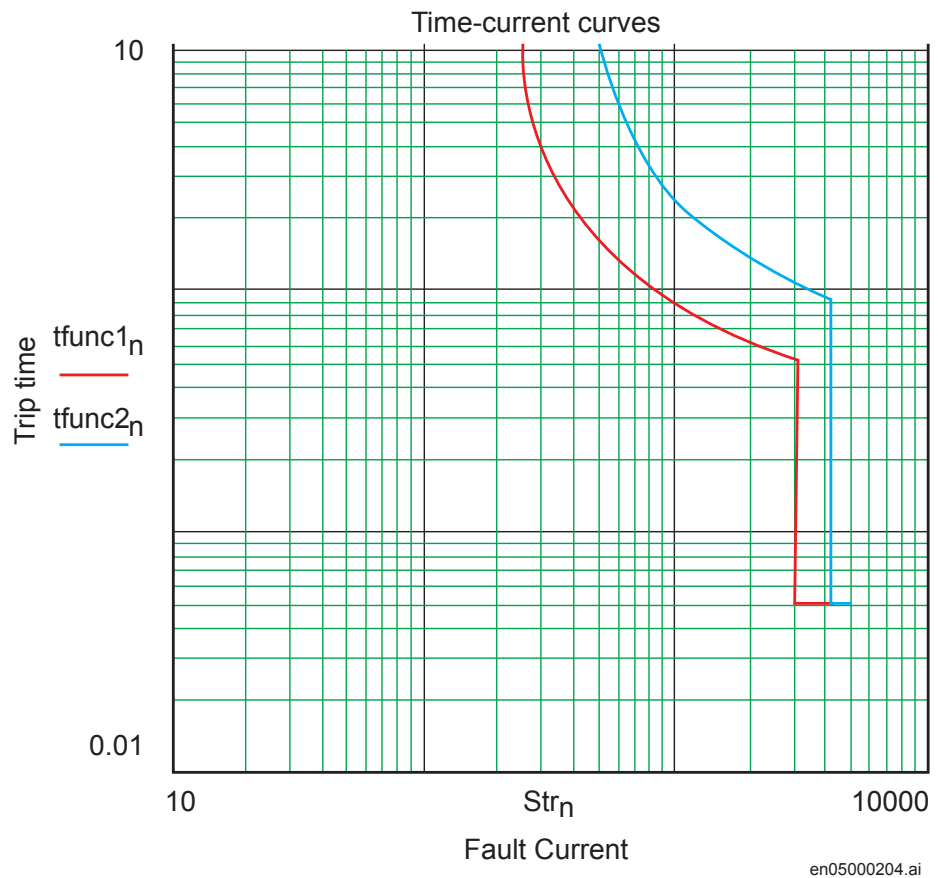


Figure 46: Fault time with maintained selectivity

The operation time can be set individually for each overcurrent protection.

To assure selectivity between different protection functions in the radial network, there has to be a minimum time difference Δt between the time delays of two protections. To determine the shortest possible time difference, the operation time of the protection, the breaker opening time and the protection resetting time must be known. These time delays can vary significantly between different protective equipment. The following time delays can be estimated:

Protection operation time:	15-60 ms
Protection resetting time:	15-60 ms
Breaker opening time:	20-120 ms

Example for time coordination

Assume two substations A and B directly connected to each other via one line, as shown in the Figure 47. Consider a fault located at another line from the station B. The fault current to the overcurrent protection of IED B1 has a magnitude so that the overcurrent protection will start and subsequently trip, and the overcurrent protection of IED A1 must have a delayed operation in order to avoid maloperation. The sequence of events during the fault can be described using a time axis shown in Figure 47.

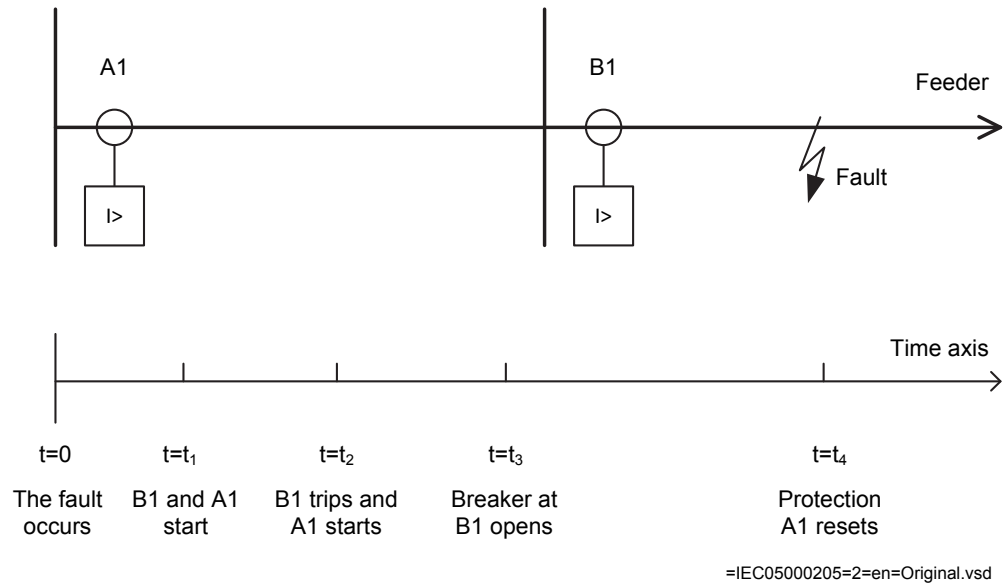


Figure 47: Sequence of events during fault

where:

- t=0 is when the fault occurs
- t=t₁ is when protection IED B1 and protection IED A1 start
- t=t₂ is when the trip signal from the overcurrent protection at IED B1 is sent to the circuit breaker.
- t=t₃ is when the circuit breaker at IED B1 opens. The circuit breaker opening time is $t_3 - t_2$
- t=t₄ is when the overcurrent protection at IED A1 resets. The protection resetting time is $t_4 - t_3$.

To ensure that the overcurrent protection at IED A1 is selective to the overcurrent protection at IED B1, the minimum time difference must be larger than the time t_3 . There are uncertainties in the values of protection operation time, breaker opening time and protection resetting time. Therefore a safety margin has to be included. With normal values the needed time difference can be calculated according to Equation 25.

$$\Delta t \geq 40\text{ ms} + 100\text{ ms} + 40\text{ ms} + 40\text{ ms} = 220\text{ ms}$$

(Equation 25)

where it is considered that:

the operate time of overcurrent protection B1 is 40 ms

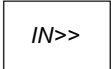
the breaker open time is 100 ms

the resetting time of protection A1 is 40 ms and

the additional margin is 40 ms

7.3 Instantaneous residual overcurrent protection EFPIOC

7.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Instantaneous residual overcurrent protection	EFPIOC		50N

7.3.2 Application

In many applications, when fault current is limited to a defined value by the object impedance, an instantaneous earth-fault protection can provide fast and selective tripping.

The Instantaneous residual overcurrent EFPIOC, which can operate in 15 ms (50 Hz nominal system frequency) for faults characterized by very high currents, is included in the IED.

7.3.3 Setting guidelines

The parameters for the Instantaneous residual overcurrent protection EFPIOC are set via the local HMI or PCM600.

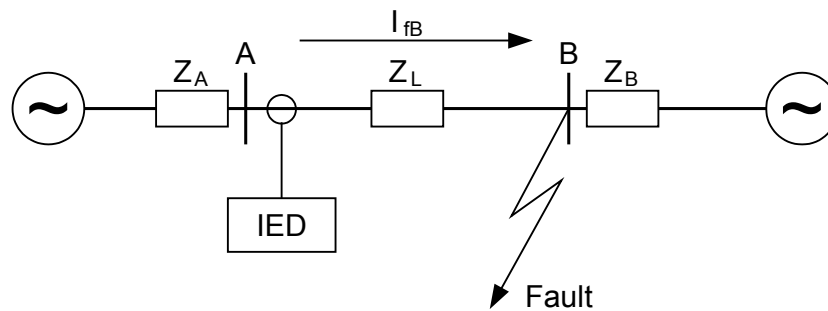
Some guidelines for the choice of setting parameter for EFPIOC is given.

Common base IED values for primary current (I_{Base}), primary voltage (U_{Base}) and primary power (S_{Base}) are set in the global base values for settings function GBASVAL.

GlobalBaseSel: This is used to select GBASVAL function for reference of base values.

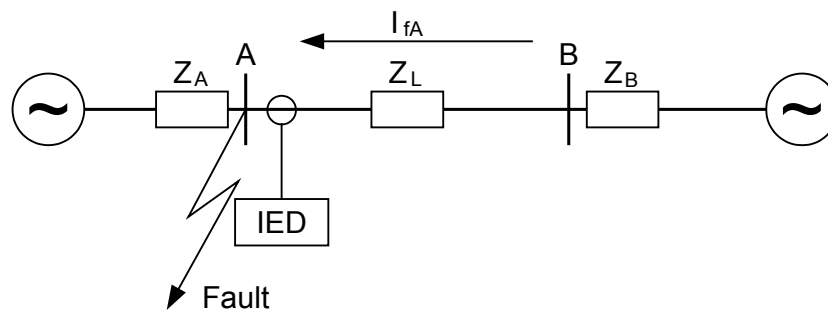
The basic requirement is to assure selectivity, that is EFPIOC shall not be allowed to operate for faults at other objects than the protected object (line).

For a normal line in a meshed system single phase-to-earth faults and phase-to-phase faults shall be calculated as shown in Figure 48 and Figure 49. The residual currents ($3I_0$) to the protection are calculated. For a fault at the remote line end this fault current is I_{fB} . In this calculation the operational state with high source impedance Z_A and low source impedance Z_B should be used. For the fault at the home busbar this fault current is I_{fA} . In this calculation the operational state with low source impedance Z_A and high source impedance Z_B should be used.



IEC09000022-1-en.vsd

Figure 48: Through fault current from A to B: I_{fB}



IEC09000023-1-en.vsd

Figure 49: Through fault current from B to A: I_{fA}

The function shall not operate for any of the calculated currents to the protection. The minimum theoretical current setting (I_{min}) will be:

$$I_{min} \geq \text{MAX}(I_{fA}, I_{fB})$$

(Equation 26)

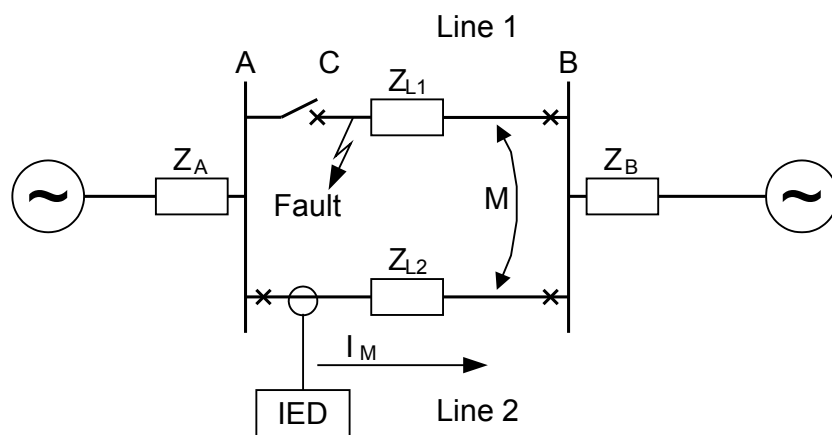
A safety margin of 5% for the maximum static inaccuracy and a safety margin of 5% for maximum possible transient overreach have to be introduced. An additional 20% is suggested due to inaccuracy of instrument transformers under transient conditions and inaccuracy in the system data.

The minimum primary current setting (I_s) is:

$$I_s = 1.3 \times I_{min}$$

(Equation 27)

In case of parallel lines with zero sequence mutual coupling a fault on the parallel line, as shown in Figure 50, should be calculated.



IEC09000025-1-en.vsd

Figure 50: Two parallel lines. Influence from parallel line to the through fault current: I_M

The minimum theoretical current setting (I_{min}) will in this case be:

$$I_{min} \geq \text{MAX}(I_{fA}, I_{fB}, I_M)$$

(Equation 28)

Where:

I_{fA} and I_{fB} have been described for the single line case.

Considering the safety margins mentioned previously, the minimum setting (I_s) is:

$$I_s = 1.3 \times I_{min}$$

(Equation 29)

The IED setting value $IN_{>>}$ is given in percent of the primary base current value, I_{Base} . The value for $IN_{>>}$ is given by the formula:

$$IN \geq (I_s / I_{Base}) * 100$$

(Equation 30)

Transformer inrush current shall be considered.

The setting of the protection is set as a percentage of the base current (I_{Base}).

Operation: set the protection to *On* or *Off*.

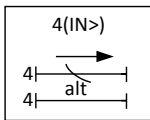
$IN \geq$: Set operate current in % of IB .

$IN \geq Max$ and $IN \geq Min$ should only be changed if remote setting of operation current level, $IN \geq$, is used. The limits are used for decreasing the used range of the $IN \geq$ setting. If $IN \geq$ is set outside $IN \geq Max$ and $IN \geq Min$, the closest of the limits to $IN \geq$ is used by the function. If $IN \geq Max$ is smaller than $IN \geq Min$, the limits are swapped.

StValMult: The set operate current can be changed by activation of the binary input ENMULT to the set factor *StValMult*.

7.4 Directional residual overcurrent protection, four steps EF4PTOC

7.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional residual overcurrent protection, four steps	EF4PTOC		51N_67N

7.4.2 Application

The directional residual overcurrent protection, four steps EF4PTOC is used in several applications in the power system. Some applications are:

- Earth-fault protection of feeders in effectively earthed distribution and subtransmission systems. Normally these feeders have radial structure.
- Back-up earth-fault protection of transmission lines.
- Sensitive earth-fault protection of transmission lines. EF4PTOC can have better sensitivity to detect resistive phase-to-earth-faults compared to distance protection.
- Back-up earth-fault protection of power transformers.
- Earth-fault protection of different kinds of equipment connected to the power system such as shunt capacitor banks, shunt reactors and others.

In many applications, several steps with different current operating levels and time delays are needed. EF4PTOC can have up to four, individual settable steps. The flexibility of each step of EF4PTOC is great. The following options are possible:

Non-directional/Directional function: In some applications the non-directional functionality is used. This is mostly the case when no fault current can be fed from the protected object itself. In order to achieve both selectivity and fast fault clearance, the directional function can be necessary. This can be the case for earth-fault protection in meshed and effectively earthed transmission systems. The directional residual overcurrent protection is also well suited to operate in teleprotection communication schemes, which enables fast clearance of earth faults on transmission lines. The directional function uses the polarizing quantity as decided by setting. Voltage polarizing is the most commonly used, but alternatively current polarizing where currents in transformer neutrals providing the neutral source (ZN) is used to polarize ($I_N \cdot Z_N$) the function. Dual polarizing, where the sum of both voltage and current components is allowed to polarize can also be selected.

Choice of time characteristics: There are several types of time characteristics available such as definite time delay and different types of inverse time characteristics. The selectivity between different overcurrent protections is normally enabled by co-ordination between the operate time of the different protections. To enable optimal co-ordination all overcurrent protections, to be co-ordinated against each other, should have the same time characteristic. Therefore a wide range of standardized inverse time characteristics are available for IEC and ANSI.

Table 17: *Time characteristics*

Curve name
ANSI Extremely Inverse
ANSI Very Inverse
ANSI Normal Inverse
ANSI Moderately Inverse
ANSI/IEEE Definite time
ANSI Long Time Extremely Inverse
ANSI Long Time Very Inverse
Table continues on next page

Curve name
ANSI Long Time Inverse
IEC Normal Inverse
IEC Very Inverse
IEC Inverse
IEC Extremely Inverse
IEC Short Time Inverse
IEC Long Time Inverse
IEC Definite Time
User Programmable
ASEA RI
RXIDG or RD (logarithmic)

It is also possible to tailor make the inverse time characteristic.

Normally it is required that EF4PTOC shall reset as fast as possible when the current level gets lower than the operation level. In some cases some sort of delayed reset is required. Therefore different kinds of reset characteristics can be used.

For some protection applications, there can be a need to change the current operating level for some time. Therefore, there is a possibility to give a setting of a multiplication factor $INxMult$ to the residual current pick-up level. This multiplication factor is activated from a binary input signal ENMULTx to the function.

Power transformers can have a large inrush current, when being energized. This inrush current can produce residual current component. The phenomenon is due to saturation of the transformer magnetic core during parts of the cycle. There is a risk that inrush current will give a residual current that reaches level above the operating current of the residual overcurrent protection. The inrush current has a large second harmonic content. This can be used to avoid unwanted operation of the protection. Therefore, EF4PTOC has a possibility of second harmonic restrain if the level of 2nd harmonic current reaches a value above a set percent of the fundamental current.

7.4.3

Setting guidelines



When inverse time overcurrent characteristic is selected, the operate time of the stage will be the sum of the inverse time delay and the set definite time delay. Thus, if only the inverse time delay is required, it is important to set the definite time delay for that stage to zero.

The parameters for the four step residual overcurrent protection are set via the local HMI or PCM600. The following settings can be done for the function.

Common base IED values for primary current (I_{Base}), primary voltage (U_{Base}) and primary power (S_{Base}) are set in the global base values for settings function GBASVAL.

GlobalBaseSel: This is used to select GBASVAL function for reference of base values.

SeqTypeUPol: This is used to select the type of voltage polarising quantity i.e. Zero seq and Neg seq for direction detection.

SeqTypeIPol: This is used to select the type of current polarising quantity i.e. Zero seq and Neg seq for direction detection.

SeqTypeIDir: This is used to select the type of operating current quantity i.e. Zero seq and Neg seq for direction detection.

7.4.3.1

Common settings for all steps

AngleRCA: Relay characteristic angle given in degree. This angle is defined as shown in Figure 51. The angle is defined positive when the residual current lags the reference voltage ($U_{pol} = 3U_0$ or U_2)

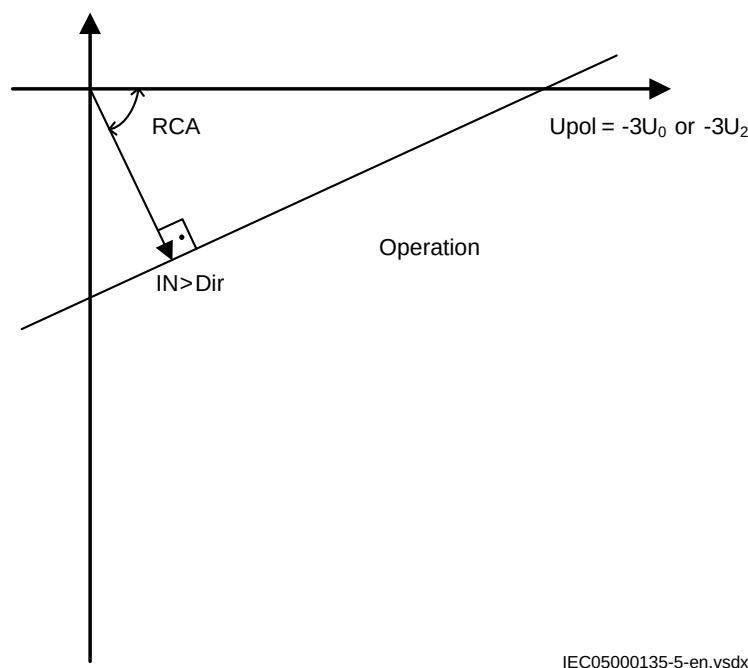


Figure 51: Relay characteristic angle given in degree

In a normal transmission network a normal value of RCA is about 65° . The setting range is -180° to $+180^\circ$.

polMethod: Defines if the directional polarization is from

- *Voltage* ($3U_0$ or U_2)
- *Current* ($3I_0 \cdot ZN_{pol}$ or $3I_2 \cdot ZN_{pol}$ where ZN_{pol} is $RN_{pol} + jXN_{pol}$), or
- both currents and voltage, *Dual* (dual polarizing, $(3U_0 + 3I_0 \cdot ZN_{pol})$ or $(U_2 + I_2 \cdot ZN_{pol})$).

Normally voltage polarizing from the internally calculated residual sum or an external open delta is used.

Current polarizing is useful when the local source is strong and a high sensitivity is required. In such cases the polarizing voltage ($3U_0$) can be below 1% and it is then necessary to use current polarizing or dual polarizing. Multiply the required set current (primary) with the minimum impedance (ZN_{pol}) and check that the percentage of the phase-to-earth voltage is definitely higher than 1% (minimum $3U_0 > UPolMin$ setting) as a verification.

RN_{pol}, *XN_{pol}*: The zero-sequence source is set in primary ohms as base for the current polarizing. The polarizing voltage is then achieved as $3I_0 \cdot ZN_{pol}$. The ZN_{pol} can be defined as $(ZS_1 - ZS_0)/3$, that is the earth return impedance of the source behind the protection. The maximum earth-fault current at the local source can be used to calculate the value of ZN as $U/(\sqrt{3} \cdot 3I_0)$. Typically, the minimum ZN_{pol} ($3 \cdot$ zero sequence source) is set. The setting is in primary ohms.

When the dual polarizing method is used, it is important that the setting *IN_x* or the product $3I_0 \cdot ZN_{pol}$ is not greater than $3U_0$. If so, there is a risk for incorrect operation for faults in the reverse direction.

IPolMin: is the minimum earth-fault current accepted for directional evaluation. For smaller currents than this value, the operation will be blocked. A typical setting is 5-10% of *IB*.

UPolMin: Minimum polarization (reference) polarizing voltage for the directional function, given in % of $U_{Base}/\sqrt{3}$.

IN_xDir: Operate residual current release level in % of *IB* for directional comparison scheme. The setting is given in % of *IB* and must be set below the lowest *IN_x* setting, set for the directional measurement. The output signals, STFW and STRV can be used in a teleprotection scheme. The appropriate signal should be configured to the communication scheme block.

7.4.3.2

2nd harmonic restrain

If a power transformer is energized there is a risk that the current transformer core will saturate during part of the period, resulting in a transformer inrush current. This will give a declining residual current in the network, as the inrush current is deviating between the phases. There is a risk that the residual overcurrent function will give an unwanted trip. The inrush current has a relatively large ratio of 2nd

harmonic component. This component can be used to create a restrain signal to prevent this unwanted function.

At current transformer saturation a false residual current can be measured by the protection. Here the 2nd harmonic restrain can prevent unwanted operation as well.

2ndHarmStab: The rate of 2nd harmonic current content for activation of the 2nd harmonic restrain signal. The setting is given in % of the fundamental frequency residual current.

7.4.3.3

Parallel transformer inrush current logic

In case of parallel transformers there is a risk of sympathetic inrush current. If one of the transformers is in operation, and the parallel transformer is switched in, the asymmetric inrush current of the switched-in transformer will cause partial saturation of the transformer already in service. This is called transferred saturation. The 2nd harmonic of the inrush currents of the two transformers will be in phase opposition. The summation of the two currents will thus give a small 2nd harmonic current. The residual fundamental current will however be significant. The inrush current of the transformer in service before the parallel transformer energizing, will be a little delayed compared to the first transformer. Therefore, we will have high 2nd harmonic current initially. After a short period this current will however be small and the normal 2nd harmonic blocking will reset.

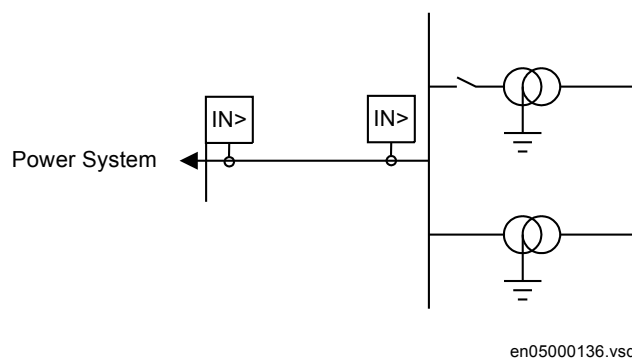


Figure 52: Application for parallel transformer inrush current logic

If the *BlkParTransf* function is activated, the 2nd harmonic restrain signal will latch as long as the residual current measured by the relay is larger than a selected step current level. Assume that step 4 is chosen to be the most sensitive step of the four step residual overcurrent protection function EF4PTOC. The harmonic restrain blocking is enabled for this step. Also the same current setting as this step is chosen for the blocking at parallel transformer energizing.

The settings for the parallel transformer logic are described below.

BlkParTransf: This is used to *On* blocking at energising of parallel transformers.

UseStartValue: Gives which current level should be used for the activation of the blocking signal. This is given as one of the settings of the steps: Step 1/2/3/4. Normally, the step having the lowest operation current level should be set.

7.4.3.4

Switch onto fault logic

In case of energizing a faulty object there is a risk of having a long fault clearance time, if the fault current is too small to give fast operation of the protection. The switch on to fault function can be activated from auxiliary signals from the circuit breaker, either the close command or the open/close position (change of position).

This logic can be used to issue a fast trip if one breaker pole does not close properly at a manual or automatic closing.

SOTF and under time are similar functions to achieve fast clearance at asymmetrical closing based on requirements from different utilities.

The function is divided into two parts. The SOTF function will give operation from step 2 or 3 during a set time after change in the position of the circuit breaker. The SOTF function has a set time delay. The under time function, which has 2nd harmonic restrain blocking, will give operation from step 4. The 2nd harmonic restrain will prevent unwanted function in case of transformer inrush current. The under time function has a set time delay.

Below the settings for switch on to fault logics are described.

SOTF: This parameter can be set: *Off/SOTF/Under Time/SOTF+Under Time*.

ActivationSOTF: This setting will select the signal to activate SOTF function; *CB position open/CB position closed/CB close command*.

StepForSOTF: If this parameter is set on step 3, the step 3 start signal will be used as current set level. If set on step 2, the step 2 start signal will be used as current set level.

HarmBlkSOTF: This is used to *On/Off* harmonic restrain during SOTF conditions.

tSOTF: Time delay for operation of the SOTF function. The setting range is 0.000 - 60.000 s in step of 0.001 s. The default setting is 0.100 s

t4U: Time interval when the SOTF function is active after breaker closing. The setting range is 0.000 - 60.000 s in step of 0.001 s. The default setting is 1.000 s.

ActUnderTime: Describes the mode to activate the sensitive undertime function. The function can be activated by Circuit breaker position (change) or Circuit breaker command.

tUnderTime: Time delay for operation of the sensitive undertime function. The setting range is 0.000 - 60.000 s in step of 0.001 s. The default setting is 0.300 s

7.4.3.5**Settings for each step (x = 1, 2, 3 and 4)**

Operation: Sets the protection to *On* or *Off*.

DirModex: The directional mode of step *x*. Possible settings are *Off/Non-directional/Forward/Reverse*.

Characteristx: Selection of time characteristic for step *x*. Definite time delay and different types of inverse time characteristics are available.

Inverse time characteristic enables fast fault clearance of high current faults at the same time as selectivity to other inverse time phase overcurrent protections can be assured. This is mainly used in radial fed networks but can also be used in meshed networks. In meshed networks, the settings must be based on network fault calculations.

To assure selectivity between different protections, in the radial network, there has to be a minimum time difference Δt between the time delays of two protections. To determine the shortest possible time difference, the operation time of protections, breaker opening time and protection resetting time must be known. These time delays can vary significantly between different protective equipment. The following time delays can be estimated:

Protection operate time:	15-60 ms
Protection resetting time:	15-60 ms
Breaker opening time:	20-120 ms

The different characteristics are described in the technical reference manual.

tx: Definite time delay for step *x*. The definite time *tx* is added to the inverse time when inverse time characteristic is selected. Note that the value set is the time between activation of the start and the trip outputs.

INx>: Operate residual current level for step *x* given in % of *IB*.

INx>Max and *INx>Min* should only be changed if remote setting of operation current level, *INx>*, is used. The limits are used for decreasing the used range of the *INx>* setting. If *INx>* is set outside *INx>Max* and *INx>Min*, the closest of the limits to *INx>* is used by the function. If *INx>Max* is smaller than *INx>Min*, the limits are swapped.

kx: Time multiplier for the dependent (inverse) characteristic for step *x*.

: Minimum operate current for step in % of *IB*. Set below *INx>* for every step to achieve ANSI reset characteristic according to standard. If is set above *INx>* for any step, signal will reset at current equals to zero.

txMin: Minimum operating time for inverse time characteristics. At high currents, the inverse time characteristic might give a very short operation time. By setting this parameter, the operation time of the step can never be shorter than the setting.

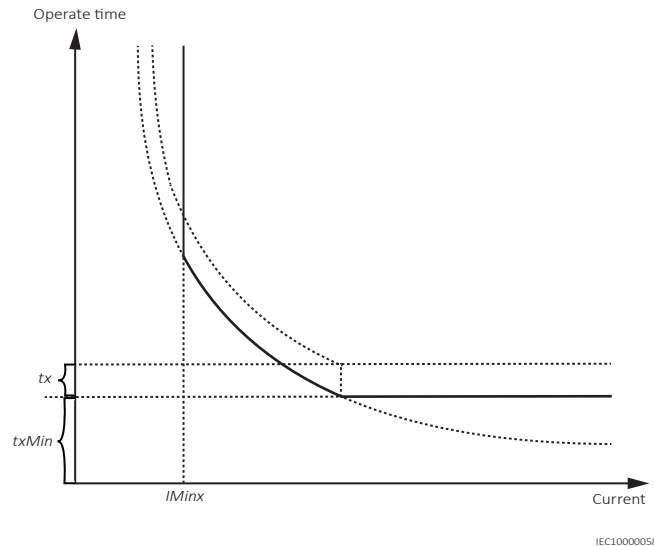


Figure 53: Minimum operate current and operate time for inverse time characteristics

In order to fully comply with the curves definition, the setting parameter *txMin* shall be set to the value which is equal to the operate time of the selected IEC inverse curve for measured current of twenty times the set current pickup value. Note that the operate time value is dependent on the selected setting value for time multiplier *kx*.

INxMult: Multiplier for scaling of the current setting value. If a binary input signal (ENMULTx) is activated, the current operation level is increased by this setting constant.

ResetTypeCrvx: The reset of the delay timer can be made in different ways. The possibilities are described in the technical reference manual.

tResetx: Constant reset time delay in s for step x.

HarmBlockx: This is used to enable block of step x from 2nd harmonic restrain function.

tPCrvx, *tACrvx*, *tBCrvx*, *tCCrvx*: Parameters for user programmable of inverse time characteristic curve. The time characteristic equation is according to equation 31:

$$t[s] = \left(\frac{A}{\left(\frac{i}{i_n} \right)^p - C} + B \right) \cdot k$$

(Equation 31)

Further description can be found in the technical reference manual.

$tPRCrvx$, $tTRCrvx$, $tCRCrvx$: Parameters for user programmable of inverse reset time characteristic curve. Further description can be found in the technical reference manual.

7.4.3.6

Transformer application example

Two main cases are of interest when residual overcurrent protection is used for a power transformer, namely if residual current can be fed from the protected transformer winding or not.

The protected winding will feed earth-fault (residual) current to earth faults in the connected power system. The residual current fed from the transformer at external phase-to-earth faults is highly dependent on the total positive and zero-sequence source impedances. It is also dependent on the residual current distribution between the network zero-sequence impedance and the transformer zero-sequence impedance. An example of this application is shown in Figure 54.

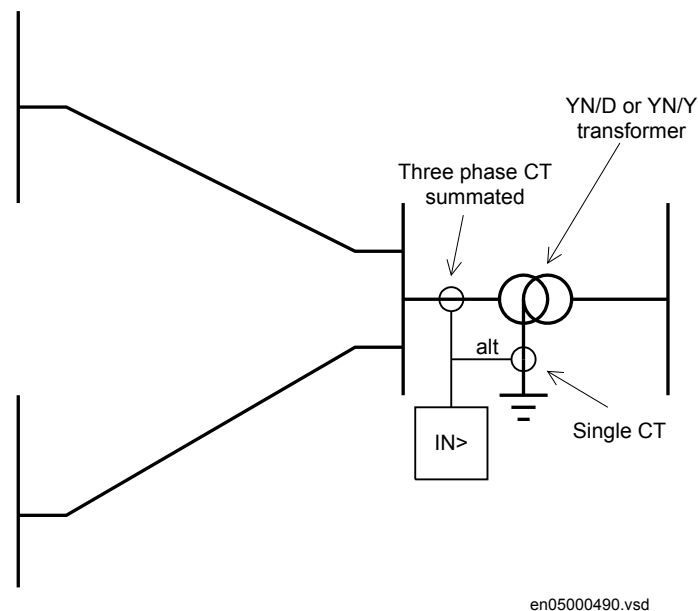


Figure 54: Residual overcurrent protection application on a directly earthed transformer winding

In this case the protection has two different tasks:

- Detection of earth faults on the transformer winding.
- Detection of earth faults in the power system.

It can be suitable to use a residual overcurrent protection with at least two steps. Step 1 shall have a short definite time delay and a relatively high current setting, in order to detect and clear high current earth faults in the transformer winding or in the power system close to the transformer. Step 2 shall have a longer time delay (definite or inverse time delay) and a lower current operation level. Step 2 shall detect and clear transformer winding earth faults with low earth-fault current, that is, faults close to the transformer winding neutral point. If the current setting gap between step 1 and step 2 is large another step can be introduced with a current and time delay setting between the two described steps.

The transformer inrush current will have a large residual current component. To prevent unwanted function of the earth-fault overcurrent protection, the 2nd harmonic restrain blocking should be used, at least for the sensitive step 2.

If the protected winding will not feed earth-fault (residual) current to earth faults in the connected power system, the application is as shown in Figure 55.

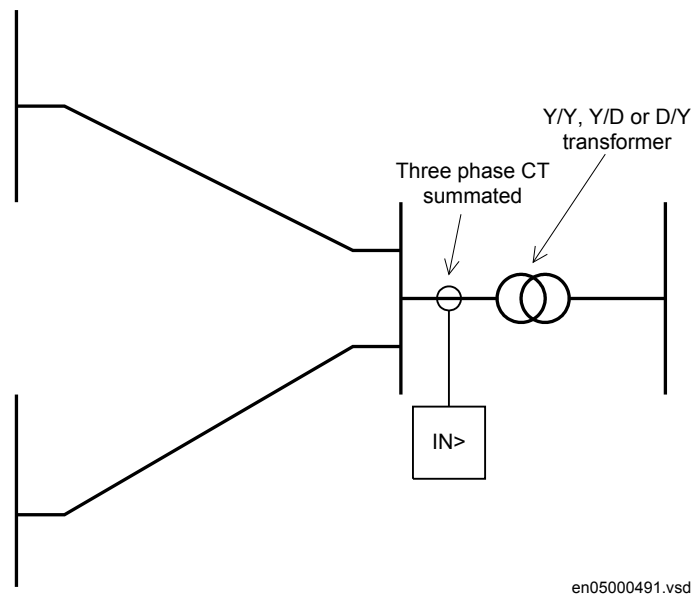


Figure 55: Residual overcurrent protection application on an isolated transformer winding

In the calculation of the fault current fed to the protection, at different earth faults, are highly dependent on the positive and zero sequence source impedances, as well as the division of residual current in the network. Earth-fault current calculations are necessary for the setting.

Setting of step 1

One requirement is that earth faults at the busbar, where the transformer winding is connected, shall be detected. Therefore a fault calculation as shown in Figure 56 is made.

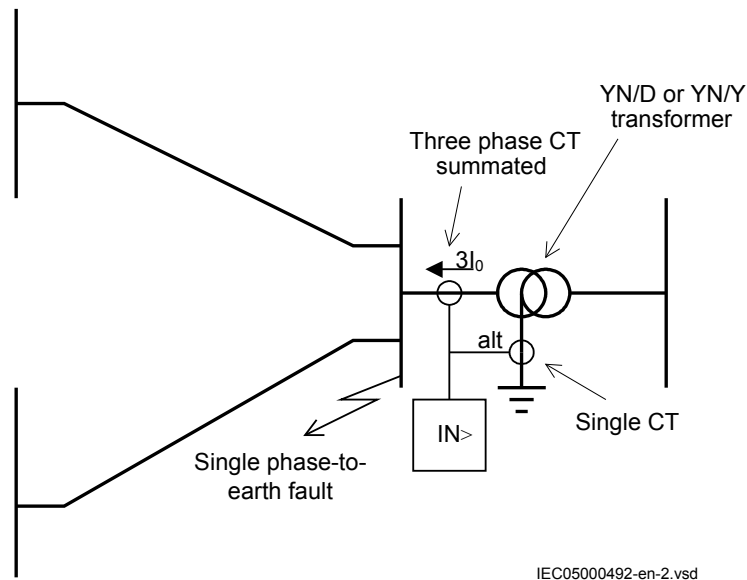


Figure 56: Step 1 fault calculation 1

This calculation gives the current fed to the protection: $3I_{0\text{fault}1}$.

To assure that step 1, selectivity to other earth-fault protections in the network a short delay is selected. Normally, a delay in the range 0.3 – 0.4 s is appropriate. To assure selectivity to line faults, tripped after a delay (typically distance protection zone 2) of about 0.5 s the current setting must be set so high so that such faults does not cause unwanted step 1 trip. Therefore, a fault calculation as shown in Figure 57 is made.

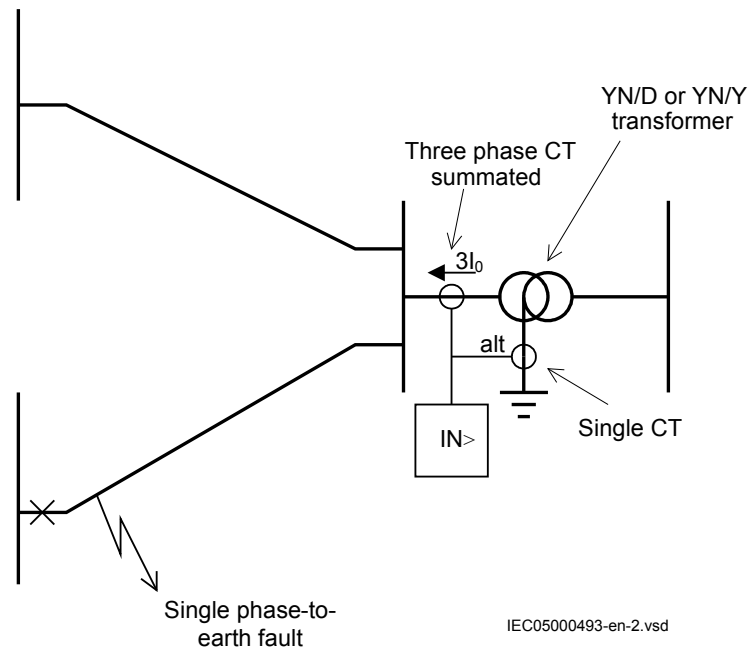


Figure 57: Step 1 fault calculation 1

The fault is located at the borderline between instantaneous and delayed operation of the line protection, such as Distance protection or line residual overcurrent protection. This calculation gives the current fed to the protection: $3I_{0\text{fault}2}$

The setting of step 1 can be chosen within the interval shown in equation 32.

$$3I_{0\text{fault}2} \cdot \text{lowmar} < I_{\text{step}1} < 3I_{0\text{fault}1} \cdot \text{highmar}$$

(Equation 32)

Where:

lowmar is a margin to assure selectivity (typical 1.2) and

highmar is a margin to assure fast fault clearance of busbar fault (typical 1.2).

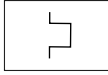
Setting of step 2

The setting of the sensitive step 2 is dependent of the chosen time delay. Often a relatively long definite time delay or inverse time delay is chosen. The current setting can be chosen very low. As it is required to detect earth faults in the transformer winding, close to the neutral point, values down to the minimum setting possibilities can be chosen. However, one must consider zero-sequence currents that can occur during normal operation of the power system. Such currents can be due to un-transposed lines.

In case to protection of transformer windings not feeding residual current at external earth faults, a fast low current step can be acceptable.

7.5 Thermal overload protection, two time constants TRPTTR

7.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Thermal overload protection, two time constants	TRPTTR		49

7.5.2 Application

Transformers in the power system are designed for a certain maximum load current (power) level. If the current exceeds this level the losses will be higher than expected. As a consequence the temperature of the transformer will increase. If the temperature of the transformer reaches too high a value, the equipment might be damaged;

- The insulation within the transformer experiences forced ageing. As a consequence of this, the risk of internal phase-to-phase or phase-to-earth faults increases.
- There might be hot spots within the transformer, which degrades the paper insulation. It might also cause bubbling in the transformer oil.

In stressed situations in the power system it can be required to overload transformers for a limited time. This should be done without the above mentioned risks. The thermal overload protection provides information and makes temporary overloading of transformers possible.

The permissible load level of a power transformer is highly dependent on the cooling system of the transformer. There are two main principles:

- OA: The air is naturally circulated to the coolers without fans and the oil is naturally circulated without pumps.
- FOA: The coolers have fans to force air for cooling and pumps to force the circulation of the transformer oil.

The protection can have two sets of parameters, one for non-forced cooling and one for forced cooling. Both the permissive steady state loading level as well as the thermal time constant is influenced by the cooling system of the transformer. The two parameters sets can be activated by the binary input signal COOLING. This

can be used for transformers where forced cooling can be taken out of operation, for example at fan or pump faults.

The thermal overload protection estimates the internal heat content of the transformer (temperature) continuously. This estimation is made by using a thermal model of the transformer which is based on current measurement.

If the heat content of the protected transformer reaches a set alarm level a signal can be given to the operator. Two alarm levels are available. This enables preventive actions in the power system to be taken before dangerous temperatures are reached. If the temperature continues to increase to the trip value, the protection initiates a trip of the protected transformer.

After tripping by the thermal overload protection, the transformer will cool down over time. There will be a time gap before the heat content (temperature) reaches such a level so that the transformer can be taken into service again. Therefore, the function will continue to estimate the heat content using a set cooling time constant. Energizing of the transformer can be blocked until the heat content has reached a set level.

7.5.3

Setting guideline

The parameters for the thermal overload protection, two time constants (TRPTTR) are set via the local HMI or Protection and Control IED Manager (PCM600).

The following settings can be done for the thermal overload protection:

Operation: Off/On

Operation: Sets the mode of operation. *Off* switches off the complete function.

GlobalBaseSel: Selects the global base value group used by the function to define (IBase), (UBase) and (SBase).

IRef: Reference level of the current given in % of *IBase*. When the current is equal to *IRef* the final (steady state) heat content is equal to 1. It is suggested to give a setting corresponding to the rated current of the transformer winding.

IRefMult: If a binary input ENMULT is activated the reference current value can be multiplied by the factor *IRefMult*. The activation could be used in case of deviating ambient temperature from the reference value. In the standard for loading of a transformer an ambient temperature of 20°C is used. For lower ambient temperatures the load ability is increased and vice versa. *IRefMult* can be set within a range: 0.01 - 10.00.

IBase1: Base current for setting given as percentage of *IBase*. This setting shall be related to the status with no COOLING input. It is suggested to give a setting corresponding to the rated current of the transformer with natural cooling (OA).

IBase2: Base current for setting given as percentage of *IBase*. This setting shall be related to the status with activated COOLING input. It is suggested to give a

setting corresponding to the rated current of the transformer with forced cooling (FOA). If the transformer has no forced cooling I_{Base2} can be set equal to I_{Base1} .

Tau1: The thermal time constant of the protected transformer, related to I_{Base1} (no cooling) given in minutes.

Tau2: The thermal time constant of the protected transformer, related to I_{Base2} (with cooling) given in minutes.

The thermal time constant should be obtained from the transformer manufacturers manuals. The thermal time constant is dependent on the cooling and the amount of oil. Normal time constants for medium and large transformers (according to IEC 60076-7) are about 2.5 hours for naturally cooled transformers and 1.5 hours for forced cooled transformers.

The time constant can be estimated from measurements of the oil temperature during a cooling sequence (described in IEC 60076-7). It is assumed that the transformer is operated at a certain load level with a constant oil temperature (steady state operation). The oil temperature above the ambient temperature is $\Delta\Theta_{o0}$. Then the transformer is disconnected from the grid (no load). After a time t of at least 30 minutes the temperature of the oil is measured again. Now the oil temperature above the ambient temperature is $\Delta\Theta_{ot}$. The thermal time constant can now be estimated as:

$$\tau = \frac{t}{\ln \Delta\Theta_{o0} - \ln \Delta\Theta_{ot}}$$

(Equation 33)

If the transformer has forced cooling (FOA) the measurement should be made both with and without the forced cooling in operation, giving *Tau2* and *Tau1*.

The time constants can be changed if the current is higher than a set value or lower than a set value. If the current is high it is assumed that the forced cooling is activated while it is deactivated at low current. The setting of the parameters below enables automatic adjustment of the time constant.

Tau1High: Multiplication factor to adjust the time constant *Tau1* if the current is higher than the set value *IHighTau1*. *IHighTau1* is set in % of I_{Base1} .

Tau1Low: Multiplication factor to adjust the time constant *Tau1* if the current is lower than the set value *ILowTau1*. *ILowTau1* is set in % of I_{Base1} .

Tau2High: Multiplication factor to adjust the time constant *Tau2* if the current is higher than the set value *IHighTau2*. *IHighTau2* is set in % of I_{Base2} .

Tau2Low: Multiplication factor to adjust the time constant *Tau2* if the current is lower than the set value *ILowTau2*. *ILowTau2* is set in % of I_{Base2} .

The possibility to change time constant with the current value as the base can be useful in different applications. Below some examples are given:

- In case a total interruption (low current) of the protected transformer all cooling possibilities will be inactive. This can result in a changed value of the time constant.
- If other components (motors) are included in the thermal protection, there is a risk of overheating of that equipment in case of very high current. The thermal time constant is often smaller for a motor than for the transformer.

ITrip: The steady state current that the transformer can withstand. The setting is given in % of *IBase1* or *IBase2*.

Alarm1: Heat content level for activation of the signal ALARM1. ALARM1 is set in % of the trip heat content level.

Alarm2: Heat content level for activation of the output signal ALARM2. ALARM2 is set in % of the trip heat content level.

ResLo: Lockout release level of heat content to release the lockout signal. When the thermal overload protection trips a lock-out signal is activated. This signal is intended to block switching on of the protected circuit transformer as long as the transformer temperature is high. The signal is released when the estimated heat content is below the set value. This temperature value should be chosen below the alarm temperature. *ResLo* is set in % of the trip heat content level.

ThetaInit: Heat content before activation of the function. This setting can be set a little below the alarm level. If the transformer is loaded before the activation of the protection function, its temperature can be higher than the ambient temperature. The start point given in the setting will prevent risk of no trip at overtemperature during the first moments after activation. *ThetaInit*: is set in % of the trip heat content level.

Warning: If the calculated time to trip factor is below the setting *Warning* a warning signal is activated. The setting is given in minutes.

7.6

Breaker failure protection CCRBRF

7.6.1

Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Breaker failure protection, 3-phase activation and output	CCRBRF	$3I > BF$	50BF

7.6.2

Application

In the design of the fault clearance system the N-1 criterion is often used. This means that a fault needs to be cleared even if any component in the fault clearance system is faulty. One necessary component in the fault clearance system is the circuit breaker. It is from practical and economical reason not feasible to duplicate the circuit breaker for the protected object. Instead a breaker failure protection is used.

Breaker failure protection, 3-phase activation and output (CCRBRF) will issue a back-up trip command to adjacent circuit breakers in case of failure to trip of the “normal” circuit breaker for the protected object. The detection of failure to break the current through the breaker is made by means of current measurement or as detection of remaining trip signal (unconditional).

CCRBRF can also give a re-trip. This means that a second trip signal is sent to the protected circuit breaker. The re-trip function can be used to increase the probability of operation of the breaker, or it can be used to avoid back-up trip of many breakers in case of mistakes during relay maintenance and testing.

7.6.3

Setting guidelines

The parameters for Breaker failure protection 3-phase activation and output CCRBRF are set via the local HMI or PCM600.

The following settings can be done for the breaker failure protection.

GlobalBaseSel: Selects the global base value group used by the function to define *IBase*, *UBase* and *SBase* as applicable.

Operation: *Off/On*

FunctionMode This parameter can be set *Current* or *Contact*. This states the way the detection of failure of the breaker is performed. In the mode *current* the current measurement is used for the detection. In the mode *Contact* the long duration of breaker position signal is used as indicator of failure of the breaker. The mode *Current/Contact* means that both ways of detections are activated. *Contact* mode can be usable in applications where the fault current through the circuit breaker is small. This can be the case for some generator protection application (for example reverse power protection) or in case of line ends with weak end infeed.

RetripMode: This setting states how the re-trip function shall operate. *Retrip Off* means that the re-trip function is not activated. *CB Pos Check* (circuit breaker position check) and *Current* means that a phase current must be larger than the operate level to allow re-trip. *CB Pos Check* (circuit breaker position check) and *Contact* means re-trip is done when circuit breaker is closed (breaker position is used). *No CBPos Check* means re-trip is done without any check of breaker position.

Table 18: *Dependencies between parameters RetripMode and FunctionMode*

<i>RetripMode</i>	<i>FunctionMode</i>	<i>Description</i>
<i>Retrip Off</i>	N/A	the re-trip function is not activated
<i>CB Pos Check</i>	<i>Current</i>	re-trip is done if the phase current is larger than the operate level after re-trip time has elapsed
	<i>Contact</i>	re-trip is done when auxiliary contact position indicates that breaker is still closed after re-trip time has elapsed
	<i>Current/Contact</i>	both methods according to above are used but taken into account also <i>I>BlkCont</i>
<i>No CBPos Check</i>	<i>Current</i>	re-trip is done without check of current level
	<i>Contact</i>	re-trip is done without check of auxiliary contact position
	<i>Current/Contact</i>	re-trip is done without check of current level or auxiliary contact position

BuTripMode: Back-up trip mode is given to state sufficient current criteria to detect failure to break. For *Current* operation *2 out of 4* means that at least two currents, of the three-phase currents and the residual current, shall be high to indicate breaker failure. *1 out of 3* means that at least one current of the three-phase currents shall be high to indicate breaker failure. *1 out of 4* means that at least one current of the three-phase currents or the residual current shall be high to indicate breaker failure. In most applications *1 out of 3* is sufficient. For *Contact* operation means back-up trip is done when circuit breaker is closed (breaker position is used).

IP>: Current level for detection of breaker failure, set in % of *IBase*. This parameter should be set so that faults with small fault current can be detected. The setting can be chosen in accordance with the most sensitive protection function to start the breaker failure protection. Typical setting is 10% of *IBase*.

I>BlkCont: If any contact based detection of breaker failure is used, this function can be blocked if any phase current is larger than this setting level. If the *FunctionMode* is set *Current/Contact* breaker failure for high current faults are safely detected by the current measurement function. To increase security the contact based function should be disabled for high currents. The setting can be given within the range 5 – 200% of *IBase*.

IN>: Residual current level for detection of breaker failure set in % of *IBase*. In high impedance earthed systems the residual current at phase- to-earth faults are normally much smaller than the short circuit currents. In order to detect breaker failure at single-phase-earth faults in these systems it is necessary to measure the residual current separately. Also in effectively earthed systems the setting of the earth-fault current protection can be chosen to relatively low current level. The

BuTripMode is set 1 out of 4. The current setting should be chosen in accordance to the setting of the sensitive earth-fault protection. The setting can be given within the range 2 – 200 % of *IBase*.

t1: Time delay of the re-trip. The setting can be given within the range 0 – 60s in steps of 0.001 s. Typical setting is 0 – 50ms.

t2: Time delay of the back-up trip. The choice of this setting is made as short as possible at the same time as unwanted operation must be avoided. Typical setting is 90 – 200ms (also dependent of re-trip timer).

The minimum time delay for the re-trip can be estimated as:

$$t2 \geq t1 + t_{cbopen} + t_{BFP\_reset} + t_{margin}$$

(Equation 34)

where:

t_{cbopen}	is the maximum opening time for the circuit breaker
t_{BFP_reset}	is the maximum time for breaker failure protection to detect correct breaker function (the current criteria reset)
t_{margin}	is a safety margin

It is often required that the total fault clearance time shall be less than a given critical time. This time is often dependent of the ability to maintain transient stability in case of a fault close to a power plant.

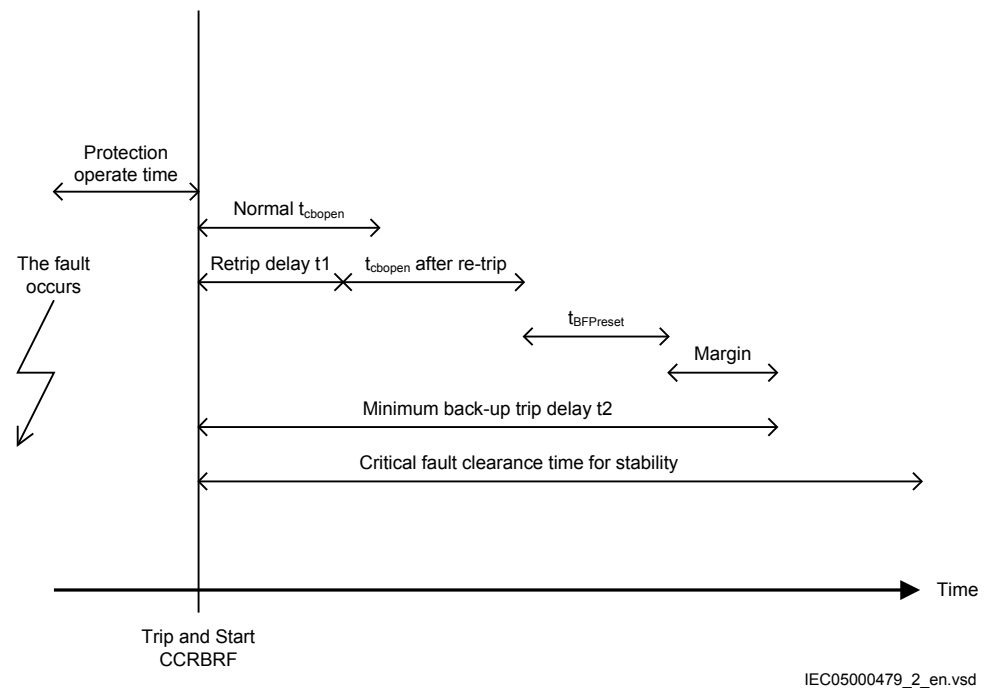


Figure 58: Time sequence

t2MPH: Time delay of the back-up trip at multi-phase start. The critical fault clearance time is often shorter in case of multi-phase faults, compared to single phase-to-earth faults. Therefore there is a possibility to reduce the back-up trip delay for multi-phase faults. Typical setting is 90 – 150 ms.

t3: Additional time delay to *t2* for a second back-up trip TRBU2. In some applications there might be a requirement to have separated back-up trip functions, tripping different back-up circuit breakers.

tCBAlarm: Time delay for alarm in case of indication of faulty circuit breaker. There is a binary input CBFLT from the circuit breaker. This signal is activated when internal supervision in the circuit breaker detect that the circuit breaker is unable to clear fault. This could be the case when gas pressure is low in a SF6 circuit breaker. After the set time an alarm is given, so that actions can be done to repair the circuit breaker. The time delay for back-up trip is bypassed when the CBFLT is active. Typical setting is 2.0 seconds.

tPulse: Trip pulse duration. This setting must be larger than the critical impulse time of circuit breakers to be tripped from the breaker failure protection. Typical setting is 200 ms.

7.7

Pole discordance protection CCPDSC

7.7.1

Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Pole discordance protection	CCPDSC	PD	52PD

7.7.2

Application

There is a risk that a circuit breaker will get discordance between the poles at circuit breaker operation: closing or opening. One pole can be open and the other two closed, or two poles can be open and one closed. Pole discordance of a circuit breaker will cause unsymmetrical currents in the power system. The consequence of this can be:

- Negative sequence currents that will give stress on rotating machines
- Zero sequence currents that might give unwanted operation of sensitive earth-fault protections in the power system.

It is therefore important to detect situations with pole discordance of circuit breakers. When this is detected the breaker should be tripped directly.

Pole discordance protection CCPDSC will detect situation with deviating positions of the poles of the protected circuit breaker. The protection has two different options to make this detection:

- By connecting the auxiliary contacts in the circuit breaker so that logic is created, a signal can be sent to the protection, indicating pole discordance. This logic can also be realized within the protection itself, by using opened and close signals for each circuit breaker pole, connected to the protection.
- Each phase current through the circuit breaker is measured. If the difference between the phase currents is larger than a *CurrUnsymLevel* this is an indication of pole discordance, and the protection will operate.

7.7.3

Setting guidelines

The parameters for the Pole discordance protection CCPDSC are set via the local HMI or PCM600.

The following settings can be done for the pole discordance protection.

GlobalBaseSel: Selects the global base value group used by the function to define *IBase*, *UBase* and *SBase* as applicable.

Operation: Off or On

tTrip: Time delay of the operation.

ContSel: Operation of the contact based pole discordance protection. Can be set: *Off*/*PD signal from CB*. If *PD signal from CB* is chosen the logic to detect pole discordance is made in the vicinity to the breaker auxiliary contacts and only one signal is connected to the pole discordance function. If the *Pole pos aux cont.* alternative is chosen each open close signal is connected to the IED and the logic to detect pole discordance is realized within the function itself.

CurrSel: Operation of the current based pole discordance protection. Can be set: *Off*/*CB oper monitor*/*Continuous monitor*. In the alternative *CB oper monitor* the function is activated only directly in connection to breaker open or close command (during 200 ms). In the alternative *Continuous monitor* function is continuously activated.

CurrUnsymLevel: Unsymmetrical magnitude of lowest phase current compared to the highest, set in % of the highest phase current. Natural difference between phase currents in 1 1/2 breaker installations must be considered. For circuit breakers in 1 1/2 breaker configured switch yards there might be natural unbalance currents through the breaker. This is due to the existence of low impedance current paths in the switch yard. This phenomenon must be considered in the setting of the parameter.

CurrRelLevel: Current magnitude for release of the function in % of *IBase*.

Section 8 Voltage protection

8.1 Two step undervoltage protection UV2PTUV

8.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Two step undervoltage protection	UV2PTUV	$3U<$	27

8.1.2 Application

Two-step undervoltage protection function (UV2PTUV) is applied to power system elements, such as generators, transformers, motors and power lines in order to detect low voltage conditions. It is used as a supervision and fault detection function for other protection functions as well, to increase the security of a complete protection system. Low voltage conditions are caused by abnormal operation or faults in the power system, such as:

- Malfunctioning of a voltage regulator or wrong settings under manual control (symmetrical voltage decrease)
- Overload (symmetrical voltage decrease)
- Short circuits, often as phase-to-earth faults (unsymmetrical voltage decrease)

UV2PTUV is used in combination with overcurrent protections, either as restraint or in logic "and gates" of the trip signals issued by the two functions. It can also be used to:

- Detect no voltage conditions, for example, before the energization of a HV line or for automatic breaker trip in case of a blackout
- Initiate voltage correction measures, like insertion of shunt capacitor banks to compensate for reactive load and thereby increasing the voltage
- Disconnect apparatuses, like electric motors, which will be damaged when subject to service under low voltage conditions.

The function has a high measuring accuracy and a settable hysteresis to allow applications to control reactive load.

In many cases, UV2PTUV is a useful function in circuits for local or remote automation processes in the power system.

8.1.3 Setting guidelines

All the voltage conditions in the system where UV2PTUV performs its functions should be considered. The same also applies to the associated equipment, its voltage and time characteristic.

There is a very wide application area where general undervoltage functions are used. All voltage-related settings are made as a percentage of the global base value *UBase*, which normally is set to the primary rated voltage level (phase-to-phase) of the power system or the high voltage equipment under consideration.

The trip time setting for UV2PTUV is normally not critical, since there must be enough time available for the main protection to clear short circuits and earth faults.

Some applications and related setting guidelines for the voltage level are described in the following sections.

8.1.3.1 Equipment protection, such as for motors and generators

The setting must be below the lowest occurring "normal" voltage and above the lowest acceptable voltage for the equipment.

8.1.3.2 Disconnected equipment detection

The setting must be below the lowest occurring "normal" voltage and above the highest occurring voltage, caused by inductive or capacitive coupling, when the equipment is disconnected.

8.1.3.3 Power supply quality

The setting must be below the lowest occurring "normal" voltage and above the lowest acceptable voltage, due to regulation, good practice or other agreements.

8.1.3.4 Voltage instability mitigation

This setting is very much dependent on the power system characteristics, and thorough studies have to be made to find the suitable levels.

8.1.3.5 Backup protection for power system faults

The setting must be below the lowest occurring "normal" voltage and above the highest occurring voltage during the fault conditions under consideration.

8.1.3.6

Settings for two step undervoltage protection

The following settings can be done for Two step undervoltage protection UV2PTUV:

ConnType: Sets whether the measurement shall be phase-to-earth fundamental value, phase-to-phase fundamental value, phase-to-earth RMS value or phase-to-phase RMS value.

Operation: Off or On.

UBase (given in *GlobalBaseSel*): Base voltage phase-to-phase in primary kV. This voltage is used as reference for voltage setting. UV2PTUV will operate if the voltage becomes lower than the set percentage of *UBase*. This setting is used when *ConnType* is set to *PhPh DFT* or *PhPh RMS*. Therefore, always set *UBase* as rated primary phase-to-phase voltage of the protected object. For more information, refer to the *Technical manual*.

The setting parameters described below are identical for the two steps ($n = 1$ or 2). Therefore, the setting parameters are described only once.

Characteristicn: This parameter gives the type of time delay to be used. The setting can be *Definite time*, *Inverse Curve A*, *Inverse Curve B*, *Prog. inv. curve*. The selection is dependent on the protection application.

OpModen: This parameter describes how many of the three measured voltages should be below the set level to give operation for step n . The setting can be *1 out of 3*, *2 out of 3* or *3 out of 3*. In most applications, it is sufficient that one phase voltage is low to give operation. If UV2PTUV shall be insensitive for single phase-to-earth faults, *2 out of 3* can be chosen. In subtransmission and transmission networks the undervoltage function is mainly a system supervision function and *3 out of 3* is selected.

Un<: Set operate undervoltage operation value for step n , given as % of the parameter *UBase*. The setting is highly dependent on the protection application. It is essential to consider the minimum voltage at non-faulted situations. Normally, this non-faulted voltage is larger than 90% of the nominal voltage.

tn: time delay of step n , given in s. This setting is dependent on the protection application. In many applications the protection function shall not directly trip when there is a short circuit or earth faults in the system. The time delay must be coordinated to the other short circuit protections.

tResetn: Reset time for step n if definite time delay is used, given in s. The default value is 25 ms.

tnMin: Minimum operation time for inverse time characteristic for step n , given in s. When using inverse time characteristic for the undervoltage function during very low voltages can give a short operation time. This might lead to unselective tripping. By setting *tnMin* longer than the operation time for other protections, such unselective tripping can be avoided.

ResetTypeCrvn: This parameter for inverse time characteristic can be set to *Instantaneous*, *Frozen time*, *Linearly decreased*. The default setting is *Instantaneous*.

tIResetrn: Reset time for step *n* if inverse time delay is used, given in s. The default value is 25 ms.

kn: Time multiplier for inverse time characteristic. This parameter is used for coordination between different inverse time delayed undervoltage protections.

ACrvn, *BCrvn*, *CCrvn*, *DCrvn*, *PCrvn*: Parameters to create a programmable under voltage inverse time characteristic. Description of this can be found in the *Technical manual*.

CrvSatn: Tuning parameter that is used to compensate for the undesired discontinuity created when the denominator in the equation for the customer programmable curve is equal to zero. For more information, see the *Technical manual*.

IntBlkSeln: This parameter can be set to *Off*, *Block of trip*, *Block all*. In case of a low voltage the undervoltage function can be blocked. This function can be used to prevent function when the protected object is switched off. If the parameter is set *Block of trip* or *Block all* unwanted trip is prevented.

IntBlkStValn: Voltage level under which the blocking is activated set in % of *UBase*. This setting must be lower than the setting *Un<*. As switch of shall be detected the setting can be very low, that is, about 10%.

tBlkUVn: Time delay to block the undervoltage step *n* when the voltage level is below *IntBlkStValn*, given in s. It is important that this delay is shorter than the operate time delay of the undervoltage protection step.

8.2 Two step overvoltage protection OV2PTOV

8.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Two step overvoltage protection	OV2PTOV	$3U>$	59

8.2.2

Application

Two step overvoltage protection OV2PTOV is applicable in all situations, where reliable detection of high voltage is necessary. OV2PTOV is used for supervision and detection of abnormal conditions, which, in combination with other protection functions, increase the security of a complete protection system.

High overvoltage conditions are caused by abnormal situations in the power system. OV2PTOV is applied to power system elements, such as generators, transformers, motors and power lines in order to detect high voltage conditions. OV2PTOV is used in combination with low current signals, to identify a transmission line, open in the remote end. In addition to that, OV2PTOV is also used to initiate voltage correction measures, like insertion of shunt reactors, to compensate for low load, and thereby decreasing the voltage. The function has a high measuring accuracy and hysteresis setting to allow applications to control reactive load.

OV2PTOV is used to disconnect apparatuses, like electric motors, which will be damaged when subject to service under high voltage conditions. It deals with high voltage conditions at power system frequency, which can be caused by:

1. Different kinds of faults, where a too high voltage appears in a certain power system, like metallic connection to a higher voltage level (broken conductor falling down to a crossing overhead line, transformer flash over fault from the high voltage winding to the low voltage winding and so on).
2. Malfunctioning of a voltage regulator or wrong settings under manual control (symmetrical voltage decrease).
3. Low load compared to the reactive power generation (symmetrical voltage decrease).
4. Earth-faults in high impedance earthed systems causes, beside the high voltage in the neutral, high voltages in the two non-faulted phases, (unsymmetrical voltage increase).

OV2PTOV prevents sensitive equipment from running under conditions that could cause their overheating or stress of insulation material, and, thus, shorten their life time expectancy. In many cases, it is a useful function in circuits for local or remote automation processes in the power system.

8.2.3

Setting guidelines

The parameters for Two step overvoltage protection (OV2PTOV) are set via the local HMI or PCM600.

All the voltage conditions in the system where OV2PTOV performs its functions should be considered. The same also applies to the associated equipment, its voltage and time characteristic.

There are wide applications where general overvoltage functions are used. All voltage related settings are made as a percentage of a settable base primary voltage,

which is normally set to the nominal voltage level (phase-to-phase) of the power system or the high voltage equipment under consideration.

The time delay for the OV2PTOV can sometimes be critical and related to the size of the overvoltage - a power system or a high voltage component can withstand smaller overvoltages for some time, but in case of large overvoltages the related equipment should be disconnected more rapidly.

Some applications and related setting guidelines for the voltage level are given below:

The hysteresis is for overvoltage functions very important to prevent that a transient voltage over set level is not “sealed-in” due to a high hysteresis. Typical values should be $\leq 0.5\%$.

8.2.3.1 Equipment protection, such as for motors, generators, reactors and transformers

High voltage will cause overexcitation of the core and deteriorate the winding insulation. The setting has to be well above the highest occurring "normal" voltage and well below the highest acceptable voltage for the equipment.

8.2.3.2 Equipment protection, capacitors

High voltage will deteriorate the dielectricum and the insulation. The setting has to be well above the highest occurring "normal" voltage and well below the highest acceptable voltage for the capacitor.

8.2.3.3 Power supply quality

The setting has to be well above the highest occurring "normal" voltage and below the highest acceptable voltage, due to regulation, good practice or other agreements.

8.2.3.4 High impedance earthed systems

In high impedance earthed systems, earth-faults cause a voltage increase in the non-faulty phases. Two step overvoltage protection (OV2PTOV) is used to detect such faults. The setting must be above the highest occurring "normal" voltage and below the lowest occurring voltage during faults. A metallic single-phase earth-fault causes the non-faulted phase voltages to increase a factor of $\sqrt{3}$.

8.2.3.5 The following settings can be done for the two step overvoltage protection

ConnType: Sets whether the measurement shall be phase-to-earth fundamental value, phase-to-phase fundamental value, phase-to-earth RMS value or phase-to-phase RMS value.

Operation: Off/On.

UBase (given in *GlobalBaseSel*): Base voltage phase to phase in primary kV. This voltage is used as reference for voltage setting. OV2PTOV measures selectively phase-to-earth voltages, or phase-to-phase voltage chosen by the setting *ConnType*. The function will operate if the voltage gets lower than the set percentage of *UBase*. When *ConnType* is set to *PhN DFT* or *PhN RMS* then the IED automatically divides set value for *UBase* by $\sqrt{3}$. When *ConnType* is set to *PhPh DFT* or *PhPh RMS* then set value for *UBase* is used. Therefore, always set *UBase* as rated primary phase-to-phase voltage of the protected object. If phase to neutral (PhN) measurement is selected as setting, the operation of phase-to-earth over voltage is automatically divided by $\sqrt{3}$. This means operation for phase-to-earth voltage over:

$$U > (\%) \cdot UBase(kV) / \sqrt{3}$$

and operation for phase-to-phase voltage over:

$$U > (\%) \cdot UBase(kV)$$

(Equation 36)

The below described setting parameters are identical for the two steps ($n = 1$ or 2). Therefore the setting parameters are described only once.

Characteristicn: This parameter gives the type of time delay to be used. The setting can be *Definite time*, *Inverse Curve A*, *Inverse Curve B*, *Inverse Curve C* or *I/Prog. inv. curve*. The choice is highly dependent of the protection application.

OpModen: This parameter describes how many of the three measured voltages that should be above the set level to give operation. The setting can be *1 out of 3*, *2 out of 3*, *3 out of 3*. In most applications it is sufficient that one phase voltage is high to give operation. If the function shall be insensitive for single phase-to-earth faults *1 out of 3* can be chosen, because the voltage will normally rise in the non-faulted phases at single phase-to-earth faults. In subtransmission and transmission networks the UV function is mainly a system supervision function and 3 out of 3 is selected.

Un>: Set operate overvoltage operation value for step n , given as % of *UBase*. The setting is highly dependent of the protection application. Here it is essential to consider the maximum voltage at non-faulted situations. Normally this voltage is less than 110% of nominal voltage.

tn: time delay of step n , given in s. The setting is highly dependent of the protection application. In many applications the protection function is used to prevent damages to the protected object. The speed might be important for example in case of protection of transformer that might be overexcited. The time delay must be coordinated with other automated actions in the system.

tResetn: Reset time for step *n* if definite time delay is used, given in s. The default value is 25 ms.

tnMin: Minimum operation time for inverse time characteristic for step *n*, given in s. For very high voltages the overvoltage function, using inverse time characteristic, can give very short operation time. This might lead to unselective trip. By setting *tnMin* longer than the operation time for other protections such unselective tripping can be avoided.

ResetTypeCrvn: This parameter for inverse time characteristic can be set: *Instantaneous*, *Frozen time*, *Linearly decreased*. The default setting is *Instantaneous*.

tIResetn: Reset time for step *n* if inverse time delay is used, given in s. The default value is 25 ms.

kn: Time multiplier for inverse time characteristic. This parameter is used for co-ordination between different inverse time delayed undervoltage protections.

ACrvn, *BCrvn*, *CCrvn*, *DCrvn*, *PCrvn*: Parameters to set to create programmable under voltage inverse time characteristic. Description of this can be found in the technical reference manual.

CrvSatn: When the denominator in the expression of the programmable curve is equal to zero the time delay will be infinity. There will be an undesired discontinuity. Therefore a tuning parameter *CrvSatn* is set to compensate for this phenomenon. In the voltage interval $Un >$ up to $Un > \cdot (1.0 + CrvSatn/100)$ the used voltage will be: $Un > \cdot (1.0 + CrvSatn/100)$. If the programmable curve is used, this parameter must be calculated so that:

$$B \cdot \frac{CrvSatn}{100} - C > 0$$

(Equation 37)

HystAbsn: Absolute hysteresis set in % of *UBase*. The setting of this parameter is highly dependent of the application. If the function is used as control for automatic switching of reactive compensation devices the hysteresis must be set smaller than the voltage change after switching of the compensation device.

8.3 Two step residual overvoltage protection ROV2PTOV

8.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Two step residual overvoltage protection	ROV2PTOV	$2(U_0 >)$	59N

8.3.2 Application

Two step residual overvoltage protection ROV2PTOV is primarily used in high impedance earthed distribution networks, mainly as a backup for the primary earth-fault protection of the feeders and the transformer. To increase the security for different earth-fault related functions, the residual overvoltage signal can be used as a release signal. The residual voltage can be measured either at the transformer neutral or from a voltage transformer open delta connection. The residual voltage can also be calculated internally, based on the measurement of the three phase-to-earth voltages.

In high impedance earthed systems the residual voltage will increase in case of any fault connected to earth. Depending on the type of fault and fault resistance the residual voltage will reach different values. The highest residual voltage, equal to three times the phase-to-earth voltage, is achieved for a single phase-to-earth fault. The residual voltage increases approximately to the same level in the whole system and does not provide any guidance in finding the faulted component. Therefore, ROV2PTOV is often used as a backup protection or as a release signal for the feeder earth-fault protection.

8.3.3 Setting guidelines

All the voltage conditions in the system where ROV2PTOV performs its functions should be considered. The same also applies to the associated equipment, its voltage withstand capability and time characteristic.

All voltage-related settings are made as a percentage of a settable base voltage, which shall be set to the primary nominal voltage (phase-phase) level of the power system or the high-voltage equipment under consideration.

The time delay for ROV2PTOV is seldom critical, since residual voltage is related to earth faults in a high-impedance earthed system, and enough time must normally be given for the primary protection to clear the fault. In some more specific

situations, where the residual overvoltage protection is used to protect some specific equipment, the time delay is shorter.

Some applications and related setting guidelines for the residual voltage level are given below.

8.3.3.1 **Equipment protection, such as for motors, generators, reactors and transformers**

High residual voltage indicates earth-fault in the system, perhaps in the component to which two step residual overvoltage protection (ROV2PTOV) is connected. For selectivity reasons to the primary protection for the faulted device, ROV2PTOV must trip the component with some time delay. The setting must be above the highest occurring "normal" residual voltage and below the highest acceptable residual voltage for the equipment.

8.3.3.2 **Equipment protection, capacitors**

High voltage will deteriorate the dielectric and the insulation. Two step residual overvoltage protection (ROV2PTOV) has to be connected to a neutral or open delta winding. The setting must be above the highest occurring "normal" residual voltage and below the highest acceptable residual voltage for the capacitor.

8.3.3.3 **Power supply quality**

The setting must be above the highest occurring "normal" residual voltage and below the highest acceptable residual voltage, due to regulation, good practice or other agreements.

8.3.3.4 **High impedance earthed systems**

In high impedance earthed systems, earth faults cause a neutral voltage in the feeding transformer neutral. Two step residual overvoltage protection ROV2PTOV is used to trip the transformer, as a backup protection for the feeder earth-fault protection, and as a backup for the transformer primary earth-fault protection. The setting must be above the highest occurring "normal" residual voltage, and below the lowest occurring residual voltage during the faults under consideration. A metallic single-phase earth fault causes a transformer neutral to reach a voltage equal to the nominal phase-to-earth voltage.

The voltage transformers measuring the phase-to-earth voltages measure zero voltage in the faulty phase. The two healthy phases will measure full phase-to-phase voltage, as the faulty phase will be connected to earth. The residual overvoltage will be three times the phase-to-earth voltage. See figure [59](#).

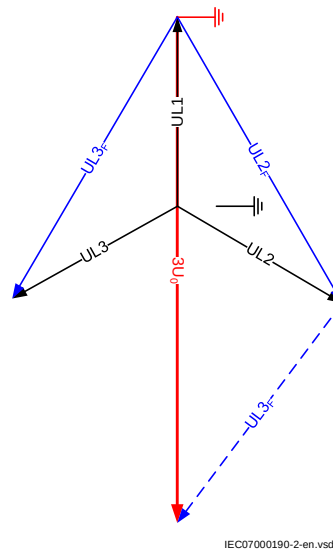


Figure 59: Earth fault in Non-effectively earthed systems

8.3.3.5

Direct earthed system

In direct earthed systems, an earth fault on one phase is indicated by voltage collapse in that phase. The other healthy phase will still have normal phase-to-earth voltage. The residual sum will have the same value as the remaining phase-to-earth voltage, which is shown in Figure 60.

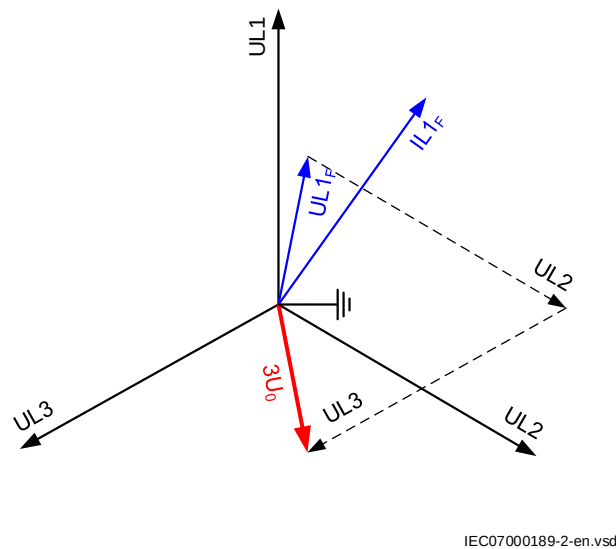


Figure 60: Earth fault in Direct earthed system

8.3.3.6

Settings for two step residual overvoltage protection

Operation: Off or On

UBase (given in *GlobalBaseSel*) is used as voltage reference for the set pickup values. The voltage can be fed to the IED in different ways:

1. The IED is fed from a normal voltage transformer group where the residual voltage is calculated internally from the phase-to-earth voltages within the protection. The setting of the analog input is given as $U_{Base}=U_{ph-ph}$.
2. The IED is fed from a broken delta connection normal voltage transformer group. In an open delta connection the protection is fed by the voltage $3U_0$ (single input). Section *Analog inputs* in the Application manual explains how the analog input needs to be set.
3. The IED is fed from a single voltage transformer connected to the neutral point of a power transformer in the power system. In this connection the protection is fed by the voltage $U_N=U_0$ (single input). Section *Analog inputs* in the Application manual explains how the analog input needs to be set.

ROV2PTOV will measure the residual voltage corresponding to the nominal phase-to-earth voltage for a high-impedance earthed system. The measurement will be based on the neutral voltage displacement.

The setting parameters described below are identical for the two steps ($n = \text{step 1 and 2}$). Therefore the setting parameters are described only once.

OperationStepn: This is to enable/disable operation of step n .

Characteristicn: Selected inverse time characteristic for step n . This parameter gives the type of time delay to be used. The setting can be, *Definite time* or *Inverse curve A* or *Inverse curve B* or *Inverse curve C* or *Prog. inv. curve*. The choice is highly dependent of the protection application.

Un>: Set operate overvoltage operation value for step n , given as % of residual voltage corresponding to *UBase*:

$$U > (\%) \cdot U_{Base}(kV) / \sqrt{3}$$

(Equation 38)

The setting depends on the required sensitivity of the protection and the type of system earthing. In non-effectively earthed systems, the residual voltage cannot be higher than three times the rated phase-to-earth voltage, which should correspond to 100%.

In effectively earthed systems, this value depends on the ratio Z_0/Z_1 . The required setting to detect high resistive earth faults must be based on network calculations.

tn: time delay of step n , given in s. The setting is highly dependent on the protection application. In many applications, the protection function has the task to prevent damage to the protected object. The speed might be important, for

example, in the case of the protection of a transformer that might be overexcited. The time delay must be co-ordinated with other automated actions in the system.

tResetn: Reset time for step *n* if definite time delay is used, given in s. The default value is 25 ms.

tnMin: Minimum operation time for inverse time characteristic for step *n*, given in s. For very high voltages the overvoltage function, using inverse time characteristic, can give very short operation time. This might lead to unselective trip. By setting *tMin* longer than the operation time for other protections such unselective tripping can be avoided.

ResetTypeCrvn: Set reset type curve for step *n*. This parameter can be set: *Instantaneous, Frozen time, Linearly decreased*. The default setting is *Instantaneous*.

tIResetn: Reset time for step *n* if inverse time delay is used, given in s. The default value is 25 ms.

kn: Time multiplier for inverse time characteristic. This parameter is used for co-ordination between different inverse time delayed undervoltage protections.

ACrvn, BCrvn, CCrvn, DCrvn, PCrvn: Parameters for step *n*, to set to create programmable undervoltage inverse time characteristic. Description of this can be found in the technical reference manual.

CrvSatn: Set tuning parameter for step *n*. When the denominator in the expression of the programmable curve is equal to zero, the time delay will be infinite. There will be an undesired discontinuity. Therefore, a tuning parameter *CrvSatn* is set to compensate for this phenomenon. In the voltage interval $U >$ up to $U > \cdot (1.0 + CrvSatn/100)$ the used voltage will be: $U > \cdot (1.0 + CrvSatn/100)$. If the programmable curve is used this parameter must be calculated so that:

$$B \cdot \frac{CrvSatn}{100} - C > 0$$

(Equation 39)

HystAbsn: Absolute hysteresis for step *n*, set in % of *UBase*. The setting of this parameter is highly dependent of the application. The hysteresis is used to avoid oscillations of the START output signal. This signal resets when the measured voltage drops below the setting level and leaves the hysteresis area. Make sure that the set value for parameter *HystABS* is somewhat smaller than the set pickup value. Otherwise there is a risk that step *n* will not reset properly.

8.4 Overexcitation protection OEXPVPH

8.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Overexcitation protection	OEXPVPH	$U/f >$	24

8.4.2 Application

When the laminated core of a power transformer is subjected to a magnetic flux density beyond its design limits, stray flux will flow into non-laminated components not designed to carry flux and cause eddy currents to flow. The eddy currents can cause excessive heating and severe damage to insulation and adjacent parts in a relatively short time.

Overvoltage, or underfrequency, or a combination of both, will result in an excessive flux density level, which is denominated overfluxing or over-excitation.

The greatest risk for overexcitation exists in a thermal power station when the generator-transformer block is disconnected from the rest of the network, or in network “islands” occurring at disturbance where high voltages and/or low frequencies can occur. Overexcitation can occur during start-up and shut-down of the generator if the field current is not properly adjusted. Loss-of load or load-shedding can also result in overexcitation if the voltage control and frequency governor is not functioning properly. Loss of load or load-shedding at a transformer substation can result in overexcitation if the voltage control function is insufficient or out of order. Low frequency in a system isolated from the main network can result in overexcitation if the voltage regulating system maintains normal voltage.

According to the IEC standards, the power transformers shall be capable of delivering rated load current continuously at an applied voltage of 105% of rated value (at rated frequency). For special cases, the purchaser may specify that the transformer shall be capable of operating continuously at an applied voltage 110% of rated value at no load, reduced to 105% at rated secondary load current.

According to ANSI/IEEE standards, the transformers shall be capable of delivering rated load current continuously at an output voltage of 105% of rated value (at rated frequency) and operate continuously with output voltage equal to 110% of rated value at no load.

The capability of a transformer (or generator) to withstand overexcitation can be illustrated in the form of a thermal capability curve, that is, a diagram which shows

the permissible time as a function of the level of over-excitation. When the transformer is loaded, the induced voltage and hence the flux density in the core can not be read off directly from the transformer terminal voltage. Normally, the leakage reactance of each separate winding is not known and the flux density in the transformer core can then not be calculated. In two-winding transformers, the low voltage winding is normally located close to the core and the voltage across this winding reflects the flux density in the core. However, depending on the design, the flux flowing in the yoke may be critical for the ability of the transformer to handle excess flux.

The Overexcitation protection (OEXPVPH) has current inputs to allow calculation of the load influence on the induced voltage. This gives a more exact measurement of the magnetizing flow. For power transformers with unidirectional load flow, the voltage to OEXPVPH should therefore be taken from the feeder side.

Heat accumulated in critical parts during a period of overexcitation will be reduced gradually when the excitation returns to the normal value. If a new period of overexcitation occurs after a short time interval, the heating will start from a higher level, therefore, OEXPVPH must have thermal memory. A fixed cooling time constant is settable within a wide range.

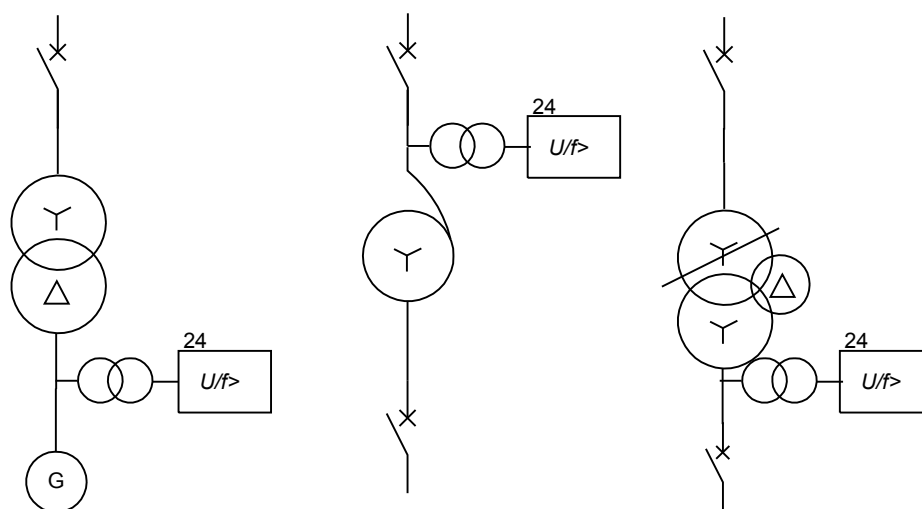
The general experience is that the overexcitation characteristics for a number of power transformers are not in accordance with standard inverse time curves. In order to make optimal settings possible, a transformer adapted characteristic is available in the IED. The operate characteristic of the protection function can be set to correspond quite well with any characteristic by setting the operate time for six different figures of overexcitation in the range from 100% to 180% of rated V/Hz.

When configured to a single phase-to-phase voltage input, a corresponding phase-to-phase current is calculated which has the same phase angle relative the phase-to-phase voltage as the phase currents have relative the phase voltages in a symmetrical system. The function should preferably be configured to use a three-phase voltage input if available. It then uses the positive sequence quantities of voltages and currents.



Analog measurements shall not be taken from any winding where a load tap changer is located.

Some different connection alternatives are shown in figure [61](#).



en05000208.vsd

Figure 61: Alternative connections of an Overexcitation protection OEXPVPH(Volt/Hertz)

8.4.3 Setting guidelines

8.4.3.1 Recommendations for input and output signals

Recommendations for Input signals

Please see the default factory configuration.

BLOCK: The input will block the operation of the Overexcitation protection OEXPVPH, for example, the block input can be used to block the operation for a limited time during special service conditions.

RESET: OEXPVPH has a thermal memory, which can take a long time to reset. Activation of the RESET input will reset the function instantaneously.

Recommendations for Output signals

Please see the default factory configuration for examples of configuration.

ERROR: The output indicates a measuring error. The reason, for example, can be configuration problems where analogue signals are missing.

START: The START output indicates that the level $V/Hz \gg$ has been reached. It can be used to initiate time measurement.

TRIP: The TRIP output is activated after the operate time for the U/f level has expired. TRIP signal is used to trip the circuit breaker(s).

ALARM: The output is activated when the alarm level has been reached and the alarm timer has elapsed. When the system voltage is high this output sends an alarm to the operator.

8.4.3.2

Settings

GlobalBaseSel: Selects the global base value group used by the function to define *IBase*, *UBase* and *SBase* as applicable.

Operation: The operation of the Overexcitation protection OEXPVPH can be set to *On/Off*.

MeasuredU: The phases involved in the measurement are set here. Normally the three phase measurement measuring the positive sequence voltage should be used but when only individual VT's are used a single phase-to-phase can be used.

MeasuredI: The phases involved in the measurement are set here. *MeasuredI:* must be in accordance with *MeasuredU*.

V/Hz>: Operating level for the inverse characteristic, IEEE or tailor made. The operation is based on the relation between rated voltage and rated frequency and set as a percentage factor. Normal setting is around 108-110% depending of the capability curve for the transformer/generator.

V/Hz>>: Operating level for the *tMin* definite time delay used at high overvoltages. The operation is based on the relation between rated voltage and rated frequency and set as a percentage factor. Normal setting is around 110-180% depending of the capability curve of the transformer/generator. Setting should be above the knee-point when the characteristic starts to be straight on the high side.

XLeak: The transformer leakage reactance on which the compensation of voltage measurement with load current is based. The setting shall be the transformer leak reactance in primary ohms. If no current compensation is used (mostly the case) the setting is not used.

TrPulse: The length of the trip pulse. Normally the final trip pulse is decided by the trip function block. A typical pulse length can be 50 ms.

CurveType: Selection of the curve type for the inverse delay. The IEEE curves or tailor made curve can be selected depending of which one matches the capability curve best.

kForIEEE: The time constant for the inverse characteristic. Select the one giving the best match to the transformer capability.

tCooling: The cooling time constant giving the reset time when voltages drops below the set value. Shall be set above the cooling time constant of the transformer. The default value is recommended to be used if the constant is not known.

tMin: The operating times at voltages higher than the set *V/Hz>>*. The setting shall match capabilities on these high voltages. Typical setting can be 1-10 second.

tMax: For overvoltages close to the set value times can be extremely long if a high K time constant is used. A maximum time can then be set to cut the longest times. Typical settings are 1800-3600 seconds (30-60 minutes)

AlarmLevel: Setting of the alarm level in percentage of the set trip level. The alarm level is normally set at around 98% of the trip level.

tAlarm: Setting of the time to alarm is given from when the alarm level has been reached. Typical setting is 5 seconds.

8.4.3.3

Service value report

A number of internal parameters are available as service values for use at commissioning and during service. Remaining time to trip (in seconds) TMTOTRIP, flux density VPERHZ, internal thermal content in percentage of trip value THERMSTA. The values are available at local HMI, Substation SAsystem and PCM600.

8.4.3.4

Setting example

Sufficient information about the overexcitation capability of the protected object(s) must be available when making the settings. The most complete information is given in an overexcitation capability diagram as shown in figure 62.

The settings $V/Hz>>$ and $V/Hz>$ are made in per unit of the rated voltage of the transformer winding at rated frequency.

Set the transformer adapted curve for a transformer with overexcitation characteristics in according to figure 62.

$V/Hz>$ for the protection is set equal to the permissible continuous overexcitation according to figure 62 = 105%. When the overexcitation is equal to $V/Hz>$, tripping is obtained after a time equal to the setting of t1.



This is the case when U_{Base} is equal to the transformer rated voltages. For other values, the percentage settings need to be adjusted accordingly.

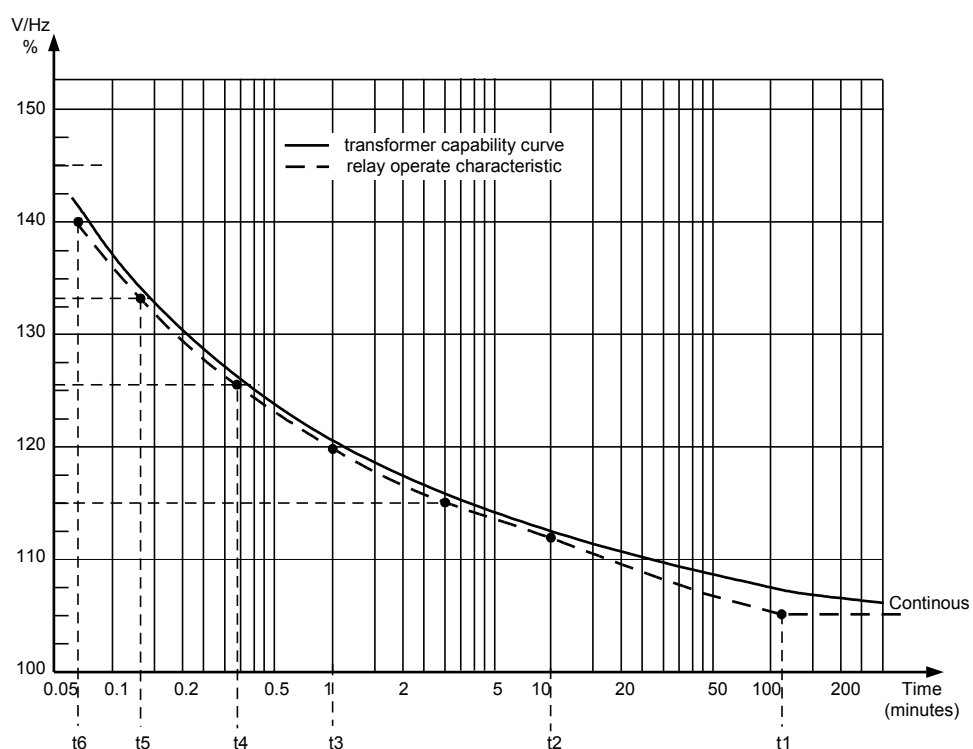
When the overexcitation is equal to the set value of $V/Hz>>$, tripping is obtained after a time equal to the setting of t6. A suitable setting would be $V/Hz>> = 140\%$ and $t6 = 4$ s.

The interval between $V/Hz>>$ and $V/Hz>$ is automatically divided up in five equal steps, and the time delays t2 to t5 will be allocated to these values of overexcitation. In this example, each step will be $(140-105)/5 = 7\%$. The setting of time delays t1 to t6 are listed in table 19.

Table 19: *Settings*

U/f op (%)	Timer	Time set (s)
105	t1	7200 (max)
112	t2	600
119	t3	60
126	t4	20
133	t5	8
140	t6	4

Information on the cooling time constant T_{cool} should be retrieved from the power transformer manufacturer.



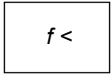
en01000377.vsd

Figure 62: *Example on overexcitation capability curve and V/Hz protection settings for power transformer*

Section 9 Frequency protection

9.1 Underfrequency protection SAPTUF

9.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Underfrequency protection	SAPTUF		81

9.1.2 Application

Underfrequency protection SAPTUF is applicable in all situations, where reliable detection of low fundamental power system frequency is needed. The power system frequency, and the rate of change of frequency, is a measure of the unbalance between the actual generation and the load demand. Low fundamental frequency in a power system indicates that the available generation is too low to fully supply the power demanded by the load connected to the power grid. SAPTUF detects such situations and provides an output signal, suitable for load shedding, generator boosting, HVDC-set-point change, gas turbine start up and so on. Sometimes shunt reactors are automatically switched in due to low frequency, in order to reduce the power system voltage and hence also reduce the voltage dependent part of the load.

SAPTUF is very sensitive and accurate and is used to alert operators that frequency has slightly deviated from the set-point, and that manual actions might be enough. The underfrequency signal is also used for overexcitation detection. This is especially important for generator step-up transformers, which might be connected to the generator but disconnected from the grid, during a roll-out sequence. If the generator is still energized, the system will experience overexcitation, due to the low frequency.

9.1.3 Setting guidelines

All the frequency and voltage magnitude conditions in the system where SAPTUF performs its functions should be considered. The same also applies to the associated equipment, its frequency and time characteristic.

There are two specific application areas for SAPTUF:

1. to protect equipment against damage due to low frequency, such as generators, transformers, and motors. Overexcitation is also related to low frequency
2. to protect a power system, or a part of a power system, against breakdown, by shedding load, in generation deficit situations.

The under frequency start value is set in Hz. All voltage magnitude related settings are made as a percentage of a global base voltage parameter. The UBase value should be set as a primary phase-to-phase value.

Some applications and related setting guidelines for the frequency level are given below:

Equipment protection, such as for motors and generators

The setting has to be well below the lowest occurring "normal" frequency and well above the lowest acceptable frequency for the equipment.

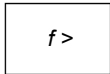
Power system protection, by load shedding

The setting has to be below the lowest occurring "normal" frequency and well above the lowest acceptable frequency for power stations, or sensitive loads. The setting level, the number of levels and the distance between two levels (in time and/or in frequency) depends very much on the characteristics of the power system under consideration. The size of the "largest loss of production" compared to "the size of the power system" is a critical parameter. In large systems, the load shedding can be set at a fairly high frequency level, and the time delay is normally not critical. In smaller systems the frequency start level has to be set at a lower value, and the time delay must be rather short.

The voltage related time delay is used for load shedding. The settings of SAPTUF could be the same all over the power system. The load shedding is then performed firstly in areas with low voltage magnitude, which normally are the most problematic areas, where the load shedding also is most efficient.

9.2 Overfrequency protection SAPTOF

9.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Overfrequency protection	SAPTOF		81

9.2.2 Application

Overfrequency protection function SAPTOF is applicable in all situations, where reliable detection of high fundamental power system frequency is needed. The power system frequency, and rate of change of frequency, is a measure of the unbalance between the actual generation and the load demand. High fundamental frequency in a power system indicates that the available generation is too large compared to the power demanded by the load connected to the power grid. SAPTOF detects such situations and provides an output signal, suitable for generator shedding, HVDC-set-point change and so on. SAPTOF is very sensitive and accurate and can also be used to alert operators that frequency has slightly deviated from the set-point, and that manual actions might be enough.

9.2.3 Setting guidelines

All the frequency and voltage magnitude conditions in the system where SAPTOF performs its functions must be considered. The same also applies to the associated equipment, its frequency and time characteristic.

There are two application areas for SAPTOF:

1. to protect equipment against damage due to high frequency, such as generators, and motors
2. to protect a power system, or a part of a power system, against breakdown, by shedding generation, in over production situations.

The overfrequency start value is set in Hz. All voltage magnitude related settings are made as a percentage of a settable global base voltage parameter *UBase*. The *UBase* value should be set as a primary phase-to-phase value.

Some applications and related setting guidelines for the frequency level are given below:

Equipment protection, such as for motors and generators

The setting has to be well above the highest occurring "normal" frequency and well below the highest acceptable frequency for the equipment.

Power system protection, by generator shedding

The setting must be above the highest occurring "normal" frequency and below the highest acceptable frequency for power stations, or sensitive loads. The setting level, the number of levels and the distance between two levels (in time and/or in frequency) depend very much on the characteristics of the power system under consideration. The size of the "largest loss of load" compared to "the size of the power system" is a critical parameter. In large systems, the generator shedding can be set at a fairly low frequency level, and the time delay is normally not critical. In smaller systems the frequency START level has to be set at a higher value, and the time delay must be rather short.

9.3 Rate-of-change of frequency protection SAPFRC

9.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Rate-of-change of frequency protection	SAPFRC		81

9.3.2 Application

Rate-of-change of frequency protection (SAPFRC) is applicable in all situations, where reliable detection of change of the fundamental power system voltage frequency is needed. SAPFRC can be used both for increasing frequency and for decreasing frequency. SAPFRC provides an output signal, suitable for load shedding or generator shedding, generator boosting, HVDC-set-point change, gas turbine start up and so on. Very often SAPFRC is used in combination with a low frequency signal, especially in smaller power systems, where loss of a fairly large generator will require quick remedial actions to secure the power system integrity. In such situations load shedding actions are required at a rather high frequency level, but in combination with a large negative rate-of-change of frequency the underfrequency protection can be used at a rather high setting.

9.3.3 Setting guidelines

The parameters for Rate-of-change frequency protection SAPFRC are set via the local HMI or or through the Protection and Control Manager (PCM600).

All the frequency and voltage magnitude conditions in the system where SAPFRC performs its functions should be considered. The same also applies to the associated equipment, its frequency and time characteristic.

There are two application areas for SAPFRC:

1. to protect equipment against damage due to high or too low frequency, such as generators, transformers, and motors
2. to protect a power system, or a part of a power system, against breakdown by shedding load or generation, in situations where load and generation are not in balance.

SAPFRC is normally used together with an overfrequency or underfrequency function, in small power systems, where a single event can cause a large imbalance

between load and generation. In such situations load or generation shedding has to take place very quickly, and there might not be enough time to wait until the frequency signal has reached an abnormal value. Actions are therefore taken at a frequency level closer to the primary nominal level, if the rate-of-change frequency is large (with respect to sign).

The start value for SAPFRC is set in Hz/s. All voltage magnitude related settings are made as a percentage of a settable base voltage, which normally is set to the primary nominal voltage level (phase-phase) of the power system or the high voltage equipment under consideration.

SAPFRC is not instantaneous, since the function needs some time to supply a stable value. It is recommended to have a time delay long enough to take care of signal noise. However, the time, rate-of-change frequency and frequency steps between different actions might be critical, and sometimes a rather short operation time is required, for example, down to 70 ms.

Smaller industrial systems might experience rate-of-change frequency as large as 5 Hz/s, due to a single event. Even large power systems may form small islands with a large imbalance between load and generation, when severe faults (or combinations of faults) are cleared - up to 3 Hz/s has been experienced when a small island was isolated from a large system. For more "normal" severe disturbances in large power systems, rate-of-change of frequency is much less, most often just a fraction of 1.0 Hz/s.

Section 10 Secondary system supervision

10.1 Current circuit supervision CCSSPVC

10.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current circuit supervision	CCSSPVC	-	87

10.1.2 Application

Open or short circuited current transformer cores can cause unwanted operation of many protection functions such as differential, earth-fault current and negative-sequence current functions. When currents from two independent three-phase sets of CTs, or CT cores, measuring the same primary currents are available, reliable current circuit supervision can be arranged by comparing the currents from the two sets. If an error in any CT circuit is detected, the protection functions concerned can be blocked and an alarm given.

In case of large currents, unequal transient saturation of CT cores with different remanence or different saturation factor may result in differences in the secondary currents from the two CT sets. Unwanted blocking of protection functions during the transient stage must then be avoided.

Current circuit supervision CCSSPVC must be sensitive and have short operate time in order to prevent unwanted tripping from fast-acting, sensitive numerical protections in case of faulty CT secondary circuits.



Open CT circuits creates extremely high voltages in the circuits which is extremely dangerous for the personnel. It can also damage the insulation and cause new problems. The application shall, thus, be done with this in consideration, especially if the protection functions are blocked.

10.1.3 Setting guidelines

GlobalBaseSel: Selects the global base value group used by the function to define *IBase*, *UBase* and *SBase* as applicable.

Current circuit supervision CCSSPVC compares the residual current from a three-phase set of current transformer cores with the neutral point current on a separate input taken from another set of cores on the same current transformer.

IMinOp: It must be set as a minimum to twice the residual current in the supervised CT circuits under normal service conditions and rated primary current.

Ip>Block: It is normally set at 150% to block the function during transient conditions.

The FAIL output is connected to the blocking input of the protection function to be blocked at faulty CT secondary circuits.

10.2 Fuse failure supervision FUFSPVC

10.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fuse failure supervision	FUFSPVC	-	-

10.2.2 Application

Different protection functions within the protection IED, operates on the basis of the measured voltage in the relay point. Examples are:

- impedance protection functions
- undervoltage function
- energizing check function and voltage check for the weak infeed logic

These functions can operate unintentionally if a fault occurs in the secondary circuits between the voltage instrument transformers and the IED.

It is possible to use different measures to prevent such unwanted operations. Miniature circuit breakers in the voltage measuring circuits should be located as close as possible to the voltage instrument transformers, and shall be equipped with auxiliary contacts that are wired to the IEDs. Separate fuse-failure monitoring IEDs or elements within the protection and monitoring devices are another possibilities. These solutions are combined to get the best possible effect in the fuse failure supervision function (FUFSPVC).

FUFSPVC function built into the IED products can operate on the basis of external binary signals from the miniature circuit breaker or from the line disconnector. The

first case influences the operation of all voltage-dependent functions while the second one does not affect the impedance measuring functions.

The negative sequence detection algorithm, based on the negative-sequence measuring quantities is recommended for use in isolated or high-impedance earthed networks: a high value of voltage $3U_2$ without the presence of the negative-sequence current $3I_2$ is a condition that is related to a fuse failure event.

The zero sequence detection algorithm, based on the zero sequence measuring quantities is recommended for use in directly or low impedance earthed networks: a high value of voltage $3U_0$ without the presence of the residual current $3I_0$ is a condition that is related to a fuse failure event. In cases where the line can have a weak-infeed of zero sequence current this function shall be avoided.

A criterion based on delta current and delta voltage measurements can be added to the fuse failure supervision function in order to detect a three phase fuse failure. This is beneficial for example during three phase transformer switching.

10.2.3 Setting guidelines

10.2.3.1 General

The negative and zero sequence voltages and currents always exist due to different non-symmetries in the primary system and differences in the current and voltage instrument transformers. The minimum value for the operation of the current and voltage measuring elements must always be set with a safety margin of 10 to 20%, depending on the system operating conditions.

Pay special attention to the dissymmetry of the measuring quantities when the function is used on long untransposed lines, on multicircuit lines and so on.

The settings of negative sequence, zero sequence and delta algorithm are in percent of the base voltage and base current for the function. Common base IED values for primary current (I_{Base}), primary voltage (U_{Base}) and primary power (S_{Base}) are set in Global Base Values $GBASVAL$. The setting $GlobalBaseSel$ is used to select a particular $GBASVAL$ and used its base values.

10.2.3.2 Setting of common parameters

Set the operation mode selector *Operation* to *On* to release the fuse failure function.

The voltage threshold $USealIn<$ is used to identify low voltage condition in the system. Set $USealIn<$ below the minimum operating voltage that might occur during emergency conditions. We propose a setting of approximately 70% of U_{Base} .

The drop off time of 200 ms for dead phase detection makes it recommended to always set *SealIn* to *On* since this will secure a fuse failure indication at persistent

fuse fail when closing the local breaker when the line is already energized from the other end. When the remote breaker closes the voltage will return except in the phase that has a persistent fuse fail. Since the local breaker is open there is no current and the dead phase indication will persist in the phase with the blown fuse. When the local breaker closes the current will start to flow and the function detects the fuse failure situation. But due to the 200 ms drop off timer the output BLKZ will not be activated until after 200 ms. This means that distance functions are not blocked and due to the “no voltage but current” situation might issue a trip.

The operation mode selector *OpMode* has been introduced for better adaptation to system requirements. The mode selector enables selecting interactions between the negative sequence and zero sequence algorithm. In normal applications, the *OpMode* is set to either *UNsINs* for selecting negative sequence algorithm or *UZsIZs* for zero sequence based algorithm. If system studies or field experiences shows that there is a risk that the fuse failure function will not be activated due to the system conditions, the dependability of the fuse failure function can be increased if the *OpMode* is set to *UZsIZs OR UNsINs* or *OptimZsNs*. In mode *UZsIZs OR UNsINs* both negative and zero sequence based algorithms are activated and working in an OR-condition. Also in mode *OptimZsNs* both negative and zero sequence algorithms are activated and the one that has the highest magnitude of measured negative or zero sequence current will operate. If there is a requirement to increase the security of the fuse failure function *OpMode* can be selected to *UZsIZs AND UNsINs* which gives that both negative and zero sequence algorithms are activated and working in an AND-condition, that is, both algorithms must give condition for block in order to activate the output signals BLKU or BLKZ.

10.2.3.3 Negative sequence based

The relay setting value $3U2>$ is given in percentage of the base voltage $UBase$ and should not be set lower than the value that is calculated according to equation 40.

$$3U2 \geq \frac{U2}{UBase / \sqrt{3}} \cdot 100$$

(Equation 40)

where:

$U2$ is the maximal negative sequence voltage during normal operation conditions, plus a margin of 10...20%

$UBase$ is the base voltage for the function according to the setting *GlobalBaseSel*

The setting of the current limit $3I2<$ is in percentage of parameter $IBase$. The setting of $3I2<$ must be higher than the normal unbalance current that might exist in the system and can be calculated according to equation 41.

$$3I2 <= \frac{I2}{I_{Base}} \cdot 100$$

(Equation 41)

where:

$I2$ is the maximal negative sequence current during normal operating conditions, plus a margin of 10...20%

I_{Base} is the base current for the function according to the setting *GlobalBaseSel*

10.2.3.4

Zero sequence based

The IED setting value $3U0>$ is given in percentage of the base voltage U_{Base} . The setting of $3U0>$ should not be set lower than the value that is calculated according to equation [42](#).

$$3U0 >= \frac{3U0}{U_{Base}/\sqrt{3}} \cdot 100$$

(Equation 42)

where:

$3U0$ is the maximal zero sequence voltage during normal operation conditions, plus a margin of 10...20%

U_{Base} is the base voltage for the function according to the setting *GlobalBaseSel*

The setting of the current limit $3I0<$ is done in percentage of I_{Base} . The setting of $3I0<$ must be higher than the normal unbalance current that might exist in the system. The setting can be calculated according to equation [43](#).

$$3I0 <= \frac{3I0}{I_{Base}} \cdot 100$$

(Equation 43)

where:

$3I0<$ is the maximal zero sequence current during normal operating conditions, plus a margin of 10...20%

I_{Base} is the base current for the function according to the setting *GlobalBaseSel*

10.2.3.5

Delta U and delta I

Set the operation mode selector *OpDUDI* to *On* if the delta function shall be in operation.

The setting of $DU>$ should be set high (approximately 60% of U_{Base}) and the current threshold $DI<$ low (approximately 10% of I_{Base}) to avoid unwanted operation due to normal switching conditions in the network. The delta current and delta voltage function shall always be used together with either the negative or zero sequence algorithm. If $U_{Set_{prim}}$ is the primary voltage for operation of dU/dt and $I_{Set_{prim}}$ the primary current for operation of dI/dt , the setting of $DU>$ and $DI<$ will be given according to equation 44 and equation 45.

$$DU> = \frac{U_{Set_{prim}}}{U_{Base}} \cdot 100$$

(Equation 44)

$$DI< = \frac{I_{Set_{prim}}}{I_{Base}} \cdot 100$$

(Equation 45)

The voltage thresholds $UPh>$ is used to identify low voltage condition in the system. Set $UPh>$ below the minimum operating voltage that might occur during emergency conditions. A setting of approximately 70% of U_{Base} is recommended.

The current threshold $IPh>$ shall be set lower than the $IMinOp$ for the distance protection function. A 5...10% lower value is recommended.

10.2.3.6

Dead line detection

The condition for operation of the dead line detection is set by the parameters $IDLD<$ for the current threshold and $UDLD<$ for the voltage threshold.

Set the $IDLD<$ with a sufficient margin below the minimum expected load current. A safety margin of at least 15-20% is recommended. The operate value must however exceed the maximum charging current of an overhead line, when only one phase is disconnected (mutual coupling to the other phases).

Set the $UDLD<$ with a sufficient margin below the minimum expected operating voltage. A safety margin of at least 15% is recommended.

Section 11 Control

11.1 Apparatus control APC

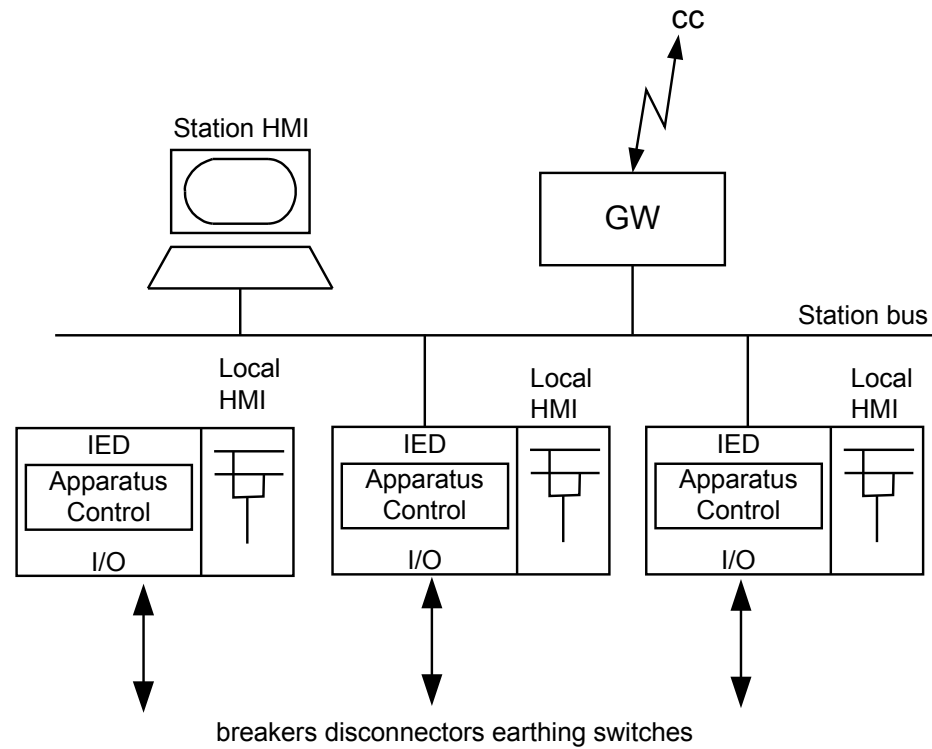
11.1.1 Application

The apparatus control is a functionality for control and supervising of circuit breakers, disconnectors, and earthing switches within a bay. Permission to operate is given after evaluation of conditions from other functions such as interlocking, synchrocheck, operator place selection and external or internal blockings.



The complete apparatus control function is not included in this product, and the information below is included for understanding of the principle for the use of QCBAY, LOCREM, LOCREMCTRL, SCILO, SCSWI, SXCBR.

Figure [63](#) shows from which places the apparatus control function receives commands. The commands to an apparatus can be initiated from the Control Centre (CC), the station HMI or the local HMI on the IED front.



IEC08000227.vsd

Figure 63: Overview of the apparatus control functions

Features in the apparatus control function:

- Operation of primary apparatuses
- Select-Execute principle to give high security
- Selection and supervision of operator place
- Command supervision
- Block/deblock of operation
- Block/deblock of updating of position indications
- Substitution of position indications
- Overriding of interlocking functions
- Overriding of synchrocheck
- Pole discordance supervision
- Operation counter
- Suppression of mid position

The apparatus control function is realized by means of a number of function blocks designated:

- Switch controller SCSWI
- Circuit breaker SXCBR
- Bay control QCBAY
- Local remote LOCREM
- Local remote control LOCREMCTRL

The signal flow between the function blocks is shown in Figure 64. The application description for all these functions can be found below. The function SCILO in the Figure below is the logical node for interlocking.

When the circuit breaker or switch is located in a breaker IED, two more functions are added:

- GOOSE receive for switching device GOOSEXLNRCV
- Proxy for signals from switching device via GOOSE XLNPROXY

The extension of the signal flow and the usage of the GOOSE communication are shown in Figure 65.

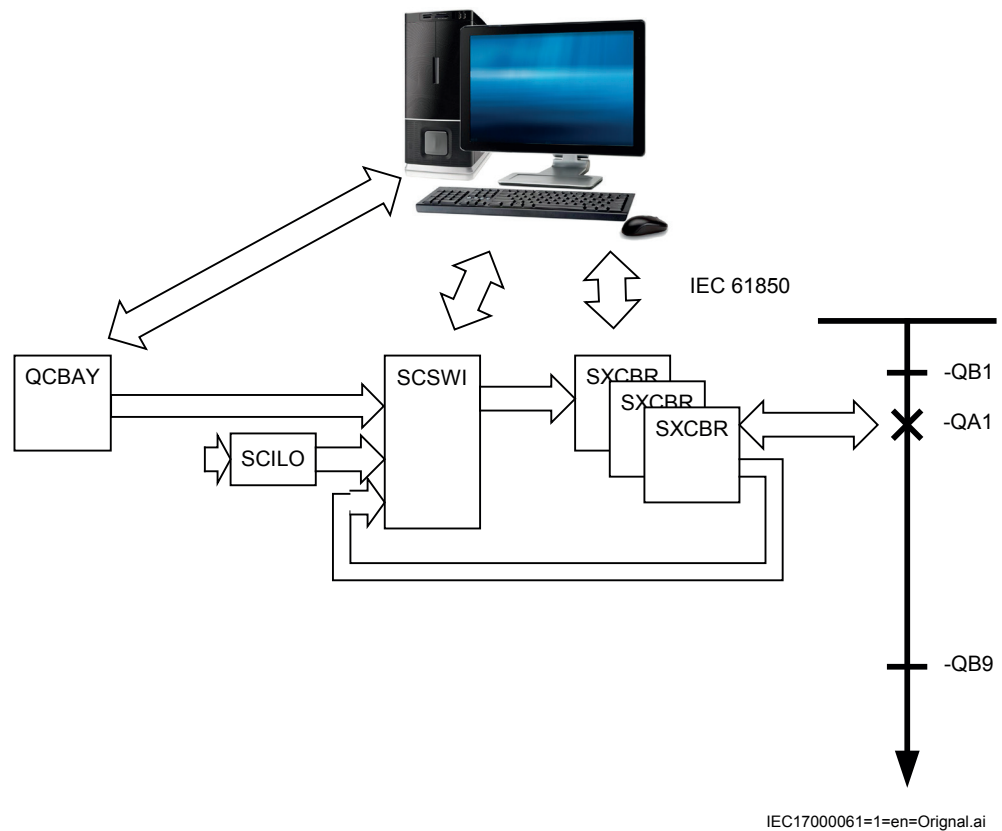


Figure 64: Signal flow between apparatus control function blocks when all functions are situated within the IED

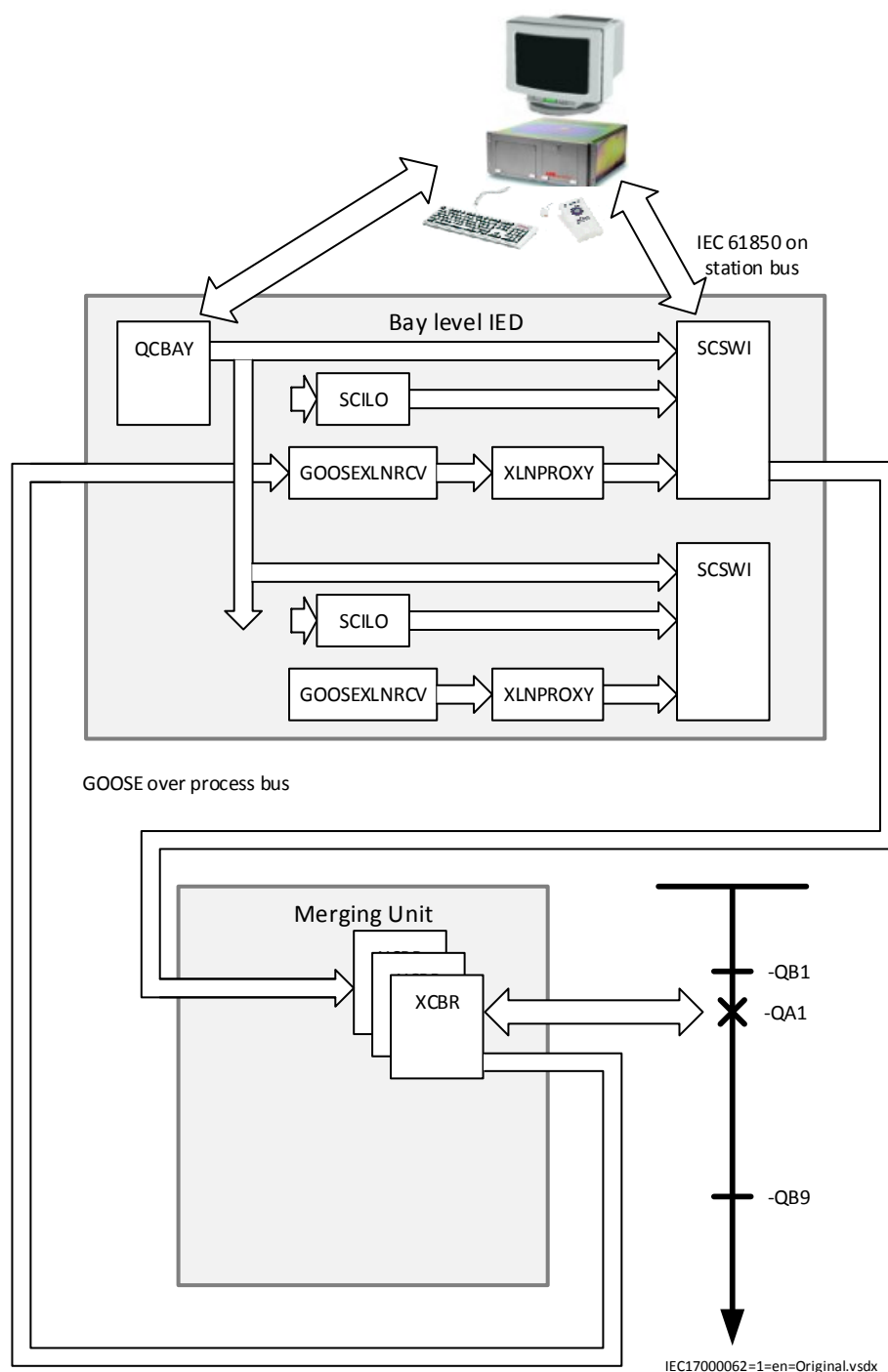


Figure 65: Signal flow between apparatus control functions with XCBR and XSWI located in a breaker IED

Control operation can be performed from the local IED HMI. If users are defined in the IED, then the local/remote switch is under authority control, otherwise the default user can perform control operations from the local IED HMI without logging in. The default position of the local/remote switch is on remote.

Accepted originator categories for PSTO

If the requested command is accepted by the authority control, the value will change. Otherwise the attribute *blocked-by-switching-hierarchy* is set in the *cause* signal. If the PSTO value is changed during a command, then the command is aborted.

The accepted originator categories for each PSTO value are shown in [Table 20](#).

Table 20: *Accepted originator categories for each PSTO*

Permitted Source To Operate	Originator (orCat)
0 = Off	4,5,6
1 = Local	1,4,5,6
2 = Remote	2,3,4,5,6
3 = Faulty	4,5,6
4 = Not in use	4,5,6
5 = All	1,2,3,4,5,6
6 = Station	2,4,5,6
7 = Remote	3,4,5,6

PSTO = All, then it is no priority between operator places. All operator places are allowed to operate.

According to IEC 61850 standard the *orCat* attribute in originator category are defined in [Table 21](#)

Table 21: *orCat attribute according to IEC 61850*

Value	Description
0	not-supported
1	bay-control
2	station-control
3	remote-control
4	automatic-bay
5	automatic-station
6	automatic-remote
7	maintenance
8	process

11.1.1.1

Bay control QCBAY

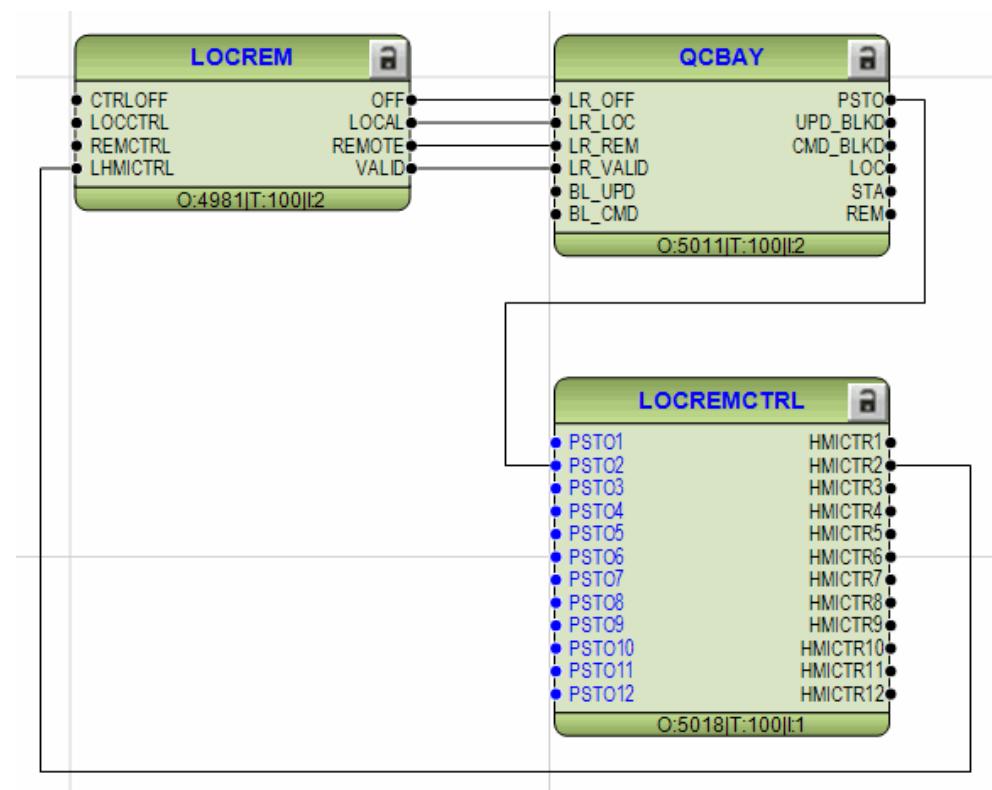
The Bay control (QCBAY) is used to handle the selection of the operator place per bay. The function gives permission to operate from two main types of locations either from Remote (for example, control centre or station HMI) or from Local

(local HMI on the IED) or from all (Local and Remote). The Local/Remote switch position can also be set to Off, which means no operator place selected that is, operation is not possible either from local or from remote.

For IEC 61850-8-1 communication, the Bay Control function can be set to discriminate between commands with orCat station and remote (2 and 3). The selection is then done through the IEC 61850-8-1 edition 2 command LocSta.

QCBAY also provides blocking functions that can be distributed to different apparatuses within the bay. There are two different blocking alternatives:

- Blocking of update of positions
- Blocking of commands



IEC13000016-2-en.vsd

Figure 66: APC - Local remote function block

11.1.1.2

Switch controller SCSWI

SCSWI may handle and operate on one three-phase device or three one-phase switching devices.

After the selection of an apparatus and before the execution, the switch controller performs the following checks and actions:

- A request initiates to reserve other bays to prevent simultaneous operation.
- Actual position inputs for interlocking information are read and evaluated if the operation is permitted.
- The synchrocheck/synchronizing conditions are read and checked, and performs operation upon positive response.
- The blocking conditions are evaluated
- The position indications are evaluated according to given command and its requested direction (open or closed).

The command sequence is supervised regarding the time between:

- Select and execute.
- Select and until the reservation is granted.
- Execute and the final end position of the apparatus.
- Execute and valid close conditions from the synchrocheck.

At error the command sequence is cancelled.

In the case when there are three one-phase switches (SXCBB) connected to the switch controller function, the switch controller will "merge" the position of the three switches to the resulting three-phase position. In case of a pole discordance situation, that is, the positions of the one-phase switches are not equal for a time longer than a settable time; an error signal will be given.

The switch controller represents the content of the SCSWI logical node (according to IEC 61850) with mandatory functionality.

11.1.1.3

Switches SXCBB

Switches are functions used to close and interrupt an ac power circuit under normal conditions, or to interrupt the circuit under fault, or emergency conditions. The intention with these functions is to represent the lowest level of a power-switching device with or without short circuit breaking capability, for example, circuit breakers, disconnectors, earthing switches etc.

The purpose of these functions is to provide the actual status of positions and to perform the control operations, that is, pass all the commands to the primary apparatus via output boards and to supervise the switching operation and position.

Switches have the following functionalities:

- Local/Remote switch intended for the switchyard
- Block/deblock for open/close command respectively
- Update block/deblock of position indication
- Substitution of position indication
- Supervision timer that the primary device starts moving after a command
- Supervision of allowed time for intermediate position
- Definition of pulse duration for open/close command respectively

The realizations of these functions are done with SXCBB representing a circuit breaker.

Circuit breaker (SXCBB) can be realized either as three one-phase switches or as one three-phase switch.

The content of this function is represented by the IEC 61850 definitions for the logical node Circuit breaker (SXCBB) with mandatory functionality.

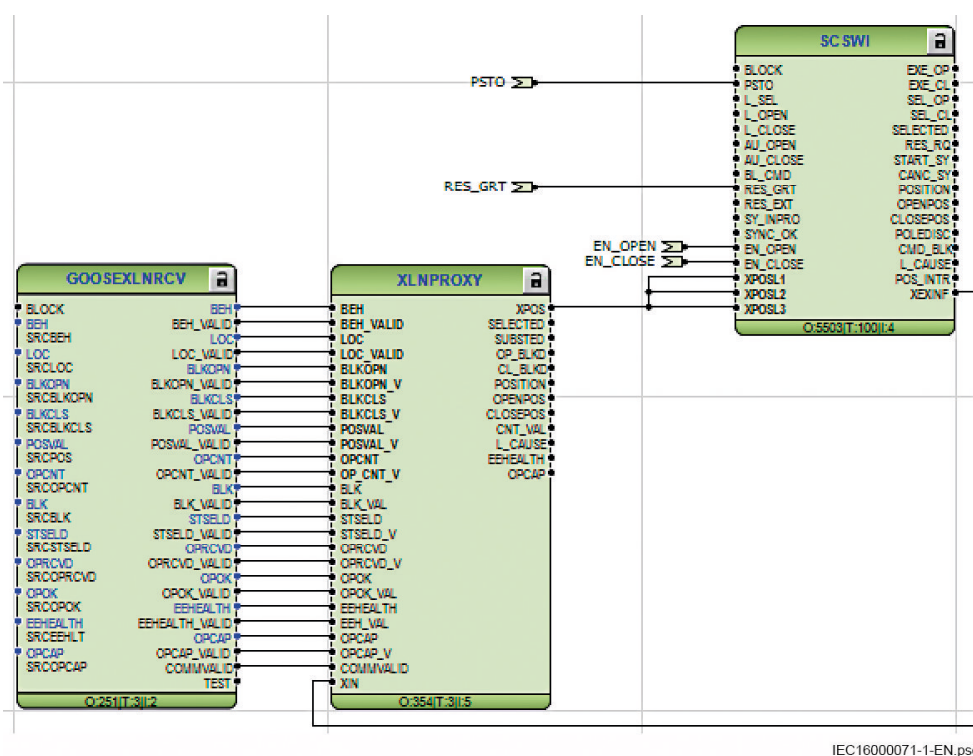
11.1.1.4

Proxy for signals from switching device via GOOSE XLNPROXY

The purpose of the proxy for signals from switching device via GOOSE (XLNPROXY) is to give the same internal representation of the position status and control response for a switch modeled in a breaker IED as if represented by a SXCBB or SXSBB function.

The command response functionality is dependent on the connection of the execution information, XIN, from the SCSBB function controlling the represented switch. Otherwise, the function only reflects the current status of the switch, such as blocking, selection, position, operating capability and operation counter.

Since different switches are represented differently on IEC 61850, the data that is mandatory to model in IEC 61850 is mandatory inputs and the other useful data for the command and status following is optional. To make it easy to choose which data to use for the XLNPROXY function, their usage is controlled by the connection of each data's signal input and valid input. These connections are usually from the GOOSEXLNRCV function (see Figure [67](#) and Figure [68](#)).



IEC16000071-1-EN.psd

Figure 67: Configuration with XLNPROXY and GOOSEXLNRCV where all the IEC 61850 modelled data is used, including selection

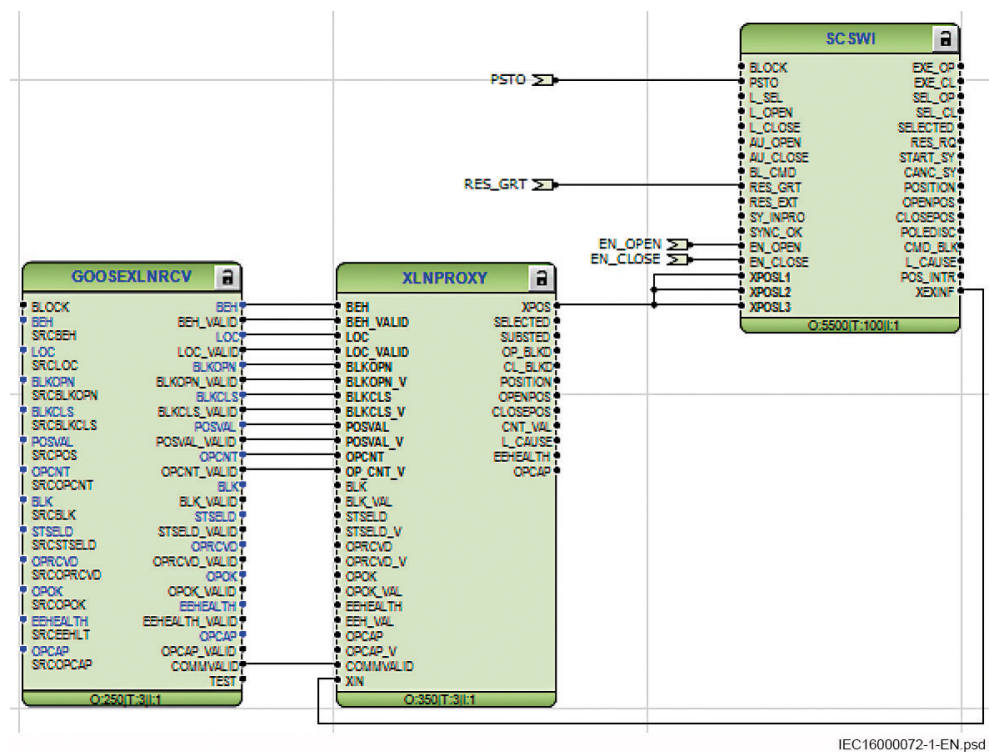


Figure 68: Configuration with XLNPROXY and GOOSEXLNRCV where only the mandatory data in the IEC 61850 modelling is used

All the information from the XLNPROXY to the SCSWI about command following status, causes for failed command and selection status is transferred in the output XPOS. The other outputs may be used by other functions in the same way as the corresponding outputs of the SXCBR and SCSWI function.

When a command has been issued from the connected SCSWI function, the XLNPROXY function awaits the response on it from the represented switch through the inputs POSVAL and OPOK. While waiting for the switch to start moving, it checks if the switch is blocked for the operation. When the switch has started moving and no blocking condition has been detected, XLNPROXY issues a response to the SCSWI function that the command has started. If OPOK is used, this response is given when XLNPROXY receives the signal.

If no movement of the switch is registered within the limit $t_{StartMove}$, the command is considered failed, and the cause of the failure is evaluated. In the evaluation, the function checks if the state of the represented switch is indicating that the command is blocked in any way during the command, and gives the appropriate cause to the SCSWI function. This cause is also shown on the output L_CAUSE as indicated in the following table:

Table 22: Possible cause values from XLNPROXY

Cause No	Cause Description	Conditions
8	Blocked-by-Mode	The BEH input is 5.
2	Blocked-by-switching-hierarchy	The LOC input indicates that only local commands are allowed for the breaker IED function.
-24	Blocked-for-open-cmd	The BLKOPN is active indicating that the switch is blocked for open commands.
-25	Blocked-for-close-cmd	The BLKCLS is active indicating that the switch is blocked for close commands.
9	Blocked-by-process	If the Blk input is connected and active indicating that the switch is dynamically blocked. Or if the OPCAP input is connected, it indicates that the operation capability of the switch is not enough to perform the command.
5	Position-reached	Switch is already in the intended position.
-31	Switch-not-start-moving	Switch did not start moving within tStartMove.
-32	Persistent-intermediate-state	The switch stopped in intermediate state for longer than tIntermediate.
-33	Switch-returned-to-init-pos	Switch returned to the initial position.
-34	Switch-in-bad-state	Switch is in a bad position.
-35	Not-expected-final-position	Switch did not reach the expected final position.



The OPCAP input and output are used for the CBOpCap data of a XCBR respectively SwOpCap for a XSWI. The interpretation for the command following is controlled through the setting *SwitchType*.

11.1.2

Interaction between modules

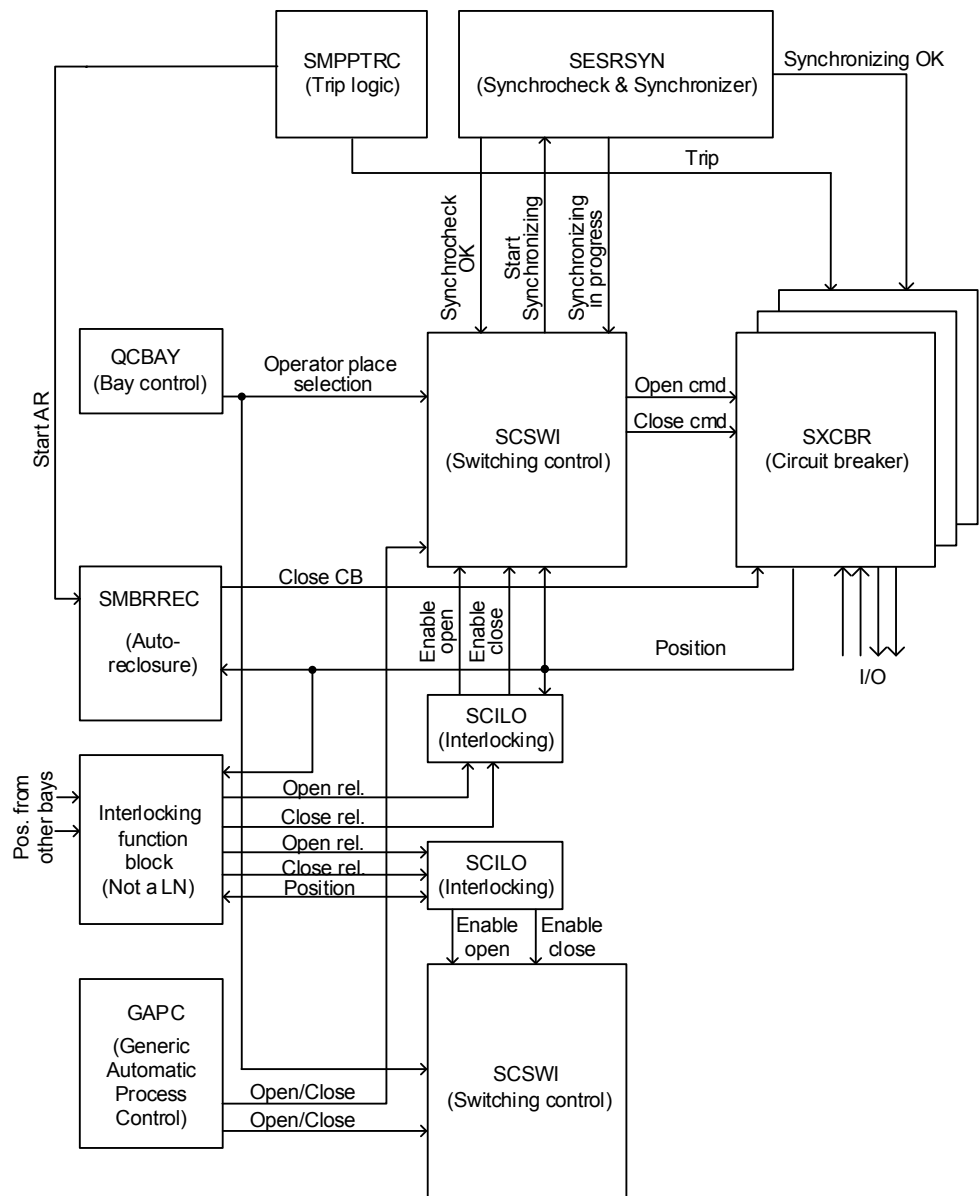
A typical bay with apparatus control function consists of a combination of logical nodes or functions that are described here:

- The Switch controller (SCSWI) initializes all operations for one apparatus. It is the command interface of the apparatus. It includes the position reporting as well as the control of the position
- The Circuit breaker (SXCBR) is the process interface to the circuit breaker for the apparatus control function.
- The Bay control (QCBAY) fulfils the bay-level functions for the apparatuses, such as operator place selection and blockings for the complete bay.
- The Protection trip logic (SMPPTRC) connects the "trip" outputs of one or more protection functions to a common "trip" to be transmitted to SXCBR.
- The Autorecloser (SMBRREC) consists of the facilities to automatically close a tripped breaker with respect to a number of configurable conditions.
- The logical node Interlocking (SCILO) provides the information to SCSWI whether it is permitted to operate due to the switchyard topology. The

interlocking conditions are evaluated with separate logic and connected to SCILO .

- The Synchrocheck, energizing check, and synchronizing (SESRSYN) calculates and compares the voltage phasor difference from both sides of an open breaker with predefined switching conditions (synchrocheck). Also the case that one side is dead (energizing-check) is included.
- The Generic Automatic Process Control function, GAPC, handles generic commands from the operator to the system.

The overview of the interaction between these functions is shown in Figure [69](#) below.



IEC17000063=1=en=Original..vsdx

Figure 69: Example overview of the interactions between functions in a typical bay

11.1.3 Setting guidelines

The setting parameters for the apparatus control function are set via the local HMI or PCM600.

11.1.3.1 Bay control (QCBAY)

If the parameter *AllPSTOValid* is set to *No priority*, all originators from local and remote are accepted without any priority.

If the parameter *RemoteIncStation* is set to *Yes*, commands from IEC 61850-8-1 clients at both station and remote level are accepted, when the QCBAY function is in Remote. If set to *No*, the command *LocSta* controls which operator place is accepted when QCBAY is in Remote. If *LocSta* is true, only commands from station level are accepted, otherwise only commands from remote level are accepted.



The parameter *RemoteIncStation* has only effect on the IEC 61850-8-1 communication. Further, when using IEC 61850 edition 1 communication, the parameter should be set to *Yes*, since the command *LocSta* is not defined in IEC 61850-8-1 edition 1.

11.1.3.2 Switch controller (SCSWI)

The parameter *CtlModel* specifies the type of control model according to IEC 61850. The default for control of circuit breakers, disconnectors and earthing switches the control model is set to *SBO Enh* (Select-Before-Operate) with enhanced security.

When the operation shall be performed in one step, and no monitoring of the result of the command is desired, the model direct control with normal security is used.

At control with enhanced security there is an additional supervision of the status value by the control object, which means that each command sequence must be terminated by a termination command.

The parameter *PosDependent* gives permission to operate depending on the position indication, that is, at *Always permitted* it is always permitted to operate independent of the value of the position. At *Not perm at 00/11* it is not permitted to operate if the position is in bad or intermediate state.

tSelect is the maximum allowed time between the select and the execute command signal, that is, the time the operator has to perform the command execution after the selection of the object to operate. When the time has expired, the selected output signal is set to false and a cause-code is given.

The time parameter *tResResponse* is the allowed time from reservation request to the feedback reservation granted from all bays involved in the reservation function. When the time has expired, the control function is reset, and a cause-code is given.

tSynchrocheck is the allowed time for the synchrocheck function to fulfill the close conditions. When the time has expired, the function tries to start the synchronizing

function. If *tSynchrocheck* is set to 0, no synchrocheck is done, before starting the synchronizing function.

The timer *tSynchronizing* supervises that the signal synchronizing in progress is obtained in SCSWI after start of the synchronizing function. The start signal for the synchronizing is set if the synchrocheck conditions are not fulfilled. When the time has expired, the control function is reset, and a cause-code is given. If no synchronizing function is included, the time is set to 0, which means no start of the synchronizing function is done, and when *tSynchrocheck* has expired, the control function is reset and a cause-code is given.

tExecutionFB is the maximum time between the execute command signal and the command termination. When the time has expired, the control function is reset and a cause-code is given.

tPoleDiscord is the allowed time to have discrepancy between the poles at control of three one-phase breakers. At discrepancy an output signal is activated to be used for trip or alarm, and during a command, the control function is reset, and a cause-code is given.

SuppressMidPos when *On* suppresses the mid-position during the time *tIntermediate* of the connected switches.

The parameter *InterlockCheck* decides if interlock check should be done at both select and operate, Sel & Op phase, or only at operate, Op phase.

11.1.3.3

Switch (SXCBR)

tStartMove is the supervision time for the apparatus to start moving after a command execution is done from the SCSWI function. When the time has expired, the command supervision is reset, and a cause-code is given.

During the *tIntermediate* time, the position indication is allowed to be in an intermediate (00) state. When the time has expired, the command supervision is reset, and a cause-code is given. The indication of the mid-position at SCSWI is suppressed during this time period when the position changes from open to close or vice-versa if the parameter *SuppressMidPos* is set to *On* in the SCSWI function.

If the parameter *AdaptivePulse* is set to *Adaptive* the command output pulse resets when a new correct end position is reached. If the parameter is set to *Not adaptive* the command output pulse remains active until the timer *tOpenPulseClosePulse* has elapsed.

tOpenPulse is the output pulse length for an open command. If *AdaptivePulse* is set to *Adaptive*, it is the maximum length of the output pulse for an open command. The default length is set to 200 ms for a circuit breaker (SXCBR).

tClosePulse is the output pulse length for a close command. If *AdaptivePulse* is set to *Adaptive*, it is the maximum length of the output pulse for an open command. The default length is set to 200 ms for a circuit breaker (SXCBR).

11.1.3.4 Proxy for signals from switching device via GOOSE XLNPROXY

The *SwitchType* setting controls the evaluation of the operating capability. If *SwitchType* is set to *Circuit Breaker*, the input OPCAP is interpreted as a breaker operating capability, otherwise it is interpreted as a switch operating capability.

Table 23: Operating capability values for breaker/switches

Value	Breaker operating capability, CbOpCap	Switch operating capability, SwOpCap
1	None	None
2	Open	Open
3	Close – Open	Close
4	Open – Close – Open	Close and Open
5	Close – Open – Close – Open	Larger values handled as 4, both Close and Open
6	Open – Close – Open – Close – Open	
7	more	

tStartMove is the supervision time for the apparatus to start moving after a command execution is done from the SCSWI function. When the time has expired, the command supervision is reset, and a cause-code is given.

During the *tIntermediate* time, the position indication is allowed to be in an intermediate (00) state. When the time has expired, the command supervision is reset, and a cause-code is given. The indication of the mid-position at SCSWI is suppressed during this time period when the position changes from open to close or vice-versa if the parameter *SuppressMidPos* is set to *On* in the SCSWI function.

In most cases, the same value can be used for both *tStartMove* and *tIntermediate* as in the source function. However, *tStartMove* may need to be increased to accommodate for the communication delays, mainly when representing a circuit breaker.

11.2 Voltage control

11.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Automatic voltage control for tap changer, single control	TR1ATCC		90
Tap changer control and supervision, 6 binary inputs	TCMYLTC	-	84

11.2.2

Application

When the load in a power network is increased the voltage will decrease and vice versa. To maintain the network voltage at a constant level, power transformers are usually equipped with on-load tap-changer. This alters the power transformer ratio in a number of predefined steps and in that way changes the voltage. Each step usually represents a change in voltage of approximately 0.5-1.7%.

The voltage control function is intended for control of power transformers with a motor driven on-load tap-changer. The function is designed to regulate the voltage at the secondary side of the power transformer. The control method is based on a step-by-step principle which means that a control pulse, one at a time, will be issued to the tap changer mechanism to move it one position up or down. The length of the control pulse can be set within a wide range to accommodate different types of tap changer mechanisms. The pulse is generated whenever the measured voltage, for a given time, deviates from the set reference value by more than the preset deadband (degree of insensitivity).

The voltage can be controlled at the point of voltage measurement, as well as at a load point located out in the network. In the latter case, the load point voltage is calculated based on the measured load current and the known impedance from the voltage measuring point to the load point.

The automatic voltage control can be either for a single transformer, or for parallel transformers. Parallel control of power transformers can be made in three alternative ways:

- With the master-follower method
- With the reverse reactance method
- With the circulating current method

Of these alternatives, the first and the last require communication between the function control blocks of the different transformers, whereas the middle alternative does not require any communication.

The voltage control includes many extra features such as possibility to avoid simultaneous tapping of parallel transformers, hot stand by regulation of a transformer within a parallel group, with a LV CB open, compensation for a possible capacitor bank on the LV side bay of a transformer, extensive tap changer monitoring including contact wear and hunting detection, monitoring of the power flow in the transformer so that for example, the voltage control can be blocked if the power reverses and so on.

The voltage control function is built up by two function blocks which both are logical nodes in IEC 61850-8-1:

- Automatic voltage control for tap changer, TR1ATCC for single control and TR8ATCC for parallel control.
- Tap changer control and supervision, 6 binary inputs, TCMYLTC and 32 binary inputs, TCLYLTC

Automatic voltage control for tap changer, TR1ATCC or TR8ATCC is a function designed to automatically maintain the voltage at the LV-side side of a power transformer within given limits around a set target voltage. A raise or lower command is generated whenever the measured voltage, for a given period of time, deviates from the set target value by more than the preset deadband value (degree of insensitivity). A time delay (inverse or definite time) is set to avoid unnecessary operation during shorter voltage deviations from the target value, and in order to coordinate with other automatic voltage controllers in the system.

TCMYLTC and TCLYLTC are an interface between the Automatic voltage control for tap changer, TR1ATCC or TR8ATCC and the transformer load tap changer itself. More specifically this means that it gives command-pulses to a power transformer motor driven load tap changer and that it receives information from the load tap changer regarding tap position, progress of given commands, and so on.

TCMYLTC and TCLYLTC also serve the purpose of giving information about tap position to the transformer differential protection.

Control location local/remote

The tap changer can be operated from the front of the IED or from a remote place alternatively. On the IED front there is a local remote switch that can be used to select the operator place. For this functionality the Apparatus control function blocks Bay control (QCBAY), Local remote (LOCREM) and Local remote control (LOCREMCTRL) are used.

Information about the control location is given to TR1ATCC or TR8ATCC function through connection of the Permitted Source to Operate (PSTO) output of the QCBAY function block to the input PSTO of the TR1ATCC or TR8ATCC function block.

Control Mode

The control mode of the automatic voltage control for tap changer function, TR1ATCC for single control and TR8ATCC for parallel control can be:

- Manual
- Automatic

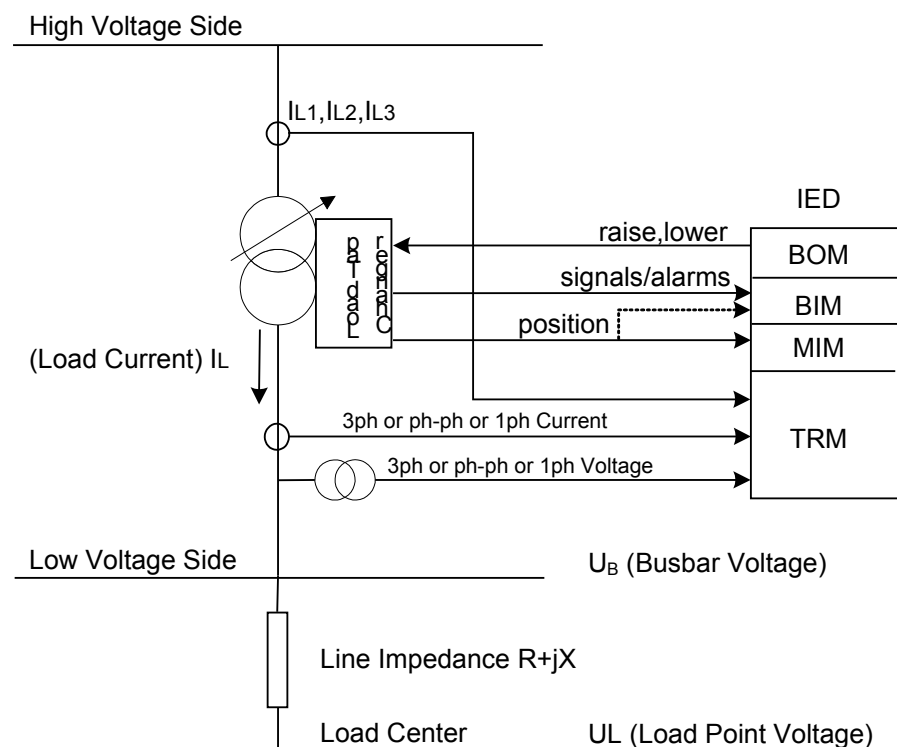
The control mode can be changed from the local location via the command menu on the local HMI under **Main menu/Control/Commands/TransformerVoltageControl(ATCC,90)**, or changed from a remote location via binary signals connected to the MANCTRL, AUTOCTRL inputs on TR1ATCC or TR8ATCC function block.

Measured Quantities

In normal applications, the LV side of the transformer is used as the voltage measuring point. If necessary, the LV side current is used as load current to calculate the line-voltage drop to the regulation point.

Automatic voltage control for tap changer, TR1ATCC for single control and TR8ATCC for parallel control function block has three inputs I3P1, I3P2 and U3P2 corresponding to HV-current, LV-current and LV-voltage respectively. These analog quantities are fed to the IED via the transformer input module, the Analog to Digital Converter and thereafter a Pre-Processing Block. In the Pre-Processing Block, a great number of quantities for example, phase-to-phase analog values, sequence values, max value in a three phase group etc., are derived. The different function blocks in the IED are then “subscribing” on selected quantities from the pre-processing blocks. In case of TR1ATCC or TR8ATCC, there are the following possibilities:

- I3P1 represents a three-phase group of phase current with the highest current in any of the three phases considered. As only the highest of the phase current is considered, it is also possible to use one single-phase current as well as two-phase currents. In these cases, the currents that are not used will be zero.
- For I3P2 and U3P2 the setting alternatives are: any individual phase current/voltage, as well as any combination of phase-phase current/voltage or the positive sequence current/voltage. Thus, single-phase as well as, phase-phase or three-phase feeding on the LV-side is possible but it is commonly selected for current and voltage.



IEC10000044-2-en.vsd

Figure 70: Signal flow for a single transformer with voltage control

On the HV side, the three-phase current is normally required in order to feed the three-phase over current protection that blocks the load tap changer in case of over-current above harmful levels.

The voltage measurement on the LV-side can be made single phase-earth. However, it shall be remembered that this can only be used in solidly earthed systems, as the measured phase-earth voltage can increase with as much as a factor $\sqrt{3}$ in case of earth faults in a non-solidly earthed system.

The analog input signals are normally common with other functions in the IED for example, protection functions.

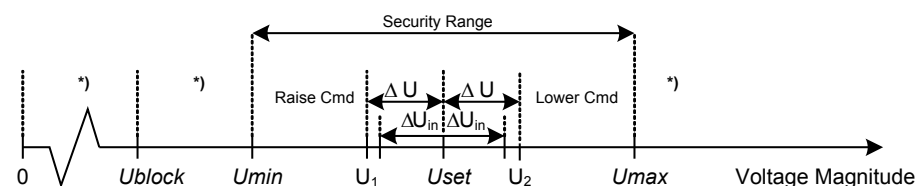


The LV-busbar voltage is designated U_B , the load current I_L and load point voltage U_L .

Automatic voltage control for a single transformer

Automatic voltage control for tap changer, single control TR1ATCC measures the magnitude of the busbar voltage U_B . If no other additional features are enabled (line voltage drop compensation), this voltage is further used for voltage regulation.

TR1ATCC then compares this voltage with the set voltage, U_{Set} and decides which action should be taken. To avoid unnecessary switching around the setpoint, a deadband (degree of insensitivity) is introduced. The deadband is symmetrical around U_{Set} , see figure 71, and it is arranged in such a way that there is an outer and an inner deadband. Measured voltages outside the outer deadband start the timer to initiate tap commands, whilst the sequence resets when the measured voltage is once again back inside the inner deadband. One half of the outer deadband is denoted ΔU . The setting of ΔU , setting $U_{deadband}$ should be set to a value near to the power transformer's tap changer voltage step (typically 75–125% of the tap changer step).



*) Action in accordance with setting

IEC06000489_2_en.vsd

Figure 71: Control actions on a voltage scale

During normal operating conditions the busbar voltage U_B stays within the outer deadband (interval between U_1 and U_2 in figure 71). In that case no actions will be taken by TR1ATCC. However, if U_B becomes smaller than U_1 , or greater than U_2 , an appropriate raise or lower timer will start. The timer will run as long as the

measured voltage stays outside the inner deadband. If this condition persists longer than the preset time delay, TR1ATCC will initiate that the appropriate ULOWER or URAISE command will be sent from TCMYLTC or TCLYLTC function block to the transformer tap changer. If necessary, the procedure will be repeated until the magnitude of the busbar voltage again falls within the inner deadband. One half of the inner deadband is denoted ΔU_{in} . The inner deadband ΔU_{in} , setting *UDeadbandInner* should be set to a value smaller than ΔU . It is recommended to set the inner deadband to 25-70% of the ΔU value.

This way of working is used by TR1ATCC while the busbar voltage is within the security range defined by settings *Umin* and *Umax*.

A situation where U_B falls outside this range will be regarded as an abnormal situation.

When U_B falls below setting *Ublock*, or alternatively, falls below setting *Umin* but still above *Ublock*, or rises above *Umax*, actions will be taken in accordance with settings for blocking conditions (refer to table 27).

If the busbar voltage rises above *Umax*, TR1ATCC can initiate one or more fast step down commands (ULOWER commands) in order to bring the voltage back into the security range (settings *Umin*, and *Umax*). The fast step down function operation can be set in one of the following three ways: off /auto/auto and manual, according to the setting *FSDMode*. The ULOWER command, in fast step down mode, is issued with the settable time delay *tFSD*.

The measured RMS magnitude of the busbar voltage U_B is shown on the local HMI as value BUSVOLT under .

Time characteristic

The time characteristic defines the time that elapses between the moment when measured voltage exceeds the deadband interval until the appropriate URAISE or ULOWER command is initiated.

The purpose of the time delay is to prevent unnecessary load tap changer operations caused by temporary voltage fluctuations and to coordinate load tap changer operations in radial networks in order to limit the number of load tap changer operations. This can be done by setting a longer time delay closer to the consumer and shorter time delays higher up in the system.

The first time delay, *tI*, is used as a time delay (usually long delay) for the first command in one direction. It can have a definite or inverse time characteristic, according to the setting *tIUse* (Constant/Inverse). For inverse time characteristics larger voltage deviations from the *USet* value will result in shorter time delays, limited by the shortest time delay equal to the *tMin* setting. This setting should be coordinated with the tap changer mechanism operation time.

Constant (definite) time delay is independent of the voltage deviation.

The inverse time characteristic for the first time delay follows the formulas:

$$DA = |U_s - U_{set}|$$

(Equation 46)

$$D = \frac{DA}{\Delta U}$$

(Equation 47)

$$tMin = \frac{t_l}{D}$$

(Equation 48)

Where:

DA absolute voltage deviation from the set point

D relative voltage deviation in respect to set deadband value

For the last equation, the condition $t_l > tMin$ shall also be fulfilled. This practically means that $tMin$ will be equal to the set t_l value when absolute voltage deviation DA is equal to ΔU (relative voltage deviation D is equal to 1). For other values see figure 72. It should be noted that operating times, shown in the figure 72 are for 30, 60, 90, 120, 150 & 180 seconds settings for t_l and 10 seconds for $tMin$.

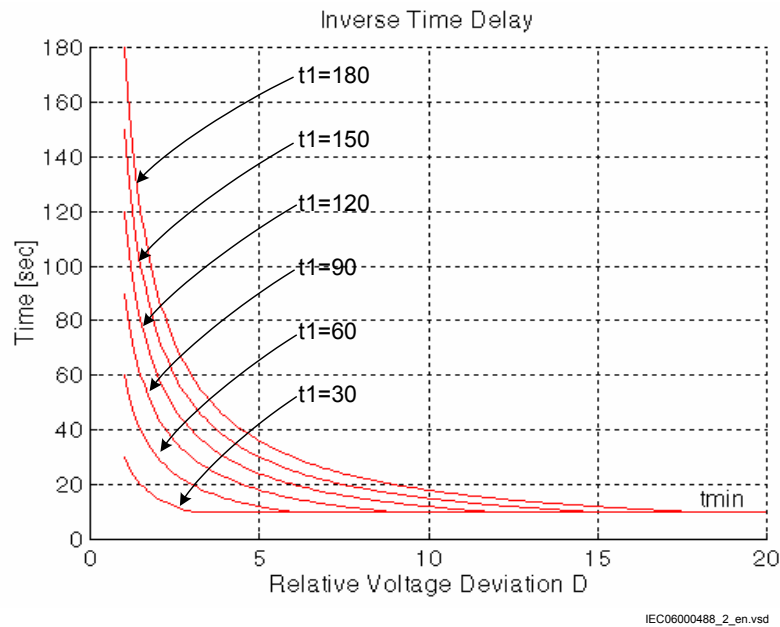


Figure 72: Inverse time characteristic for TR1ATCC and TR8ATCC

The second time delay, t_2 , will be used for consecutive commands (commands in the same direction as the first command). It can have a definite or inverse time characteristic according to the setting t_2Use (Constant/Inverse). Inverse time

characteristic for the second time delay follows the similar formulas as for the first time delay, but the $t2$ setting is used instead of $t1$.

Line voltage drop

The purpose with the line voltage drop compensation is to control the voltage, not at the power transformer low voltage side, but at a point closer to the load point.

Figure 73 shows the vector diagram for a line modelled as a series impedance with the voltage U_B at the LV busbar and voltage U_L at the load center. The load current on the line is I_L , the line resistance and reactance from the station busbar to the load point are R_L and X_L . The angle between the busbar voltage and the current, is φ . If all these parameters are known U_L can be obtained by simple vector calculation.

Values for R_L and X_L are given as settings in primary system ohms. If more than one line is connected to the LV busbar, an equivalent impedance should be calculated and given as a parameter setting.

The line voltage drop compensation function can be turned *On/Off* by the setting parameter *OperationLDC*. When it is enabled, the voltage U_L will be used by the Automatic voltage control for tap changer function, TR1ATCC for single control and TR8ATCC for parallel control for voltage regulation instead of U_B . However, TR1ATCC or TR8ATCC will still perform the following two checks:

1. The magnitude of the measured busbar voltage U_B , shall be within the security range, (setting U_{min} and U_{max}). If the busbar voltage falls-out of this range the line voltage drop compensation calculations will be temporarily stopped until the voltage U_B comes back within the range.
2. The magnitude of the calculated voltage U_L at the load point, can be limited such that it is only allowed to be equal to or smaller than the magnitude of U_B , otherwise U_B will be used. However, a situation where $U_L > U_B$ can be caused by a capacitive load condition, and if the wish is to allow for a situation like that, the limitation can be removed by setting the parameter *OperCapaLDC* to *On*.

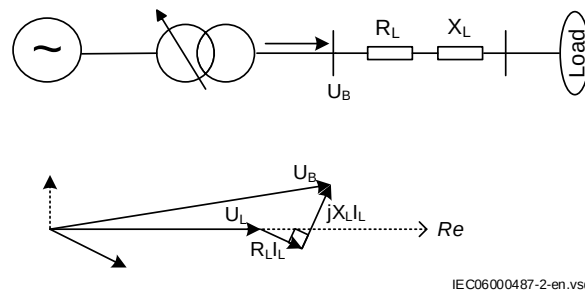


Figure 73: Vector diagram for line voltage drop compensation

The calculated load voltage U_L is shown on the local HMI as value ULOAD under **Main menu/Test/Function status/Control/TransformerVoltageControl(ATCC, 90)**.

Load voltage adjustment

Due to the fact that most loads are proportional to the square of the voltage, it is possible to provide a way to shed part of the load by decreasing the supply voltage a couple of percent. During high load conditions, the voltage drop might be considerable and there might be reasons to increase the supply voltage to keep up the power quality and customer satisfaction.

It is possible to do this voltage adjustment in two different ways in Automatic voltage control for tap changer, single control TR1ATCC and parallel control TR8ATCC:

1. Automatic load voltage adjustment, proportional to the load current.
2. Constant load voltage adjustment with four different preset values.

In the first case the voltage adjustment is dependent on the load and maximum voltage adjustment should be obtained at rated load of the transformer.

In the second case, a voltage adjustment of the set point voltage can be made in four discrete steps (positive or negative) activated with binary signals connected to TR1ATCC or TR8ATCC function block inputs LVA1, LVA2, LVA3 and LVA4. The corresponding voltage adjustment factors are given as setting parameters $LVAConst1$, $LVAConst2$, $LVAConst3$ and $LVAConst4$. The inputs are activated with a pulse, and the latest activation of anyone of the four inputs is valid. Activation of the input LVARESET in TR1ATCC or TR8ATCC block, brings the voltage setpoint back to U_{Set} .

With these factors, TR1ATCC or TR8ATCC adjusts the value of the set voltage U_{Set} according to the following formula:

$$U_{setadjust} = U_{set} + S_a \cdot \frac{I_L}{I_{2Base}} + S_{ci}$$

(Equation 49)

$U_{set, adjust}$	Adjusted set voltage in per unit
U_{set}	Original set voltage: Base quality is U_{n2}
S_a	Automatic load voltage adjustment factor, setting <i>VRAuto</i>
I_L	Load current
I_{2Base}	Rated current, LV winding
S_{ci}	Constant load voltage adjust. factor for active input <i>i</i> (corresponding to <i>LVAConst1</i> , <i>LVAConst2</i> , <i>LVAConst3</i> and <i>LVAConst4</i>)

It shall be noted that the adjustment factor is negative in order to decrease the load voltage and positive in order to increase the load voltage. After this calculation $U_{set, adjust}$ will be used by TR1ATCC or TR8ATCC for voltage regulation instead of the original value U_{set} . The calculated set point voltage $U_{set, adjust}$ is shown on the local HMI as a service value under **Main menu/Test/Function status/Control/TransformerVoltageControl(ATCC,90)**.

Automatic control of parallel transformers

Control of parallel transformers means control of two or more power transformers connected to the same busbar on the LV side and in most cases also on the HV side. Special measures must be taken in order to avoid a runaway situation where the tap changers on the parallel transformers gradually diverge and end up in opposite end positions.

Three alternative methods can be used for parallel control with the Automatic voltage control for tap changer, single/parallel control TR8ATCC:

- master-follower method
- reverse reactance method
- circulating current method

In order to realize the need for special measures to be taken when controlling transformers in parallel, consider first two parallel transformers which are supposed to be equal with similar tap changers. If they would each be in automatic voltage control for single transformer that is, each of them regulating the voltage on the LV busbar individually without any further measures taken, then the following could happen. Assuming for instance that they start out on the same tap position and that the LV busbar voltage U_B is within $U_{set} \pm \Delta U$, then a gradual increase or decrease in the load would at some stage make U_B fall outside $U_{set} \pm \Delta U$ and a raise or lower command would be initiated. However, the rate of change of voltage would normally be slow, which would make one tap changer act before the other. This is unavoidable and is due to small inequalities in measurement and so on. The one tap changer that responds first on a low voltage condition with a

raise command will be prone to always do so, and vice versa. The situation could thus develop such that, for example T1 responds first to a low busbar voltage with a raise command and thereby restores the voltage. When the busbar voltage thereafter at a later stage gets high, T2 could respond with a lower command and thereby again restore the busbar voltage to be within the inner deadband. However, this has now caused the load tap changer for the two transformers to be 2 tap positions apart, which in turn causes an increasing circulating current. This course of events will then repeat with T1 initiating raise commands and T2 initiating lower commands in order to keep the busbar voltage within $U_{Set} \pm \Delta U$, but at the same time it will drive the two tap changers to their opposite end positions. High circulating currents and loss of control would be the result of this runaway tap situation.

Parallel control with the master-follower method

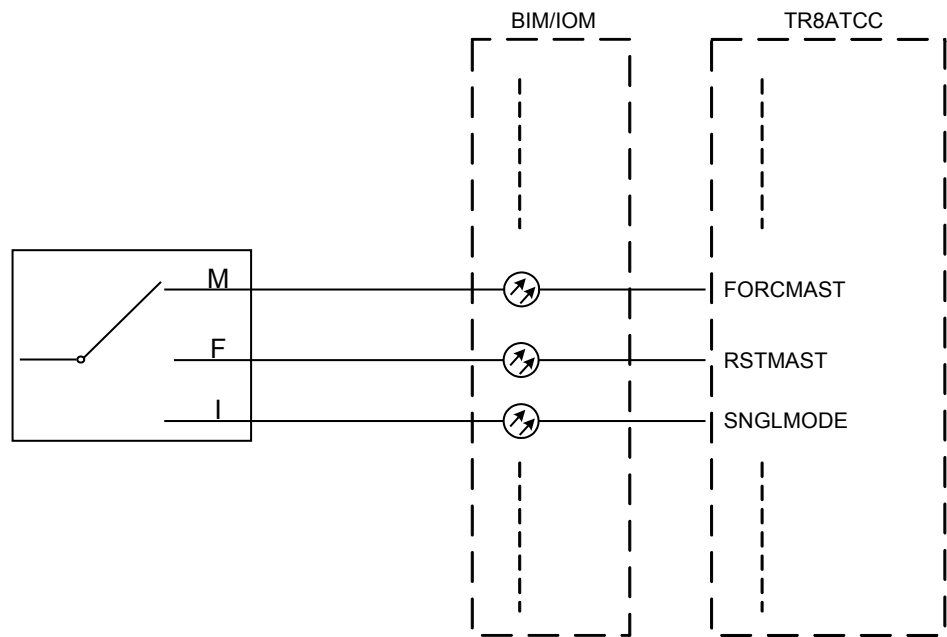
In the master-follower method, one of the transformers is selected to be master, and will regulate the voltage in accordance with the principles for Automatic voltage control. Selection of the master is made by activating the binary input FORCMAST in TR8ATCC function block for one of the transformers in the group.

The followers can act in two alternative ways depending on the setting of the parameter *MFMode*. When this setting is *Follow Cmd*, raise and lower commands (URAISE and ULOWER) generated by the master, will initiate the corresponding command in all follower TR8ATCCs simultaneously, and consequently they will blindly follow the master irrespective of their individual tap positions. Effectively this means that if the tap positions of the followers were harmonized with the master from the beginning, they would stay like that as long as all transformers in the parallel group continue to participate in the parallel control. On the other hand for example, one transformer is disconnected from the group and misses a one tap step operation, and thereafter is reconnected to the group again, it will thereafter participate in the regulation but with a one tap position offset.

If the parameter *MFMode* is set to *Follow Tap*, then the followers will read the tap position of the master and adopt to the same tap position or to a tap position with an offset relative to the master, and given by setting parameter *TapPosOffs* (positive or negative integer value). The setting parameter *tAutoMSF* introduces a time delay on URAISE/ULOWER commands individually for each follower when setting *MFMode* has the value *Follow Tap*.

Selecting a master is made by activating the input FORCMAST in TR8ATCC function block. Deselecting a master is made by activating the input RSTMAST. These two inputs are pulse activated, and the most recent activation is valid that is, an activation of any of these two inputs overrides previous activations. If none of these inputs has been activated, the default is that the transformer acts as a follower (given of course that the settings are parallel control with the master follower method).

When the selection of master or follower in parallel control, or automatic control in single mode, is made with a three position switch in the substation, an arrangement as in figure 74 below is arranged with application configuration.



IEC06000633-2-en.vsd

Figure 74: Principle for a three-position switch Master/Follower/Single

Parallel control with the reverse reactance method

Consider Figure 75 with two parallel transformers with equal rated data and similar tap changers. The tap positions will diverge and finally end up in a runaway tap situation if no measures to avoid this are taken.

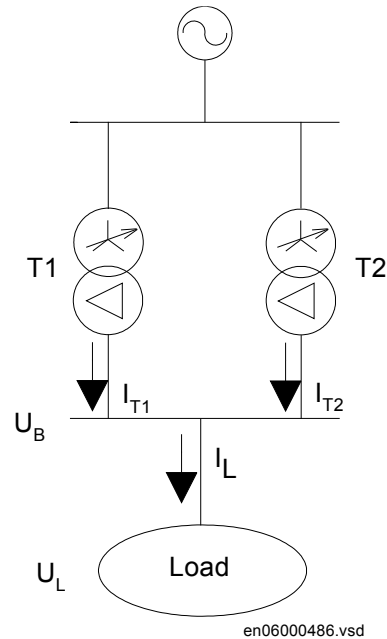


Figure 75: Parallel transformers with equal rated data.

In the reverse reactance method, the line voltage drop compensation is used. The original of the line voltage drop compensation function purpose is to control the voltage at a load point further out in the network. The very same function can also be used here to control the voltage at a load point inside the transformer, by choosing a negative value of the parameter X_{line} .

Figure 76, shows a vector diagram where the principle of reverse reactance has been introduced for the transformers in figure 75. The transformers are here supposed to be on the same tap position, and the busbar voltage is supposed to give a calculated compensated value U_L that coincides with the target voltage U_{Set} .

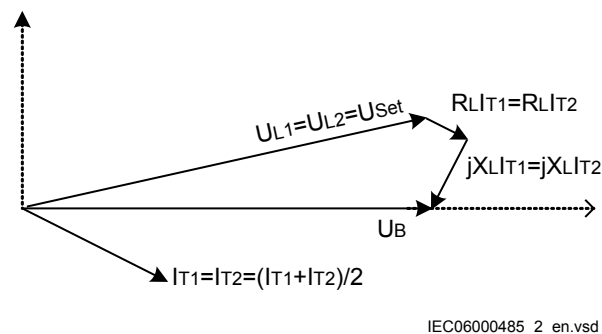


Figure 76: Vector diagram for two transformers regulated exactly on target voltage.

A comparison with figure 73 gives that the line voltage drop compensation for the purpose of reverse reactance control is made with a value with opposite sign on X_L ,

hence the designation “reverse reactance” or “negative reactance”. Effectively this means that, whereas the line voltage drop compensation in figure 73 gave a voltage drop along a line from the busbar voltage U_B to a load point voltage U_L , the line voltage drop compensation in figure 76 gives a voltage increase (actually, by adjusting the ratio X_L/R_L with respect to the power factor, the length of the vector U_L will be approximately equal to the length of U_B) from U_B up towards the transformer itself. Thus in principal the difference between the vector diagrams in figure 73 and figure 76 is the sign of the setting parameter X_L .

If now the tap position between the transformers will differ, a circulating current will appear, and the transformer with the highest tap (highest no load voltage) will be the source of this circulating current. Figure 77 below shows this situation with T1 being on a higher tap than T2.

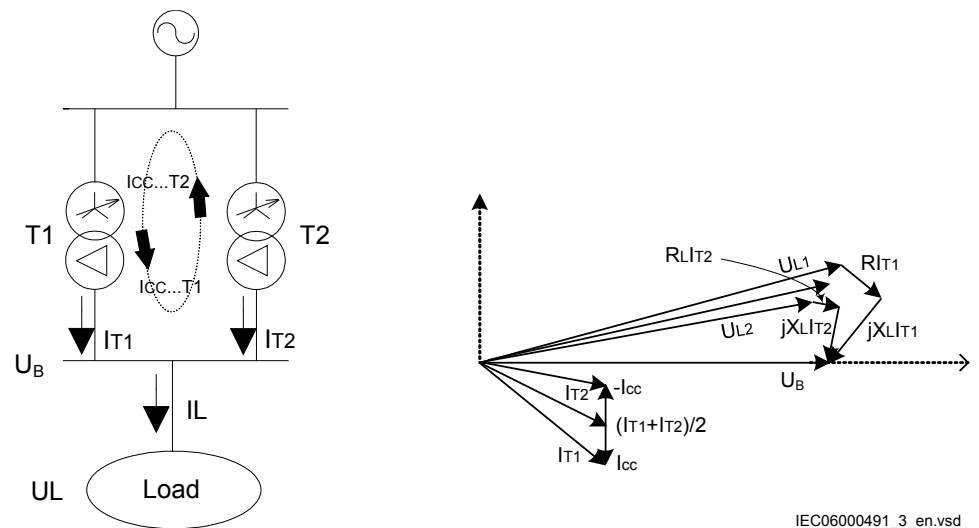


Figure 77: Circulating current caused by T1 on a higher tap than T2.

The circulating current I_{cc} is predominantly reactive due to the reactive nature of the transformers. The impact of I_{cc} on the individual transformer currents is that it increases the current in T1 (the transformer that is driving I_{cc}) and decreases it in T2 at the same time as it introduces contradictory phase shifts, as can be seen in figure 77. The result is thus, that the line voltage drop compensation calculated voltage U_L for T1 will be higher than the line voltage drop compensation calculated voltage U_L for T2, or in other words, the transformer with the higher tap position will have the higher U_L value and the transformer with the lower tap position will have the lower U_L value. Consequently, when the busbar voltage increases, T1 will be the one to tap down, and when the busbar voltage decreases, T2 will be the one to tap up. The overall performance will then be that the runaway tap situation will be avoided and that the circulating current will be minimized.

Parallel control with the circulating current method

Two transformers with different turns ratio, connected to the same busbar on the HV-side, will apparently show different LV-side voltage. If they are now connected to the same LV busbar but remain unloaded, this difference in no-load voltage will cause a circulating current to flow through the transformers. When load is put on the transformers, the circulating current will remain the same, but now it will be superimposed on the load current in each transformer. Voltage control of parallel transformers with the circulating current method means minimizing of the circulating current at a given voltage target value, thereby achieving:

1. that the busbar or load voltage is regulated to a preset target value
2. that the load is shared between parallel transformers in proportion to their ohmic short circuit reactance

If the transformers have equal percentage impedance given in the respective transformer MVA base, the load will be divided in direct proportion to the rated power of the transformers when the circulating current is minimized.

This method requires extensive exchange of data between the TR8ATCC function blocks (one TR8ATCC function for each transformer in the parallel group). TR8ATCC function block can either be located in the same IED, where they are configured in PCM600 to co-operate, or in different IEDs. If the functions are located in different IEDs they must communicate via GOOSE interbay communication on the IEC 61850 communication protocol. Complete exchange of TR8ATCC data, analog as well as binary, via GOOSE is made cyclically every 300 ms.

The busbar voltage U_B is measured individually for each transformer in the parallel group by its associated TR8ATCC function. These measured values will then be exchanged between the transformers, and in each TR8ATCC block, the mean value of all U_B values will be calculated. The resulting value U_{Bmean} will then be used in each IED instead of U_B for the voltage regulation, thus assuring that the same value is used by all TR8ATCC functions, and thereby avoiding that one erroneous measurement in one transformer could upset the voltage regulation. At the same time, supervision of the VT mismatch is also performed. This works such that, if a measured voltage U_B , differs from U_{Bmean} with more than a preset value (setting parameter *VTmismatch*) and for more than a pre set time (setting parameter *tVTmismatch*) an alarm signal VTALARM will be generated.

The calculated mean busbar voltage U_{Bmean} is shown on the local HMI as a service value BusVolt under **Main menu/Test/Function status/Control/TransformerVoltageControl(ATCC,90)**.

Measured current values for the individual transformers must be communicated between the participating TR8ATCC functions, in order to calculate the circulating current.

The calculated circulating current I_{cc_i} for transformer “i” is shown on the HMI as a service value ICIRCUL under **Main menu/Test/Function status/Control/TransformerVoltageControl(ATCC,90)**.

When the circulating current is known, it is possible to calculate a no-load voltage for each transformer in the parallel group. To do that the magnitude of the circulating current in each bay, is first converted to a voltage deviation, U_{di} , with equation 50:

$$U_{di} = C_i \times I_{cc\_i} \times X_i$$

(Equation 50)

where X_i is the short-circuit reactance for transformer i and C_i , is a setting parameter named *Comp* which serves the purpose of alternatively increasing or decreasing the impact of the circulating current in TR8ATCC control calculations. It should be noted that U_{di} will have positive values for transformers that produce circulating currents and negative values for transformers that receive circulating currents.

Now the magnitude of the no-load voltage for each transformer can be approximated with:

$$U_i = U_{Bmean} + U_{di}$$

(Equation 51)

This value for the no-load voltage is then simply put into the voltage control function for single transformer. There it is treated as the measured busbar voltage, and further control actions are taken as described previously in section ["Automatic voltage control for a single transformer"](#). By doing this, the overall control strategy can be summarized as follows.

For the transformer producing/receiving the circulating current, the calculated no-load voltage will be greater/smaller than the measured voltage U_{Bmean} . The calculated no-load voltage will then be compared with the set voltage U_{Set} . A steady deviation which is outside the outer deadband will result in ULOWER or URAISE being initiated alternatively. In this way the overall control action will always be correct since the position of a tap changer is directly proportional to the transformer no-load voltage. The sequence resets when U_{Bmean} is inside the inner deadband at the same time as the calculated no-load voltages for all transformers in the parallel group are inside the outer deadband.

In parallel operation with the circulating current method, different U_{Set} values for individual transformers can cause the voltage regulation to be unstable. For this reason, the mean value of U_{Set} for parallel operating transformers can be automatically calculated and used for the voltage regulation. This is set *On/Off* by setting parameter *OperUsetPar*. The calculated mean U_{Set} value is shown on the local HMI as a service value USETPAR under **Main menu/Test/Function status/Control/TransformerVoltageControl(ATCC,90)**.

The use of mean U_{Set} is recommended for parallel operation with the circulating current method, especially in cases when Load Voltage Adjustment is also used.

Line voltage drop compensation for parallel control

The line voltage drop compensation for a single transformer is described in section ["Line voltage drop"](#). The same principle is used for parallel control with the circulating current method and with the master – follower method, except that the total load current, I_L , is used in the calculation instead of the individual transformer current. (See figure [73](#) for details). The same values for the parameters R_{line} and X_{line} shall be set in all IEDs in the same parallel group. There is no automatic change of these parameters due to changes in the substation topology, thus they should be changed manually if needed.

Avoidance of simultaneous tapping

Avoidance of simultaneous tapping (operation with the circulating current method)

For some types of tap changers, especially older designs, an unexpected interruption of the auxiliary voltage in the middle of a tap manoeuvre, can jam the tap changer. In order not to expose more than one tap changer at a time, simultaneous tapping of parallel transformers (regulated with the circulating current method) can be avoided. This is done by setting parameter *OperSimTap* to *On*. Simultaneous tapping is then avoided at the same time as tapping actions (in the long term) are distributed evenly amongst the parallel transformers.

The algorithm in Automatic voltage control for tap changer, parallel control TR8ATCC will select the transformer with the greatest voltage deviation U_{di} to tap first. That transformer will then start timing, and after time delay $t1$ the appropriate URAISE or ULOWER command will be initiated. If now further tapping is required to bring the busbar voltage inside $U_{DeadbandInner}$, the process will be repeated, and the transformer with the then greatest value of U_{di} amongst the remaining transformers in the group will tap after a further time delay $t2$, and so on. This is made possible as the calculation of I_{cc} is cyclically updated with the most recent measured values. If two transformers have equal magnitude of U_{di} then there is a predetermined order governing which one is going to tap first.

Avoidance of simultaneous tapping (operation with the master follower method)

A time delay for the follower in relation to the command given from the master can be set when the setting *MFMode* is *Follow Tap* that is, when the follower follows the tap position (with or without an offset) of the master. The setting parameter *tAutoMSF* then introduces a time delay on UVRAISE/ULOWER commands individually for each follower, and effectively this can be used to avoid simultaneous tapping.

Homing

Homing (operation with the circulating current method)

This function can be used with parallel operation of power transformers using the circulating current method. It makes possible to keep a transformer energized from the HV side, but open on the LV side (hot stand-by), to follow the voltage regulation of loaded parallel transformers, and thus be on a proper tap position when the LV circuit breaker closes.

For this function, it is needed to have the LV VTs for each transformer on the cable (tail) side (not the busbar side) of the CB, and to have the LV CB position hardwired to the IED.

In TR8ATCC block for one transformer, the state "Homing" will be defined as the situation when the transformer has information that it belongs to a parallel group (for example, information on T1INCLD=1 or T2INCLD=1 ... and so on), at the same time as the binary input DISC on TR8ATCC block is activated by open LV CB. If now the setting parameter *OperHoming* = On for that transformer, TR8ATCC will act in the following way:

- The algorithm calculates the “true” busbar voltage, by averaging the voltage measurements of the other transformers included in the parallel group (voltage measurement of the “disconnected transformer” itself is not considered in the calculation).
- The value of this true busbar voltage is used in the same way as U_{set} for control of a single transformer. The “disconnected transformer” will then automatically initiate URAISE or ULOWER commands (with appropriate $t1$ or $t2$ time delay) in order to keep the LV side of the transformer within the deadband of the busbar voltage.

Homing (operation with the master follower method)

If one (or more) follower has its LV circuit breaker open and its HV circuit breaker closed, and if *OperHoming* = On, this follower continues to follow the master just as it would have made with the LV circuit breaker closed. On the other hand, if the LV circuit breaker of the master opens, automatic control will be blocked and TR8ATCC function output MFERR will be activated as the system will not have a master.

Adapt mode, manual control of a parallel group**Adapt mode (operation with the circulating current method)**

When the circulating current method is used, it is also possible to manually control the transformers as a group. To achieve this, the setting *OperationAdapt* must be set On, then the control mode for one TR8ATCC shall be set to “Manual” via the binary input MANCTRL or the local HMI under **Main menu/Control/Commands/TransformerVoltageControl(ATCC,90)** whereas the other TR8ATCCs are left in “Automatic”. TR8ATCCs in automatic mode will then observe that one transformer in the parallel group is in manual mode and will then automatically be set in adapt mode. As the name indicates they will adapt to the manual tapping of the transformer that has been put in manual mode.

TR8ATCC in adapt mode will continue the calculation of U_{di} , but instead of adding U_{di} to the measured busbar voltage, it will compare it with the deadband ΔU . The following control rules are used:

1. If U_{di} is positive and its modulus is greater than ΔU , then initiate an ULOWER command. Tapping will then take place after appropriate $t1/t2$ timing.
2. If U_{di} is negative and its modulus is greater than ΔU , then initiate an URAISE command. Tapping will then take place after appropriate $t1/t2$ timing.
3. If U_{di} modulus is smaller than ΔU , then do nothing.

The binary output signal ADAPT on the TR8ATCC function block will be activated to indicate that this TR8ATCC is adapting to another TR8ATCC in the parallel group.

It shall be noted that control with adapt mode works as described under the condition that only one transformer in the parallel group is set to manual mode via the binary input MANCTRL or, the local HMI **Main menu/Control/Commands/TransformerVoltageControl(ATCC,90)**.

In order to operate each tap changer individually when the circulating current method is used, the operator must set each TR8ATCC in the parallel group, in manual.

Adapt mode (operation with the master follower method)

When in master follower mode, the adapt situation occurs when the setting *OperationAdapt* is *On*, and the master is put in manual control with the followers still in parallel master-follower control. In this situation the followers will continue to follow the master the same way as when it is in automatic control.

If one follower in a master follower parallel group is put in manual mode, still with the setting *OperationAdaptOn*, the rest of the group will continue in automatic master follower control. The follower in manual mode will of course disregard any possible tapping of the master. However, as one transformer in the parallel group is now exempted from the parallel control, the binary output signal ADAPT on TR8ATCC function block will be activated for the rest of the parallel group.

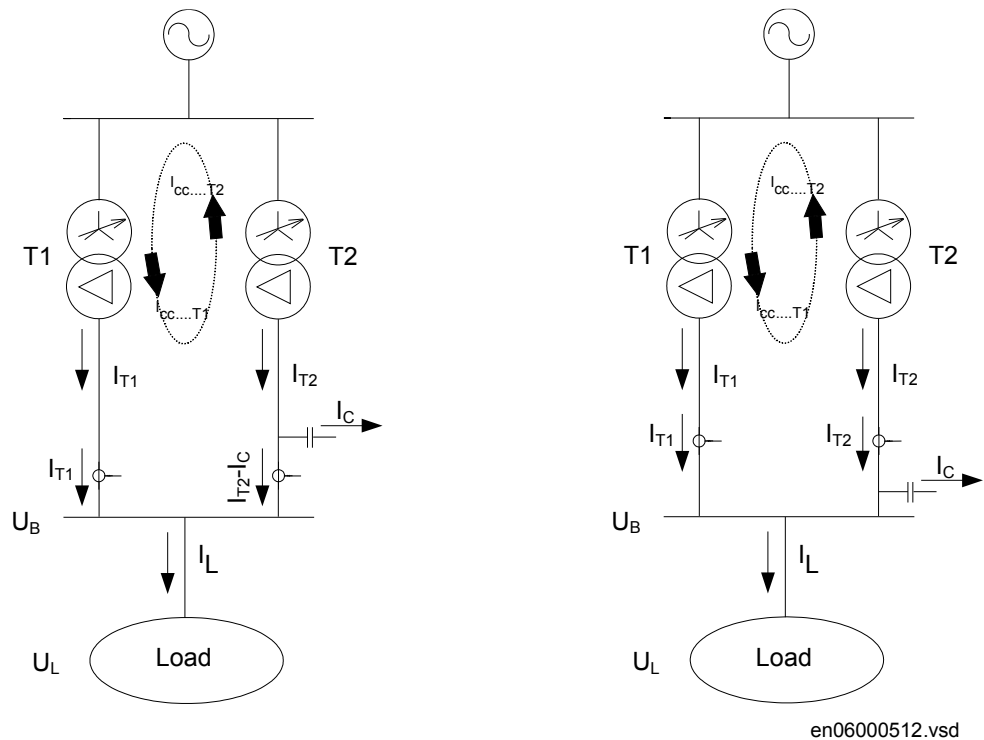
Plant with capacitive shunt compensation (for operation with the circulating current method)

If significant capacitive shunt generation is connected in a substation and it is not symmetrically connected to all transformers in a parallel group, the situation may require compensation of the capacitive current to the ATCC.

An asymmetric connection will exist if for example, the capacitor is situated on the LV-side of a transformer, between the CT measuring point and the power transformer or at a tertiary winding of the power transformer, see figure 78. In a situation like this, the capacitive current will interact in opposite way in the different ATCCs with regard to the calculation of circulating currents. The capacitive current is part of the imaginary load current and therefore essential in the calculation. The calculated circulating current and the real circulating currents

will in this case not be the same, and they will not reach a minimum at the same time. This might result in a situation when minimizing of the calculated circulating current will not regulate the tap changers to the same tap positions even if the power transformers are equal.

However if the capacitive current is also considered in the calculation of the circulating current, then the influence can be compensated for.



en06000512.vsd

Figure 78: Capacitor bank on the LV-side

From figure 78 it is obvious that the two different connections of the capacitor banks are completely the same regarding the currents in the primary network. However the CT measured currents for the transformers would be different. The capacitor bank current may flow entirely to the load on the LV side, or it may be divided between the LV and the HV side. In the latter case, the part of I_C that goes to the HV side will divide between the two transformers and it will be measured with opposite direction for T2 and T1. This in turn would be misinterpreted as a circulating current, and would upset a correct calculation of I_{CC} . Thus, if the actual connection is as in the left figure the capacitive current I_C needs to be compensated for regardless of the operating conditions and in ATCC this is made numerically. The reactive power of the capacitor bank is given as a setting Q1, which makes it possible to calculate the reactive capacitance:

$$X_c = \frac{U^2}{Q1}$$

(Equation 52)

Thereafter the current I_C at the actual measured voltage U_B can be calculated as:

$$I_C = \frac{U_B}{\sqrt{3} \times X_c}$$

(Equation 53)

In this way the measured LV currents can be adjusted so that the capacitor bank current will not influence the calculation of the circulating current.

Three independent capacitor bank values $Q1$, $Q2$ and $Q3$ can be set for each transformer in order to make possible switching of three steps in a capacitor bank in one bay.

Power monitoring

The level (with sign) of active and reactive power flow through the transformer, can be monitored. This function can be utilized for different purposes for example, to block the voltage control function when active power is flowing from the LV side to the HV side or to initiate switching of reactive power compensation plant, and so on.

There are four setting parameters $P>$, $P<$, $Q>$ and $Q<$ with associated outputs in TR8ATCC and TR1ATCC function blocks PGTFWD, PLTREV, QGTFWD and QLTREV. When passing the pre-set value, the associated output will be activated after the common time delay setting $tPower$.

The definition of direction of the power is such that the active power P is forward when power flows from the HV-side to the LV-side as shown in figure 79. The reactive power Q is forward when the total load on the LV side is inductive (reactance) as shown in figure 79.

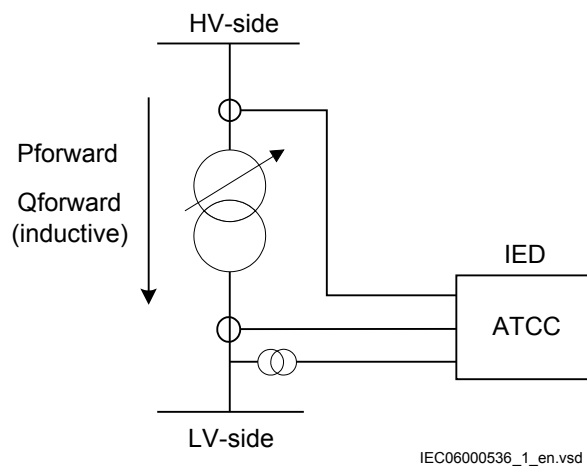


Figure 79: Power direction references

With the four outputs in the function block available, it is possible to do more than just supervise a level of power flow in one direction. By combining the outputs with logical elements in application configuration, it is also possible to cover for example, intervals as well as areas in the P-Q plane.

Busbar topology logic

Information of the busbar topology that is, position of circuit breakers and isolators, yielding which transformers that are connected to which busbar and which busbars that are connected to each other, is vital for the Automatic voltage control for tap changer, parallel control function TR8ATCC when the circulating current or the master-follower method is used. This information tells each TR8ATCC, which transformers that it has to consider in the parallel control.

In a simple case, when only the switchgear in the transformer bays needs to be considered, there is a built-in function in TR8ATCC block that can provide information on whether a transformer is connected to the parallel group or not. This is made by connecting the transformer CB auxiliary contact status to TR8ATCC function block input DISC, which can be made via a binary input, or via GOOSE from another IED in the substation. When the transformer CB is open, this activates that input which in turn will make a corresponding signal DISC=1 in TR8ATCC data set. This data set is the same data package as the package that contains all TR8ATCC data transmitted to the other transformers in the parallel group (see section ["Exchange of information between TR8ATCC functions"](#) for more details). Figure 80 shows an example where T3 is disconnected which will lead to T3 sending the DISC=1 signal to the other two parallel TR8ATCC modules (T1 and T2) in the group. Also see table 26.

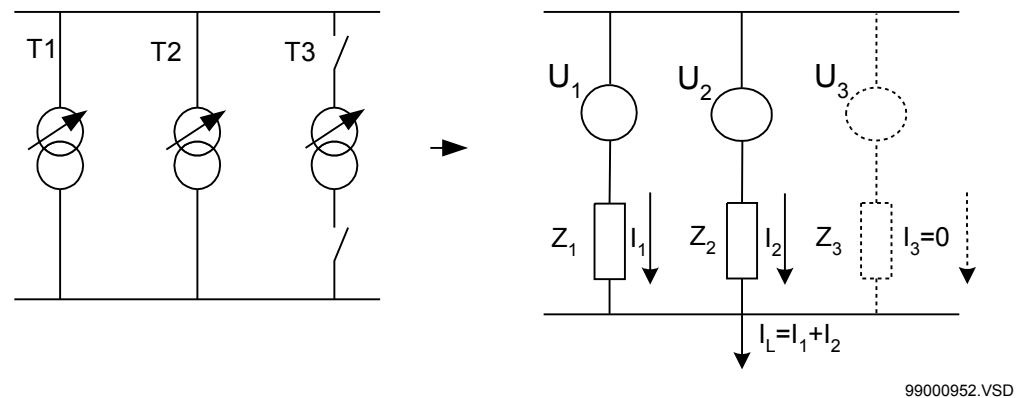


Figure 80: Disconnection of one transformer in a parallel group

When the busbar arrangement is more complicated with more buses and bus couplers/bus sections, it is necessary to engineer a specific station topology logic. This logic can be built in the application configuration in PCM600 and will keep record on which transformers that are in parallel (in one or more parallel groups). In each TR8ATCC function block there are eight binary inputs (T1INCLD,..., T8INCLD) that will be activated from the logic depending on which transformers that are in parallel with the transformer to whom the TR8ATCC function block belongs.

TR8ATCC function block is also fitted with eight outputs (T1PG,..., T8PG) for indication of the actual composition of the parallel group that it itself is part of. If parallel operation mode has been selected in the IED with setting $Trfld = Tx$, then the TxPG signal will always be set to 1. The parallel function will consider communication messages only from the voltage control functions working in parallel (according to the current station configuration). When the parallel voltage control function detects that no other transformers work in parallel it will behave as a single voltage control function in automatic mode.

Exchange of information between TR8ATCC functions

Each transformer in a parallel group needs an Automatic voltage control for tap changer, parallel control TR8ATCC function block of its own for the parallel voltage control. Communication between these TR8ATCCs is made either on the GOOSE interbay communication on the IEC 61850 protocol if TR8ATCC functions reside in different IEDs, or alternatively configured internally in one IED if multiple instances of TR8ATCC reside in the same IED. Complete exchange of TR8ATCC data, analog as well as binary, on GOOSE is made cyclically every 300 ms.

TR8ATCC function block has an output ATCCOUT. This output contains two sets of signals. One is the data set that needs to be transmitted to other TR8ATCC blocks in the same parallel group, and the other is the data set that is transferred to the TCMYLTC or TCLYLTC function block for the same transformer as TR8ATCC block belongs to.

There are 10 binary signals and 6 analog signals in the data set that is transmitted from one TR8ATCC block to the other TR8ATCC blocks in the same parallel group:

Table 24: *Binary signals*

Signal	Explanation
TimerOn	This signal is activated by the transformer that has started its timer and is going to tap when the set time has expired.
automaticCTRL	Activated when the transformer is set in automatic control
mutualBlock	Activated when the automatic control is blocked
disc	Activated when the transformer is disconnected from the busbar
receiveStat	Signal used for the horizontal communication
TermIsForcedMaster	Activated when the transformer is selected Master in the master-follower parallel control mode
TermIsMaster	Activated for the transformer that is master in the master-follower parallel control mode
termReadyForMSF	Activated when the transformer is ready for master-follower parallel control mode
raiseVoltageOut	Order from the master to the followers to tap up
lowerVoltageOut	Order from the master to the followers to tap down

Table 25: *Analog signals*

Signal	Explanation
voltageBusbar	Measured busbar voltage for this transformer
ownLoadCurrim	Measured load current imaginary part for this transformer
ownLoadCurre	Measured load current real part for this transformer
reacSec	Transformer reactance in primary ohms referred to the LV side
relativePosition	The transformer's actual tap position
voltage Setpoint	The transformer's set voltage (U_{Set}) for automatic control



Manual configuration of VCTR GOOSE data set is required. Note that both data value attributes and quality attributes have to be mapped. The following data objects must be configured:

- BusV
- LodAIm
- LodARe
- PosRel
- SetV
- VCTRStatus
- X2

The transformers controlled in parallel with the circulating current method or the master-follower method must be assigned unique identities. These identities are entered as a setting in each TR8ATCC, and they are predefined as T1, T2, T3,..., T8 (transformers 1 to 8). In figure 80 there are three transformers with the parameter *Trfld* set to T1, T2 and T3, respectively.

For parallel control with the circulating current method or the master-follower method alternatively, the same type of data set as described above, must be exchanged between two TR8ATCC. To achieve this, each TR8ATCC is transmitting its own data set on the output ATCCOUT as previously mentioned. To receive data from the other transformers in the parallel group, the output ATCCOUT from each transformer must be connected (via GOOSE or internally in the application configuration) to the inputs HORIZx (x = identifier for the other transformers in the parallel group) on TR8ATCC function block. Apart from this, there is also a setting in each TR8ATCC =/,..., =/*T1RXOP=Off/On*,..., *T8RXOP=Off/ On*. This setting determines from which of the other transformer individuals that data shall be received. Settings in the three TR8ATCC blocks for the transformers in figure 80, would then be according to the table 26:

Table 26: *Setting of TxRXOP*

Trfld=T1	T1RXOP= Off	T2RXOP= On	T3RXOP= On	T4RXOP= Off	T5RXOP= Off	T6RXOP= Off	T7RXOP= Off	T8RXOP= Off
Trfld=T2	T1RXOP= On	T2RXOP= Off	T3RXOP= On	T4RXOP= Off	T5RXOP= Off	T6RXOP= Off	T7RXOP= Off	T8RXOP= Off
Trfld=T3	T1RXOP= On	T2RXOP= On	T3RXOP= Off	T4RXOP= Off	T5RXOP= Off	T6RXOP= Off	T7RXOP= Off	T8RXOP= Off

Observe that this parameter must be set to *Off* for the “own” transformer. (for transformer with identity T1 parameter *T1RXOP* must be set to *Off*, and so on.

Blocking

Blocking conditions

The purpose of blocking is to prevent the tap changer from operating under conditions that can damage it, or otherwise when the conditions are such that power system related limits would be exceeded or when, for example the conditions for automatic control are not met.

For the Automatic voltage control for tap changer function, TR1ATCC for single control and TR8ATCC for parallel control, three types of blocking are used:

Partial Block: Prevents operation of the tap changer only in one direction (only URAISE or ULOWER command is blocked) in manual and automatic control mode.

Auto Block: Prevents automatic voltage regulation, but the tap changer can still be controlled manually.

Total Block: Prevents any tap changer operation independently of the control mode (automatic as well as manual).

Setting parameters for blocking that can be set in TR1ATCC or TR8ATCC under general settings in PST/local HMI are listed in table 27.

Table 27: *Blocking settings*

Setting	Values (Range)	Description
OCBk (automatically reset)	Alarm Auto Block Auto&Man Block	When any one of the three HV currents exceeds the preset value <i>IBlock</i> , TR1ATCC or TR8ATCC will be temporarily totally blocked. The outputs IBLK and TOTBLK or AUTOBLK will be activated depending on the actual parameter setting.
OVPartBk (automatically reset)	Alarm Auto&Man Block	
UVPartBk (automatically reset)	Alarm Auto&Man Block	
UVBk (automatically reset)	Alarm Auto Block Auto&Man Block	If the busbar voltage U_B falls below <i>Ublock</i> this blocking condition is active. It is recommended to block automatic control in this situation and allow manual control. This is because the situation normally would correspond to a disconnected transformer and then it should be allowed to operate the tap changer before reconnecting the transformer. The outputs UBLK and TOTBLK or AUTOBLK will be activated depending on the actual parameter setting.
RevActPartBk(auto matically reset)	Alarm Auto Block	The risk of voltage instability increases as transmission lines become more heavily loaded in an attempt to maximize the efficient use of existing generation and transmission facilities. In the same time lack of reactive power may move the operation point of the power network to the lower part of the P-V-curve (unstable part). Under these conditions, when the voltage starts to drop, it might happen that an URAISE command can give reversed result that is, a lower busbar voltage. Tap changer operation under voltage instability conditions makes it more difficult for the power system to recover. Therefore, it might be desirable to block TR1ATCC or TR8ATCC temporarily. Requirements for this blocking are: • The load current must exceed the set value <i>RevActLim</i> • After an URAISE command, the measured busbar voltage shall have a lower value than its previous value • The second requirement has to be fulfilled for two consecutive URAISE commands If all three requirements are fulfilled, TR1ATCC or TR8ATCC automatic control will be blocked for raise commands for a period of time given by the setting parameter <i>tRevAct</i> and the output signal REVACBLK will be set. The reversed action feature can be turned off/on with the setting parameter <i>OperationRA</i>.
Table continues on next page		

Setting	Values (Range)	Description
CmdErrBk (manually reset)	Alarm Auto Block Auto&Man Block	Typical operating time for a tap changer mechanism is around 3-8 seconds. Therefore, the function should wait for a position change before a new command is issued. The command error signal, CMDERRAL on the TCMYLTC or TCLYLTC function block, will be set if the tap changer position does not change one step in the correct direction within the time given by the setting <i>tTCTimeout</i> in TCMYLTC or TCLYLTC function block. The tap changer module TCMYLTC or TCLYLTC will then indicate the error until a successful command has been carried out or it has been reset by changing control mode of TR1ATCC or TR8ATCC function to Manual and then back to Automatic. The outputs CMDERRAL on TCMYLTC or TCLYLTC and TOTBLK or AUTOBLK on TR1ATCC or TR8ATCC will be activated depending on the actual parameter setting. This error condition can be reset by the input RESETERR on TCMYLTC function block, or alternatively by changing control mode of TR1ATCC or TR8ATCC function to Manual and then back to Automatic.
TapChgBk (manually reset)	Alarm Auto Block Auto&Man Block	If the input TCINPROG of TCMYLTC or TCLYLTC function block is connected to the tap changer mechanism, then this blocking condition will be active if the TCINPROG input has not reset when the <i>tTCTimeout</i> timer has timed out. The output TCERRAL will be activated depending on the actual parameter setting. In correct operation the TCINPROG shall appear during the URAISE/ULOWER output pulse and disappear before the <i>tTCTimeout</i> time has elapsed. This error condition can be reset by the input RESETERR on TCMYLTC function block, or alternatively by changing control mode of TR1ATCC or TR8ATCC function to Manual and then back to Automatic.
Table continues on next page		

Setting	Values (Range)	Description
TapPosBk (automatically reset/manually reset)	Alarm Auto Block Auto&Man Block	This blocking/alarm is activated by either: 1. The tap changer reaching an end position i.e. one of the extreme positions according to the setting parameters <i>LowVoltTap</i> and <i>HighVoltTap</i>. When the tap changer reaches one of these two positions further commands in the corresponding direction will be blocked. Effectively this will then be a partial block if <i>Auto Block</i> or <i>Auto&Man Block</i> is set. The outputs POSERRAL and LOPOSAL or HIPOSAL will be activated. 2. Tap Position Error which in turn can be caused by one of the following conditions: • Tap position is out of range that is, the indicated position is above or below the end positions. • The tap changer indicates that it has changed more than one position on a single raise or lower command. • The tap position reading shows a BCD code error (unaccepted combination) or a parity fault. • The reading of tap position shows a mA value that is out of the mA-range. Supervision of the input signal for MIM is made by setting the MIM parameters <i>I_Max</i> and <i>I_Min</i> to desired values, for example, <i>I_Max</i> = 20mA and <i>I_Min</i> = 4mA. • Very low or negative mA-values. • Indication of hardware fault on BIM or MIM module. Supervision of the input hardware module is provided by connecting the corresponding error signal to the INERR input (input module error) or BIERR on TCMYLTCC or TCLYLTC function block. • Interruption of communication with the tap changer. The outputs POSERRAL and AUTOBLK or TOTBLK will be set. This error condition can be reset by the input RESETERR on TCMYLTCC function block, or alternatively by changing control mode of TR1ATCC or TR8ATCC function to Manual and then back to Automatic.
CircCurrBk (automatically reset)	Alarm Auto Block Auto&Man Block	When the magnitude of the circulating current exceeds the preset value (setting parameter <i>CircCurrLimit</i>) for longer time than the set time delay (setting parameter <i>tCircCurr</i>) it will cause this blocking condition to be fulfilled provided that the setting parameter <i>OperCCBlock</i> is <i>On</i>. The signal resets automatically when the circulating current decreases below the preset value. Usually this can be achieved by manual control of the tap changers. TR1ATCC or TR8ATCC outputs ICIRC and TOTBLK or AUTOBLK will be activated depending on the actual parameter setting.
MFPoSDiffBk (manually reset)	Alarm Auto Block	In the master-follower mode, if the tap difference between a follower and the master is greater than the set value (setting parameter <i>MFPoSDiffLim</i>) then this blocking condition is fulfilled and the outputs OUTFPOS and AUTOBLK (alternatively an alarm) will be set.

Setting parameters for blocking that can be set in TR1ATCC or TR8ATCC under setting group Nx in PST/ local HMI are listed in table [28](#).

Table 28: *Blocking settings*

Setting	Value (Range)	Description
TotalBlock (manually reset)	<i>On/ Off</i>	TR1ATCC or TR8ATCC function can be totally blocked via the setting parameter <i>TotalBlock</i> , which can be set <i>On/ Off</i> from the local HMI or PST. The output TOTBLK will be activated.
AutoBlock (manually reset)	<i>On/ Off</i>	TR1ATCC or TR8ATCC function can be blocked for automatic control via the setting parameter <i>AutoBlock</i> , which can be set <i>On/ Off</i> from the local HMI or PST. The output AUTOBLK will be set.

TR1ATCC or TR8ATCC blockings that can be made via input signals in the function block are listed in table [29](#).

Table 29: *Blocking via binary inputs*

Input name	Activation	Description
BLOCK (manually reset)	<i>On/ Off</i> (via binary input)	The voltage control function can be totally blocked via the binary input BLOCK on TR1ATCC or TR8ATCC function block. The output TOTBLK will be activated.
EAUTOBLK (manually reset)	<i>On/ Off</i> (via binary input)	The voltage control function can be blocked for automatic control via the binary input EAUTOBLK on TR1ATCC or TR8ATCC function block. The output AUTOBLK will be activated. Deblocking is made via the input DEBLKAUT.

Blockings activated by the operating conditions, without setting or separate external activation possibilities, are listed in table [30](#).

Table 30: *Blockings without setting possibilities*

Activation	Type of blocking	Description
Disconnected transformer (automatically reset)	Auto Block	Automatic control is blocked for a transformer when parallel control with the circulating current method is used, and that transformer is disconnected from the LV-busbar. (This is under the condition that the setting <i>OperHoming</i> is selected <i>Off</i> for the disconnected transformer. Otherwise the transformer will get into the state Homing). The binary input signal DISC in TR1ATCC or TR8ATCC function shall be used to supervise if the transformer LV circuit breaker is closed or not. The outputs TRFDISC and AUTOBLK will be activated. Blocking will be removed when the transformer is reconnected (input signal DISC set back to zero).
No Master/More than one Master (automatically reset)	Auto Block	Automatic control is blocked when parallel control with the master-follower method is used, and the master is disconnected from the LV-busbar. Also if there for some reason should be a situation with more than one master in the system, the same blocking will occur. The binary input signal DISC in TR1ATCC or TR8ATCC function shall be used to supervise if the transformer LV circuit breaker is closed or not. The outputs TRFDISC, MFERR and AUTOBLK will be activated. The followers will also be blocked by mutual blocking in this situation. Blocking will be removed when the transformer is reconnected (input signal DISC set back to zero).
One transformer in a parallel group switched to manual control (automatically reset)	Auto Block	When the setting <i>OperationAdapt</i> is "Off", automatic control will be blocked when parallel control with the master-follower or the circulating current method is used, and one of the transformers in the group is switched from auto to manual. The output AUTOBLK will be activated.
Communication error (COMMERR) (automatic deblocking)	Auto block	If the horizontal communication (GOOSE) for any one of TR8ATCCs in the group fails it will cause blocking of automatic control in all TR8ATCC functions, which belong to that parallel group. This error condition will be reset automatically when the communication is re-established. The outputs COMMERR and AUTOBLK will be set.

Circulating current method

Mutual blocking

When one parallel instance of voltage control TR8ATCC blocks its operation, all other TR8ATCCs working in parallel with that module, shall block their operation as well. To achieve this, the affected TR8ATCC function broadcasts a mutual block to the other group members via the horizontal communication. When mutual block is received from any of the group members, automatic operation is blocked in the receiving TR8ATCCs that is, all units of the parallel group.

The following conditions in any one of TR8ATCCs in the group will cause mutual blocking when the circulating current method is used:

-
- Over-Current
 - Total block via settings
 - Total block via configuration
 - Analog input error
 - Automatic block via settings
 - Automatic block via configuration
 - Under-Voltage
 - Command error
 - Position indication error
 - Tap changer error
 - Reversed Action
 - Circulating current
 - Communication error

Master-follower method

When the master is blocked, the followers will not tap by themselves and there is consequently no need for further mutual blocking. On the other hand, when a follower is blocked there is a need to send a mutual blocking signal to the master. This will prevent a situation where the rest of the group otherwise would be able to tap away from the blocked individual, and that way cause high circulating currents.

Thus, when a follower is blocked, it broadcasts a mutual block on the horizontal communication. The master picks up this message, and blocks its automatic operation as well.

Besides the conditions listed above for mutual blocking with the circulating current method, the following blocking conditions in any of the followers will also cause mutual blocking:

- Master-follower out of position
- Master-follower error (No master/More than one master)

General

It should be noted that partial blocking will not cause mutual blocking.

TR8ATCC, which is the “source” of the mutual blocking will set its AUTOBLK output as well as the output which corresponds to the actual blocking condition for example, IBLK for over-current blocking. The other TR8ATCCs that receive a mutual block signal will only set its AUTOBLK output.

The mutual blocking remains until TR8ATCC that dispatched the mutual block signal is de-blocked. Another way to release the mutual blocking is to force TR8ATCC, which caused mutual blocking to Single mode operation. This is done by activating the binary input SNGLMODE on TR8ATCC function block or by setting the parameter *OperationPAR* to *Off* from the built-in local HMI or PST.

TR8ATCC function can be forced to single mode at any time. It will then behave exactly the same way as described in section ["Automatic voltage control for a](#)

[single transformer](#)", except that horizontal communication messages are still sent and received, but the received messages are ignored. TR8ATCC is at the same time also automatically excluded from the parallel group.

Disabling of blockings in special situations

When the Automatic voltage control for tap changer TR1ATCC for single control and TR8ATCC for parallel control, function block is connected to read back information (tap position value and tap changer in progress signal) it may sometimes be difficult to find timing data to be set in TR1ATCC or TR8ATCC for proper operation. Especially at commissioning of for example, older transformers the sensors can be worn and the contacts maybe bouncing etc. Before the right timing data is set it may then happen that TR1ATCC or TR8ATCC becomes totally blocked or blocked in auto mode because of incorrect settings. In this situation, it is recommended to temporarily set these types of blockings to alarm instead until the commissioning of all main items are working as expected.

Tap Changer position measurement and monitoring

Tap changer extreme positions

This feature supervises the extreme positions of the tap changer according to the settings *LowVoltTap* and *HighVoltTap*. When the tap changer reaches its lowest/highest position, the corresponding ULOWER/URAISE command is prevented in both automatic and manual mode.

Monitoring of tap changer operation

The Tap changer control and supervision, 6 binary inputs TCMYLTC or 32 binary inputs TCLYLTC output signal URAISE or ULOWER is set high when TR1ATCC or TR8ATCC function has reached a decision to operate the tap changer. These outputs from TCMYLTC and TCLYLTC function blocks shall be connected to a binary output module, BOM in order to give the commands to the tap changer mechanism. The length of the output pulse can be set via TCMYLTC or TCLYLTC setting parameter *tPulseDur*. When an URAISE/ULOWER command is given, a timer (set by setting *tCTimeout*) (settable in PST/local HMI) is also started, and the idea is then that this timer shall have a setting that covers, with some margin, a normal tap changer operation.

Usually the tap changer mechanism can give a signal, "Tap change in progress", during the time that it is carrying through an operation. This signal from the tap changer mechanism can be connected via a BIM module to TCMYLTC or TCLYLTC input TCINPROG, and it can then be used by TCMYLTC or TCLYLTC function in three ways, which is explained below with the help of figure [81](#).

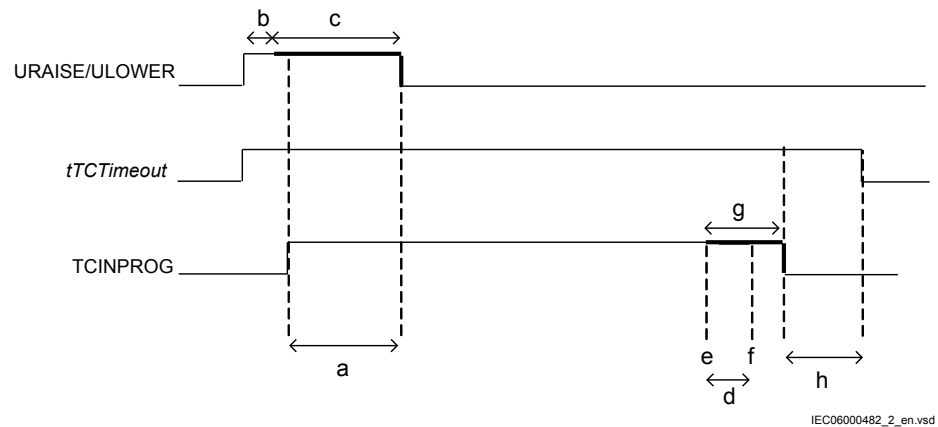


Figure 81: Timing of pulses for tap changer operation monitoring

pos	Description
a	Safety margin to avoid that TCINPROG is not set high without the simultaneous presence of an URAISE or ULOWER command.
b	Time setting $tPulseDur$.
c	Fixed extension 4 sec. of $tPulseDur$, made internally in TCMYLTC or TCLYLTC function.
d	Time setting $tStable$
e	New tap position reached, making the signal "tap change in progress" disappear from the tap changer, and a new position reported.
f	The new tap position available in TCMYLTC or TCLYLTC.
g	Fixed extension 2 sec. of TCINPROG, made internally in TCMYLTC or TCLYLTC function.
h	Safety margin to avoid that TCINPROG extends beyond $tCTTimeout$.

The first use is to reset the Automatic voltage control for tap changer function TR1ATCC for single control and TR8ATCC for parallel control as soon as the signal TCINPROG disappears. If the TCINPROG signal is not fed back from the tap changer mechanism, TR1ATCC or TR8ATCC will not reset until $tCTTimeout$ has timed out. The advantage with monitoring the TCINPROG signal in this case is thus that resetting of TR1ATCC or TR8ATCC can sometimes be made faster, which in turn makes the system ready for consecutive commands in a shorter time.

The second use is to detect a jammed tap changer. If the timer $tCTTimeout$ times out before the TCINPROG signal is set back to zero, the output signal TCERRAL is set high and TR1ATCC or TR8ATCC function is blocked.

The third use is to check the proper operation of the tap changer mechanism. As soon as the input signal TCINPROG is set back to zero TCMYLTC or TCLYLTC function expects to read a new and correct value for the tap position. If this does not happen the output signal CMDERRAL is set high and TR1ATCC or TR8ATCC function is blocked. The fixed extension (g) 2 sec. of TCINPROG, is made to prevent a situation where this could happen despite no real malfunction.

In figure 81, it can be noted that the fixed extension (c) 4 sec. of $tPulseDur$, is made to prevent a situation with TCINPROG set high without the simultaneous presence of an URAISE or ULOWER command. If this would happen, TCMYLTC or TCLYLTC would see this as a spontaneous TCINPROG signal without an accompanying URAISE or ULOWER command, and this would then lead to the output signal TCERRAL being set high and TR1ATCC or TR8ATCC function being blocked. Effectively this is then also a supervision of a run-away tap situation.

Hunting detection

Hunting detection is provided in order to generate an alarm when the voltage control gives an abnormal number of commands or abnormal sequence of commands within a pre-defined period of time.

There are three hunting functions:

1. The Automatic voltage control for tap changer function, TR1ATCC for single control and TR8ATCC for parallel control will activate the output signal DAYHUNT when the number of tap changer operations exceed the number given by the setting *DayHuntDetect* during the last 24 hours (sliding window). Active as well in manual as in automatic mode.
2. TR1ATCC or TR8ATCC function will activate the output signal HOURHUNT when the number of tap changer operations exceed the number given by the setting *HourHuntDetect* during the last hour (sliding window). Active as well in manual as in automatic mode.
3. TR1ATCC or TR8ATCC function will activate the output signal HUNTING when the total number of contradictory tap changer operations (RAISE, LOWER, RAISE, LOWER, and so on) exceeds the pre-set value given by the setting *NoOpWindow* within the time sliding window specified via the setting parameter *tWindowHunt*. Only active in automatic mode.

Hunting can be the result of a narrow deadband setting or some other abnormalities in the control system.

Wearing of the tap changer contacts

Two counters, ContactLife and NoOfOperations are available within the Tap changer control and supervision function, 6 binary inputs TCMYLTC or 32 binary inputs TCLYLTC. They can be used as a guide for maintenance of the tap changer mechanism. The ContactLife counter represents the remaining number of operations (decremental counter) at rated load.

$$\text{ContactLife}_{n+1} = \text{ContactLife}_n - \left(\frac{I_{load}}{I_{rated}} \right)^\alpha$$

(Equation 54)

where n is the number of operations and α is an adjustable setting parameter, *CLFactor*, with default value is set to 2. With this default setting an operation at

rated load (current measured on HV-side) decrements the ContactLife counter with 1.

The NoOfOperations counter simply counts the total number of operations (incremental counter).

Both counters are stored in a non-volatile memory as well as, the times and dates of their last reset. These dates are stored automatically when the command to reset the counter is issued. It is therefore necessary to check that the IED internal time is correct before these counters are reset. The counter value can be reset on the local HMI under **Main menu/Reset/Reset counters/TransformerTapControl(YLTC, 84)/Reset Counter and ResetCLCounter**

Both counters and their last reset dates are shown on the local HMI as service values under **Main menu/Test/Function status/Control/TransformerTapControl(YLTC,84)/CLCNT_VAL** and **Main menu/Test/Function status/Control/TransformerTapControl (YLTC,84)/TCMYLTC:x/TCLYLTC:x/CNT_VAL**

11.2.3 Setting guidelines

11.2.3.1 TR1ATCC or TR8ATCC general settings

TrfId: The transformer identity is used to identify transformer individuals in a parallel group. Thus, transformers that can be part of the same parallel group must have unique identities. Moreover, all transformers that communicate over the same horizontal communication (GOOSE) must have unique identities.

Xr2: The reactance of the transformer in primary ohms referred to the LV side.

tAutoMSF: Time delay set in a follower for execution of a raise or lower command given from a master. This feature can be used when a parallel group is controlled in the master-follower mode, follow tap, and it is individually set for each follower, which means that different time delays can be used in the different followers in order to avoid simultaneous tapping if this is wanted. It shall be observed that it is not applicable in the follow command mode.

OperationAdapt: This setting enables or disables adapt mode for parallel control with the circulating current method or the master-follower method.

MFMde: Selection of Follow Command or Follow Tap in the master-follower mode.

CircCurrBk: Selection of action to be taken in case the circulating current exceeds CircCurrLimit.

CmdErrBk: Selection of action to be taken in case the feedback from the tap changer has resulted in command error.

OCBk: Selection of action to be taken in case any of the three phase currents on the HV-side has exceeded *Iblock*.

MFPosDiffBk: Selection of action to be taken in case the tap difference between a follower and the master is greater than *MFPosDiffLim*.

OVPartBk: Selection of action to be taken in case the busbar voltage U_B exceeds *Umax*.

RevActPartBk: Selection of action to be taken in case Reverse Action has been activated.

TapChgBk: Selection of action to be taken in case a Tap Changer Error has been identified.

TapPosBk: Selection of action to be taken in case of Tap Position Error, or if the tap changer has reached an end position.

UVBk: Selection of action to be taken in case the busbar voltage U_B falls below *Ublock*.

UVPartBk: Selection of action to be taken in case the busbar voltage U_B is between *Ublock* and *Umin*.

11.2.3.2

TR1ATCC or TR8ATCC Setting group

General

Operation: Switching automatic voltage control for tap changer, TR1ATCC for single control and TR8ATCC for parallel control function *On/Off*.

I1Base: Base current in primary Ampere for the HV-side of the transformer.

I2Base: Base current in primary Ampere for the LV-side of the transformer.

UBase: Base voltage in primary kV for the LV-side of the transformer.

MeasMode: Selection of single phase, or phase-phase, or positive sequence quantity to be used for voltage and current measurement on the LV-side. The involved phases are also selected. Thus, single phase as well as phase-phase or three-phase feeding on the LV-side is possible but it is commonly selected for current and voltage.

Q1, *Q2* and *Q3*: Mvar value of a capacitor bank or reactor that is connected between the power transformer and the CT, such that the current of the capacitor bank (reactor) needs to be compensated for in the calculation of circulating currents. There are three independent settings *Q1*, *Q2* and *Q3* in order to make possible switching of three steps in a capacitor bank in one bay.

TotalBlock: When this setting is *On* the voltage control function, TR1ATCC for single control and TR8ATCC for parallel control, is totally blocked for manual as well as automatic control.

AutoBlock: When this setting is *On* the voltage control function, TR1ATCC for single control and TR8ATCC for parallel control, is blocked for automatic control.

Operation

FSDMode: This setting enables/disables the fast step down function. Enabling can be for automatic and manual control, or for only automatic control alternatively.

tFSD: Time delay to be used for the fast step down tapping.

Voltage

UseCmdUSet: This setting enabled makes it possible to set the target voltage level via IEC 61850 set point command. This, in turn, makes the setting *USet* redundant.

USet: Setting value for the target voltage, to be set in percent of *UBase*.

UDeadband: Setting value for one half of the outer deadband, to be set in percent of *UBase*. The deadband is symmetrical around *USet*, see section "[Automatic voltage control for a single transformer](#)", figure 71. In that figure *UDeadband* is equal to ΔU . The setting is normally selected to a value near the power transformer's tap changer voltage step (typically 75 - 125% of the tap changer step).

UDeadbandInner: Setting value for one half of the inner deadband, to be set in percent of *UBase*. The inner deadband is symmetrical around *USet*, see section "[Automatic voltage control for a single transformer](#)", figure 71. In that figure *UDeadbandInner* is equal to ΔU_{in} . The setting shall be smaller than *UDeadband*. Typically the inner deadband can be set to 25-70% of the *UDeadband* value.

Umax: This setting gives the upper limit of permitted busbar voltage (see section "[Automatic voltage control for a single transformer](#)", figure 71). It is set in percent of *UBase*. If *OVPartBk* is set to *Auto&ManBlock*, then busbar voltages above *Umax* will result in a partial blocking such that only lower commands are permitted.

Umin This setting gives the lower limit of permitted busbar voltage (see section "[Automatic voltage control for a single transformer](#)", figure 71). It is set in percent of *UBase*. If *UVPartBk* is set to *Auto Block* or *Auto&ManBlock*, then busbar voltages below *Umin* will result in a partial blocking such that only raise commands are permitted.

Ublock: Voltages below *Ublock* normally correspond to a disconnected transformer and therefore it is recommended to block automatic control for this condition (setting *UVBk*). *Ublock* is set in percent of *UBase*.

Time

t1Use: Selection of time characteristic (definite or inverse) for *t1*.

t1: Time delay for the initial (first) raise/lower command.

t2Use: Selection of time characteristic (definite or inverse) for *t2*.

t2: Time delay for consecutive raise/lower commands. In the circulating current method, the second, third, etc. commands are all executed with time delay *t2* independently of which transformer in the parallel group that is tapping. In the master-follower method with the follow tap option, the master is executing the second, third, etc. commands with time delay *t2*. The followers on the other hand read the master's tap position, and adapt to that with the additional time delay given by the setting *tAutoMSF* and set individually for each follower.

tMin: The minimum operate time when inverse time characteristic is used (see section ["Time characteristic"](#), figure [72](#)).

Line voltage drop compensation (LDC)

OpertionLDC: Sets the line voltage drop compensation function *On/Off*.

OperCapaLDC: This setting, if set *On*, will permit the load point voltage to be greater than the busbar voltage when line voltage drop compensation is used. That situation can be caused by a capacitive load. When the line voltage drop compensation function is used for parallel control with the reverse reactance method, then *OperCapaLDC* must always be set *On*.

Rline and *Xline*: For line voltage drop compensation, these settings give the line resistance and reactance from the station busbar to the load point. The settings for *Rline* and *Xline* are given in primary system ohms. If more than one line is connected to the LV busbar, equivalent *Rline* and *Xline* values should be calculated and given as settings.

When the line voltage drop compensation function is used for parallel control with the reverse reactance method, then the compensated voltage which is designated "load point voltage" U_L is effectively an increase in voltage up into the transformer. To achieve this voltage increase, *Xline* must be negative. The sensitivity of the parallel voltage regulation is given by the magnitude of *Rline* and *Xline* settings, with *Rline* being important in order to get a correct control of the busbar voltage. This can be realized in the following way. Figure [73](#) shows the vector diagram for a transformer controlled in a parallel group with the reverse reactance method and with no circulation (for example, assume two equal transformers on the same tap position). The load current lags the busbar voltage U_B with the power factor φ and the argument of the impedance *Rline* and *Xline* is designated φ_l .

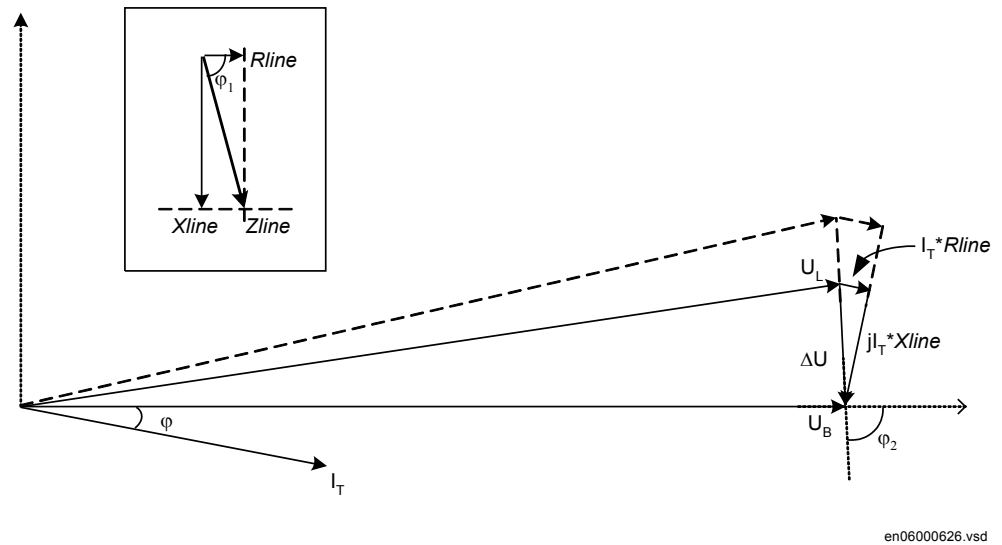


Figure 82: Transformer with reverse reactance regulation and no circulating current

The voltage $\Delta U = U_B - U_L = I_T \cdot R_{line} + j I_T \cdot X_{line}$ has the argument φ_2 and it is realised that if φ_2 is slightly less than -90° , then U_L will have approximately the same length as U_B regardless of the magnitude of the transformer load current I_T (indicated with the dashed line). The automatic tap change control regulates the voltage towards a set target value, representing a voltage magnitude, without considering the phase angle. Thus, U_B as well as U_L and also the dashed line could all be said to be on the target value.

Assume that we want to achieve that $\varphi_2 = -90^\circ$, then:

$$\begin{aligned} \overline{\Delta U} &= \overline{Z} \times \overline{I} \\ \Downarrow \\ \Delta U e^{-j90^\circ} &= Z e^{j\varphi_1} \times I e^{j\varphi} = Z I e^{j(\varphi_1 + \varphi)} \\ \Downarrow \\ -90^\circ &= \varphi_1 + \varphi \\ \Downarrow \\ \varphi_1 &= -\varphi - 90^\circ \end{aligned}$$

(Equation 55)

If for example $\cos\varphi = 0.8$ then $\varphi = \arccos 0.8 = 37^\circ$. With the references in figure 82, φ will be negative (inductive load) and we get:

$$\varphi_1 = -(-37^\circ) - 90^\circ = -53^\circ$$

(Equation 56)

To achieve a more correct regulation, an adjustment to a value of φ_2 slightly less than -90° ($2 - 4^\circ$ less) can be made.

The effect of changing power factor of the load will be that φ_2 will no longer be close to -90° resulting in U_L being smaller or greater than U_B if the ratio R_{line}/X_{line} is not adjusted.

Figure 83 shows an example of this where the settings of R_{line} and X_{line} for $\varphi = 11^\circ$ from figure 82 has been applied with a different value of φ ($\varphi = 30^\circ$).

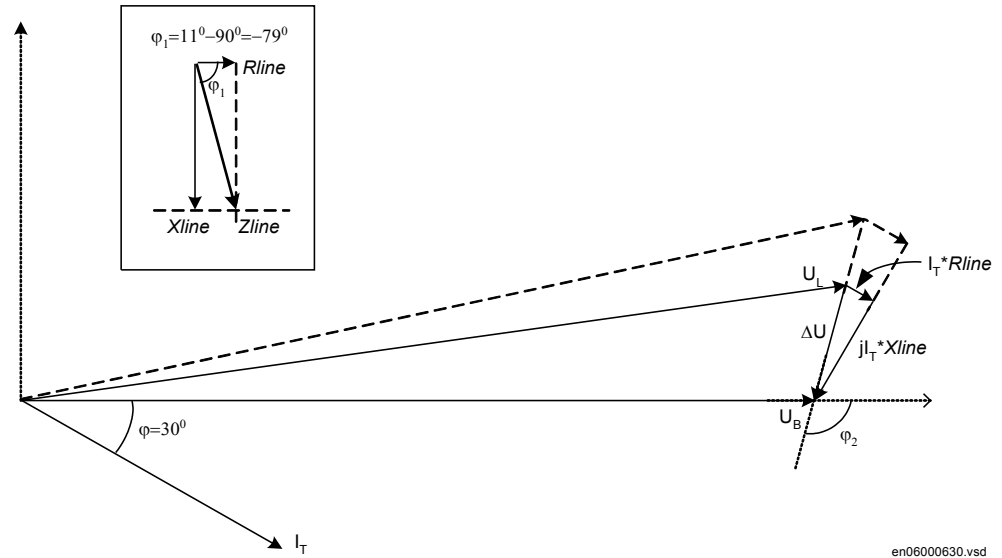


Figure 83: Transformer with reverse reactance regulation poorly adjusted to the power factor

As can be seen in figure 83, the change of power factor has resulted in an increase of φ_2 which in turn causes the magnitude of U_L to be greater than U_B . It can also be noted that an increase in the load current aggravates the situation, as does also an increase in the setting of Z_{line} (R_{line} and X_{line}).

Apparently the ratio R_{line}/X_{line} according to equation 56, that is the value of φ_1 must be set with respect to the power factor, also meaning that the reverse reactance method should not be applied to systems with varying power factor.

The setting of X_{line} gives the sensitivity of the parallel regulation. If X_{line} is set too low, the transformers will not pull together and a run away tap situation will occur. On the other hand, a high setting will keep the transformers strongly together with no, or only a small difference in tap position, but the voltage regulation as such will be more sensitive to a deviation from the anticipated power factor. A too high setting of X_{line} can cause a hunting situation as the transformers will then be prone to over react on deviations from the target value.

There is no rule for the setting of X_{line} such that an optimal balance between control response and susceptibility to changing power factor is achieved. One way of determining the setting is by trial and error. This can be done by setting e.g.

Xline equal to half of the transformer reactance, and then observe how the parallel control behaves during a couple of days, and then tune it as required. It shall be emphasized that a quick response of the regulation that quickly pulls the transformer tap changers into equal positions, not necessarily corresponds to the optimal setting. This kind of response is easily achieved by setting a high *Xline* value, as was discussed above, and the disadvantage is then a high susceptibility to changing power factor.

A combination of line voltage drop compensation and parallel control with the negative reactance method is possible to do simply by adding the required *Rline* values and the required *Xline* values separately to get the combined impedance. However, the line drop impedance has a tendency to drive the tap changers apart, which means that the reverse reactance impedance normally needs to be increased.

Load voltage adjustment (LVA)

LVAConst1: Setting of the first load voltage adjustment value. This adjustment of the target value *USet* is given in percent of *UBase*.

LVAConst2: Setting of the second load voltage adjustment value. This adjustment of the target value *USet* is given in percent of *UBase*.

LVAConst3: Setting of the third load voltage adjustment value. This adjustment of the target value *USet* is given in percent of *UBase*.

LVAConst4: Setting of the fourth load voltage adjustment value. This adjustment of the target value *USet* is given in percent of *UBase*.

VRAuto: Setting of the automatic load voltage adjustment. This adjustment of the target value *USet* is given in percent of *UBase*, and it is proportional to the load current with the set value reached at the nominal current *I2Base*.

RevAct

OperationRA: This setting enables/disables the reverse action partial blocking function.

tRevAct: After the reverse action has picked up, this time setting gives the time during which the partial blocking is active.

RevActLim: Current threshold for the reverse action activation. This is just one of two criteria for activation of the reverse action partial blocking.

Tap changer control (TCtrl)

Iblock: Current setting of the over current blocking function. In case, the transformer is carrying a current exceeding the rated current of the tap changer for example, because of an external fault. The tap changer operations shall be temporarily blocked. This function typically monitors the three phase currents on the HV side of the transformer.

DayHuntDetect: Setting of the number of tap changer operations required during the last 24 hours (sliding window) to activate the signal DAYHUNT

HourHuntDetect: Setting of the number of tap changer operations required during the last hour (sliding window) to activate the signal HOURHUNT

tWindowHunt: Setting of the time window for the window hunting function. This function is activated when the number of contradictory commands to the tap changer exceeds the specified number given by *NoOpWindow* within the time *tWindowHunt*.

NoOpWindow: Setting of the number of contradictory tap changer operations (RAISE, LOWER, RAISE, LOWER etc.) required during the time window *tWindowHunt* to activate the signal HUNTING.

Power

P>: When the active power exceeds the value given by this setting, the output PGTFWD will be activated after the time delay *tPower*. It shall be noticed that the setting is given with sign, which effectively means that a negative value of *P>* means an active power greater than a value in the reverse direction. This is shown in figure 84 where a negative value of *P>* means pickup for all values to the right of the setting. Reference is made to figure 79 for definition of forward and reverse direction of power through the transformer.

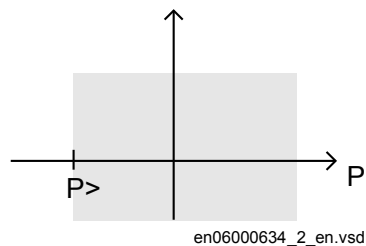


Figure 84: Setting of a negative value for *P>*

P<: When the active power falls below the value given by this setting, the output PLTREV will be activated after the time delay *tPower*. It shall be noticed that the setting is given with sign, which effectively means that, for example a positive value of *P<* means an active power less than a value in the forward direction. This is shown in figure 85 where a positive value of *P<* means pickup for all values to the left of the setting. Reference is made to figure 79 for definition of forward and reverse direction of power through the transformer.

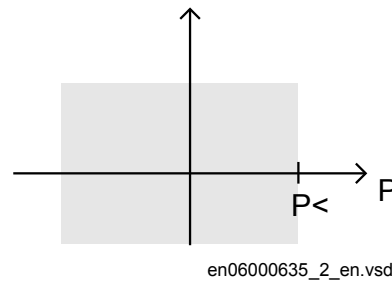


Figure 85: Setting of a positive value for $P<$

$Q>$: When the reactive power exceeds the value given by this setting, the output QGTFWD will be activated after the time delay $tPower$. It shall be noticed that the setting is given with sign, which effectively means that the function picks up for all values of reactive power greater than the set value, similar to the functionality for $P>$.

$Q<$: When the reactive power falls below the value given by this setting, the output QLTREV will be activated after the time delay $tPower$. It shall be noticed that the setting is given with sign, which effectively means that the function picks up for all values of reactive power less than the set value, similar to the functionality for $P<$.

$tPower$: Time delay for activation of the power monitoring output signals (PGTFWD, PLTREV, QGTFWD and QLTREV).

Parallel control (ParCtrl)

OperationPAR: Setting of the method for parallel operation.

OperCCBlock: This setting enables/disables blocking if the circulating current exceeds *CircCurrLimit*.

CircCurrLimit: Pick up value for the circulating current blocking function. The setting is made in percent of $I2Base$.

$tCircCurr$: Time delay for the circulating current blocking function.

Comp: When parallel operation with the circulating current method is used, this setting increases or decreases the influence of the circulating current on the regulation.

If the transformers are connected to the same bus on the HV- as well as the LV-side, *Comp* can be calculated with the following formula which is valid for any number of two-winding transformers in parallel, irrespective if the transformers are of different size and short circuit impedance.

$$Comp = a \times \frac{2 \times \Delta U}{n \times p} \times 100\%$$

(Equation 57)

where:

- ΔU is the deadband setting in percent.
- n denotes the desired number of difference in tap position between the transformers, that shall give a voltage deviation U_{di} which corresponds to the dead-band setting.
- p is the tap step (in percent of transformer nominal voltage).
- a is a safety margin that shall cover component tolerances and other non-linear measurements at different tap positions (for example, transformer reactances changes from rated value at the ends of the regulation range). In most cases a value of $a = 1.25$ serves well.

This calculation gives a setting of *Comp* that will always initiate an action (start timer) when the transformers have n tap positions difference.

OperSimTap: Enabling/disabling the functionality to allow only one transformer at a time to execute a Lower/Raise command. This setting is applicable only to the circulating current method, and when enabled, consecutive tap changes of the next transformer (if required) will be separated with the time delay $t2$.

OperUsetPar: Enables/disables the use of a common setting for the target voltage *USet*. This setting is applicable only to the circulating current method, and when enabled, a mean value of the *USet* values for the transformers in the same parallel group will be calculated and used.

OperHoming: Enables/disables the homing function. Applicable for parallel control with the circulating current method, as well for parallel control with the master-follower method.

VTmismatch: Setting of the level for activation of the output VTALARM in case the voltage measurement in one transformer bay deviates to the mean value of all voltage measurements in the parallel group.

tVTmismatch: Time delay for activation of the output VTALARM.

T1RXOP.....T8RXOP: This setting is set *On* for every transformer that can participate in a parallel group with the transformer in case. For this transformer (own transformer), the setting must always be *Off*.

TapPosOffs: This setting gives the tap position offset in relation to the master so that the follower can follow the master's tap position including this offset. Applicable when regulating in the follow tap command mode.

MFPosDiffLim: When the difference (including a possible offset according to *TapPosOffs*) between a follower and the master reaches the value in this setting, then the output OUTOFPOS in the Automatic voltage control for tap changer, parallel control TR8ATCC function block of the follower will be activated after the time delay *tMFPosDiff*.

tMFPoSDiff: Time delay for activation of the output OUTOFPOS.

11.2.3.3

TCMYLTC and TCLYLTC general settings

LowVoltTap: This gives the tap position for the lowest LV-voltage.

HighVoltTap: This gives the tap position for the highest LV-voltage.

mA_{Low}: The mA value that corresponds to the lowest tap position. Applicable when reading of the tap position is made via a mA signal.

mA_{High}: The mA value that corresponds to the highest tap position. Applicable when reading of the tap position is made via a mA signal.

CodeType: This setting gives the method of tap position reading.

UseParity: Sets the parity check *On/Off* for tap position reading when this is made by Binary, BCD, or Gray code.

tStable: This is the time that needs to elapse after a new tap position has been reported to TCMYLTC until it is accepted.

CLFactor: This is the factor designated “a” in [equation 57](#). When a tap changer operates at nominal load current (current measured on the HV-side), the ContactLife counter decrements with 1, irrespective of the setting of *CLFactor*. The setting of this factor gives the weighting of the deviation with respect to the load current.

InitCLCounter: The ContactLife counter monitors the remaining number of operations (decremental counter). The setting *InitCLCounter* then gives the start value for the counter that is, the total number of operations at rated load that the tap changer is designed for.

EnabTapCmd: This setting enables/disables the lower and raise commands to the tap changer. It shall be *On* for voltage control, and *Off* for tap position feedback to the transformer differential protection T2WPDIF or T3WPDIF.

TCMYLTC and TCLYLTC Setting group

General

Operation: Switching the TCMYLTC or TCLYLTC function *On/Off*.

I_{Base}: Base current in primary Ampere for the HV-side of the transformer.

tCTimeout: This setting gives the maximum time interval for a raise or lower command to be completed.

tPulseDur: Length of the command pulse (URAISE/ULOWER) to the tap changer. It shall be noticed that this pulse has a fixed extension of 4 seconds that adds to the setting value of *tPulseDur*.

11.3 Logic rotating switch for function selection and LHMI presentation SLGAPC

11.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Logic rotating switch for function selection and LHMI presentation	SLGAPC	-	-

11.3.2 Application

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

SLGAPC function block has two operating inputs (UP and DOWN), one blocking input (BLOCK) and one operator position input (PSTO).

SLGAPC can be activated both from the local HMI and from external sources (switches), via the IED binary inputs. It also allows the operation from remote (like the station computer). SWPOSN is an integer value output, giving the actual output number. Since the number of positions of the switch can be established by settings (see below), one must be careful in coordinating the settings with the configuration (if one sets the number of positions to x in settings – for example, there will be only the first x outputs available from the block in the configuration). Also the frequency of the (UP or DOWN) pulses should be lower than the setting *tPulse*.

From the local HMI, the selector switch can be operated from Single-line diagram (SLD).

11.3.3 Setting guidelines

The following settings are available for the Logic rotating switch for function selection and LHMI presentation (SLGAPC) function:

Operation: Sets the operation of the function *On* or *Off*.

NrPos: Sets the number of positions in the switch (max. 32).

OutType: *Steady* or *Pulsed*.

tPulse: In case of a pulsed output, it gives the length of the pulse (in seconds).

tDelay: The delay between the UP or DOWN activation signal positive front and the output activation.

StopAtExtremes: Sets the behavior of the switch at the end positions – if set to *Disabled*, when pressing UP while on first position, the switch will jump to the last position; when pressing DOWN at the last position, the switch will jump to the first position; when set to *Enabled*, no jump will be allowed.

11.4 Selector mini switch VSGAPC

11.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Selector mini switch	VSGAPC	-	43

11.4.2 Application

Selector mini switch (VSGAPC) function is a multipurpose function used in the configuration tool in PCM600 for a variety of applications, as a general purpose switch. VSGAPC can be used for both acquiring an external switch position (through the IPOS1 and the IPOS2 inputs) and represent it through the single line diagram symbols (or use it in the configuration through the outputs POS1 and POS2) as well as, a command function (controlled by the PSTO input), giving switching commands through the CMDPOS12 and CMDPOS21 outputs.

The output POSITION is an integer output, showing the actual position as an integer number 0 – 3, where 0 = MidPos, 1 = Open, 2 = Closed and 3 = Error.

An example where VSGAPC is configured to switch Autorecloser on–off from a button symbol on the local HMI is shown in figure [86](#). The I and O buttons on the local HMI are normally used for on–off operations of the circuit breaker.

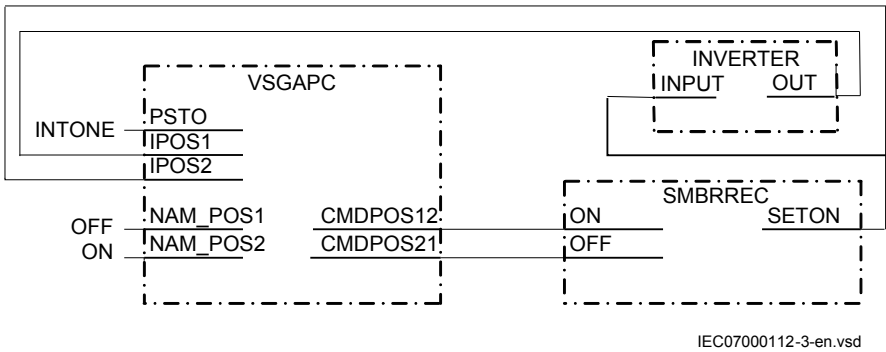


Figure 86: Control of Autorecloser from local HMI through Selector mini switch

VSGAPC is also provided with IEC 61850 communication so it can be controlled from SA system as well.

11.4.3

Setting guidelines

Selector mini switch (VSGAPC) function can generate pulsed or steady commands (by setting the *Mode* parameter). When pulsed commands are generated, the length of the pulse can be set using the *tPulse* parameter. Also, being accessible on the single line diagram (SLD), this function block has two control modes (settable through *CtlModel*): *Dir Norm* and *SBO Enh*.

11.5

Generic communication function for Double Point indication DPGAPC

11.5.1

Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Generic communication function for Double Point indication	DPGAPC	-	-

11.5.2

Application

Generic communication function for Double Point indication (DPGAPC) function block is used to send double point position indication to other systems, equipment or functions in the substation through IEC 61850-8-1 or other communication protocols. It is especially intended to be used in the interlocking station-wide logics. To be able to get the signals into other systems, equipment or functions, one must use other tools, described in the Engineering manual, and define which

function block in which systems, equipment or functions should receive this information.

More specifically, DPGAPC function reports a combined double point position indication output POSITION, by evaluating the value and the timestamp attributes of the inputs OPEN and CLOSE, together with the logical input signal VALID.

When the input signal VALID is active, the values of the OPEN and CLOSE inputs determine the two-bit integer value of the output POSITION. The timestamp of the output POSITION will have the latest updated timestamp of the inputs OPEN and CLOSE.

When the input signal VALID is inactive, DPGAPC function forces the position to intermediated state.

When the value of the input signal VALID changes, the timestamp of the output POSITION will be updated as the time when DPGAPC function detects the change.

Refer to Table 31 for the description of the input-output relationship in terms of the value and the quality attributes.

Table 31: Description of the input-output relationship

VALID	OPEN	CLOSE	POSITION	
			Value	Description
0	-	-	0	Intermediate
1	0	0	0	Intermediate
1	1	0	1	Open
1	0	1	2	Closed
1	1	1	3	Bad State

11.5.3

Setting guidelines

The function does not have any parameters available in the local HMI or PCM600.

11.6

Single point generic control 8 signals SPC8GAPC

11.6.1

Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Single point generic control 8 signals	SPC8GAPC	-	-

11.6.2 Application

The Single point generic control 8 signals (SPC8GAPC) function block is a collection of 8 single point commands that can be used for direct commands for example reset of LED's or putting IED in "ChangeLock" state from remote. In this way, simple commands can be sent directly to the IED outputs, without confirmation. Confirmation (status) of the result of the commands is supposed to be achieved by other means, such as binary inputs and SPGAPC function blocks.



PSTO is the universal operator place selector for all control functions. Even if PSTO can be configured to allow LOCAL or ALL operator positions, the only functional position usable with the SPC8GAPC function block is REMOTE.

11.6.3 Setting guidelines

The parameters for the single point generic control 8 signals (SPC8GAPC) function are set via the local HMI or PCM600.

Operation: turning the function operation *On/Off*.

There are two settings for every command output (totally 8):

PulseModex: decides if the command signal for output *x* is *Latched* (steady) or *Pulsed*.

tPulsex: if *PulseModex* is set to *Pulsed*, then *tPulsex* will set the length of the pulse (in seconds).

11.7 AutomationBits, command function for DNP3.0 AUTOBITS

11.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
AutomationBits, command function for DNP3	AUTOBITS	-	-

11.7.2 Application

Automation bits, command function for DNP3 (AUTOBITS) is used within PCM600 in order to get into the configuration the commands coming through the DNP3.0 protocol. The AUTOBITS function plays the same role as functions GOOSEBINRCV (for IEC 61850) and MULTICMDRCV (for LON). AUTOBITS function block have 32 individual outputs which each can be mapped as a Binary Output point in DNP3. The output is operated by a "Object 12" in DNP3. This object contains parameters for control-code, count, on-time and off-time. To operate an AUTOBITS output point, send a control-code of latch-On, latch-Off, pulse-On, pulse-Off, Trip or Close. The remaining parameters are regarded as appropriate. For example, pulse-On, on-time=100, off-time=300, count=5 would give 5 positive 100 ms pulses, 300 ms apart.

For description of the DNP3 protocol implementation, refer to the Communication manual.

11.7.3 Setting guidelines

AUTOBITS function block has one setting, (*Operation: On/Off*) enabling or disabling the function. These names will be seen in the DNP3 communication management tool in PCM600.

11.8 Single command, 16 signals SINGLECMD

11.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Single command, 16 signals	SINGLECMD	-	-

11.8.2 Application

Single command, 16 signals (SINGLECMD) is a common function and always included in the IED.

The IEDs may be provided with a function to receive commands either from a substation automation system or from the local HMI. That receiving function block has outputs that can be used, for example, to control high voltage apparatuses in switchyards. For local control functions, the local HMI can also be used. Together with the configuration logic circuits, the user can govern pulses or steady output signals for control purposes within the IED or via binary outputs.

Figure 87 shows an application example of how the user can connect SINGLECMD via configuration logic circuit to control a high-voltage apparatus. This type of command control is normally carried out by sending a pulse to the binary outputs of the IED. Figure 87 shows a close operation. An open breaker operation is performed in a similar way but without the synchro-check condition.

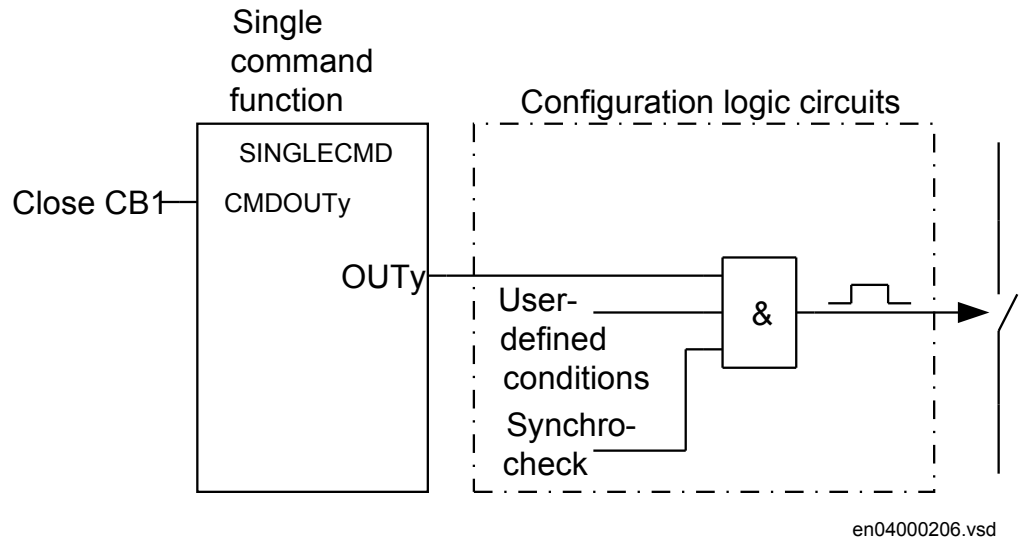


Figure 87: Application example showing a logic diagram for control of a circuit breaker via configuration logic circuits

Figure 88 and figure 89 show other ways to control functions, which require steady On/Off signals. Here, the output is used to control built-in functions or external devices.

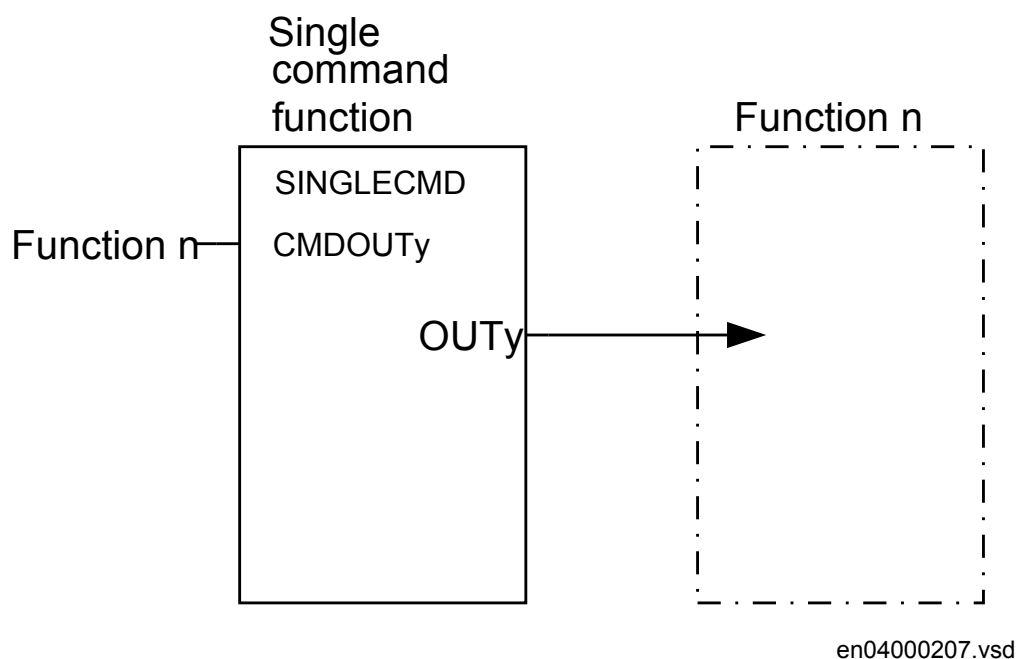


Figure 88: Application example showing a logic diagram for control of built-in functions

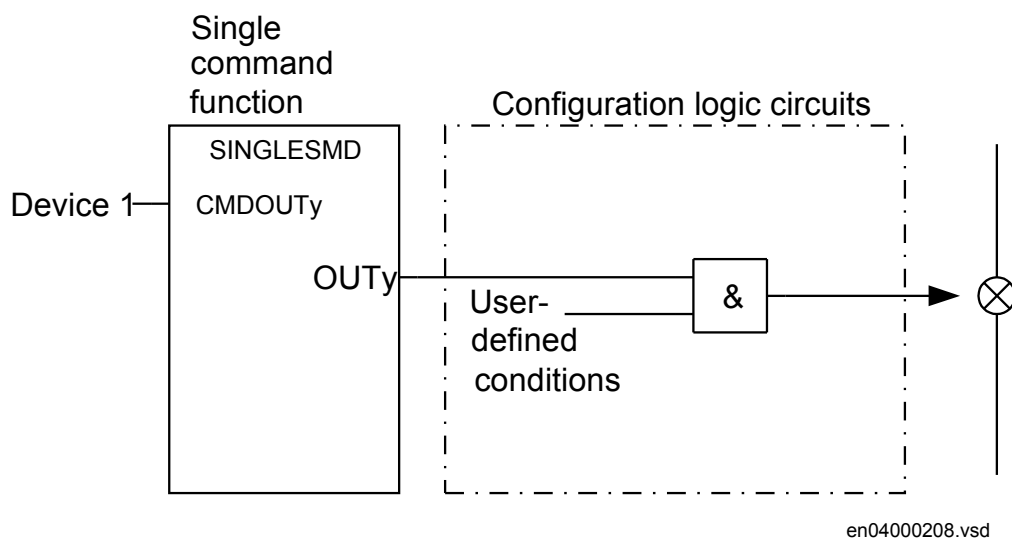


Figure 89: Application example showing a logic diagram for control of external devices via configuration logic circuits

11.8.3

Setting guidelines

The parameters for Single command, 16 signals (SINGLECMD) are set via the local HMI or PCM600.

Parameters to be set are MODE, common for the whole block, and CMDOUTy which includes the user defined name for each output signal. The MODE input sets the outputs to be one of the types Off, Steady, or Pulse.

- Off, sets all outputs to 0, independent of the values sent from the station level, that is, the operator station or remote-control gateway.
- Steady, sets the outputs to a steady signal 0 or 1, depending on the values sent from the station level.
- Pulse, gives a pulse with 100 ms duration, if a value sent from the station level is changed from 0 to 1. That means the configured logic connected to the command function block may not have a cycle time longer than the cycle time for the command function block.

Section 12 Logic

12.1 Tripping logic SMPPTRC

12.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Tripping logic	SMPPTRC	1 -> 0	94

12.1.2 Application

All trip signals from the different protection functions shall be routed through the trip logic. All start signals and directional information can be routed through the trip logic as well. In its simplest form, the trip logic will only link the TRIP signal to a binary output and make sure that the pulse time is long enough.

Tripping logic SMPPTRC offers three different operating modes:

- Three-phase tripping for all fault types (3ph operating mode)
- Single-phase tripping for single-phase faults and three-phase tripping for multi-phase and evolving faults (1ph/3ph operating mode).
- Single-phase tripping for single-phase faults, two-phase tripping for two-phase faults and three-phase tripping for three-phase faults (1ph/2ph/3ph operating mode).

If the OHL is connected to the substation via more than one breaker, one SMPPTRC function block should be used for each breaker. For example when single-phase tripping and autoreclosing is used on the line, both breakers are normally set up for 1/3-phase tripping and 1/3-phase autoreclosing. Alternatively, the breaker chosen as master can have single-phase tripping, while the slave breaker could have three-phase tripping and autoreclosing. In the case of a permanent fault, only one of the breakers has to be operated when the fault is energized a second time. In the event of a transient fault the slave breaker performs a three-phase reclosing onto the non-faulted line.

The same philosophy can be used for two-phase tripping and autoreclosing.

To prevent closing of a circuit breaker after a trip, the function offers a lockout function.

12.1.2.1

Three-phase tripping

Connect the inputs from the protection functions to the input TRIN. The TMGAPC function block is used to combine up to 32 inputs into one output. Connect the output TRIP to the binary outputs on the IO board.

This signal can also be used for other purposes internally in the IED. An example could be the starting of breaker failure protection. The three outputs TRL1, TRL2, TRL3 will always be activated at every trip and can be utilized on individual trip outputs if single-phase operating devices are available on the circuit breaker even when a three-phase tripping scheme is selected.

Set the function block to *Program = 3 phase* and set the required length of the trip pulse to for example, $t_{TripMin} = 150ms$.

The typical connection is shown below in figure 90.

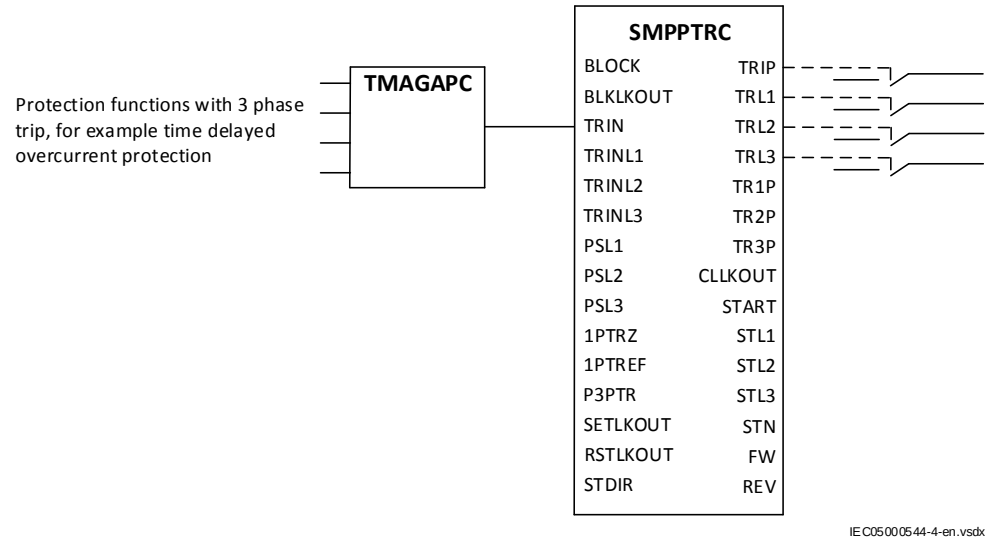


Figure 90: Tripping logic SMPPTRC is used for a simple three-phase tripping application

12.1.2.2

Single- and/or three-phase tripping

The single-/three-phase tripping operation mode will give single-phase tripping for single-phase faults and three-phase tripping for multi-phase fault. This operating mode is always used together with a single-phase autoreclosing scheme.

The single-phase tripping operation mode can include different options and the use of the different inputs in the function block. Inputs TRINL1, TRINL2 and TRINL3

shall be used for trip signals from functions with built-in phase selection logic such as distance or line differential protection functions.

The inputs 1PTRZ and 1PTREF are used for single-phase tripping from functions which do not have built-in phase selection logic:

- 1PTRZ can be connected to the carrier aided trip signal from the distance protection scheme (it means that another distance protection function has seen or detected the fault)
- 1PTREF can be connected to an earth fault function such as EF4PTOC or a carrier aided trip signal from the earth fault protection scheme

These two inputs are combined with the external phase selection logic. Phase selection signals from the external phase selector must be connected to the inputs PSL1, PSL2 and PSL3 to achieve the tripping on the respective single-phase trip outputs TRL1, TRL2 and TRL3. The output TRIP is a general trip and is always activated independent of which phase is involved. Depending on which phases are involved the outputs TR1P, TR2P and TR3P will be activated as well.

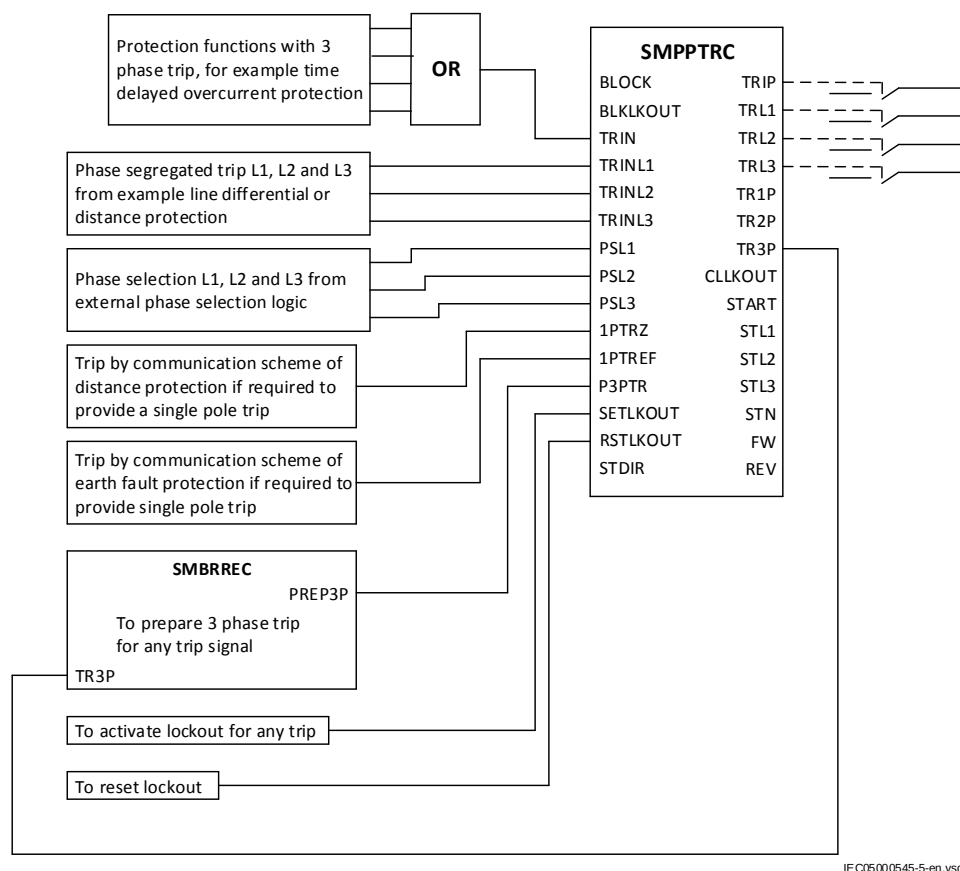
When single-phase tripping schemes are used, a single-phase autoreclosing attempt is expected to follow. For cases where the autoreclosing is not in service or will not follow for some reason, the input prepare three-phase trip P3PTR must be activated. This input is normally connected to the output PREP3P on the autorecloser function SMBRREC but can also be connected to other signals, for example, an external logic signal. If two circuit breakers are involved, one SMPPTRC block instance and one SMBRREC instance are used for each circuit breaker. This will ensure correct operation and behavior of each circuit breaker.

The output TR3P must be connected to the input TR3P on the SMBRREC function in order to switch SMBRREC to perform a three-phase reclosing. If this signal is not activated, SMBRREC will use single-phase dead time.



If a second line protection is utilizing the same SMBRREC, the three-phase trip signal must be generated as OR conditions from both line protections.

Other back-up functions are connected to the input TRIN as described above for three-phase tripping. A typical connection for a single-phase tripping scheme is shown in figure [91](#).



IEC05000545-5-en.vsd

Figure 91: The trip logic function *SMPPTRC* used for single-phase tripping application

12.1.2.3

Single-, two- or three-phase tripping

The single-/two-/three-phase tripping mode provides single-phase tripping for single-phase faults, two-phase tripping for two-phase faults and three-phase tripping for three-phase faults. The operating mode is always used together with an autoreclosing scheme with setting $ARMode = 1/2/3\ ph$ or $ARMode = 1/2\ ph$.

The functionality is very similar to the single-phase scheme described above. However, in addition to the connections for single phase *SMBRREC* must also be informed that the trip is two phases by connecting the output *TR2P* to the input *TR2P* in the *SMBRREC* function.

12.1.2.4

Lock-out

The *SMPPTRC* function block is provided with possibilities to initiate lock-out. The lock-out can be set to only activate the block closing output *CLLKOUT* or initiate the block closing output and also maintain the trip signal output *TR3P* (latched trip).

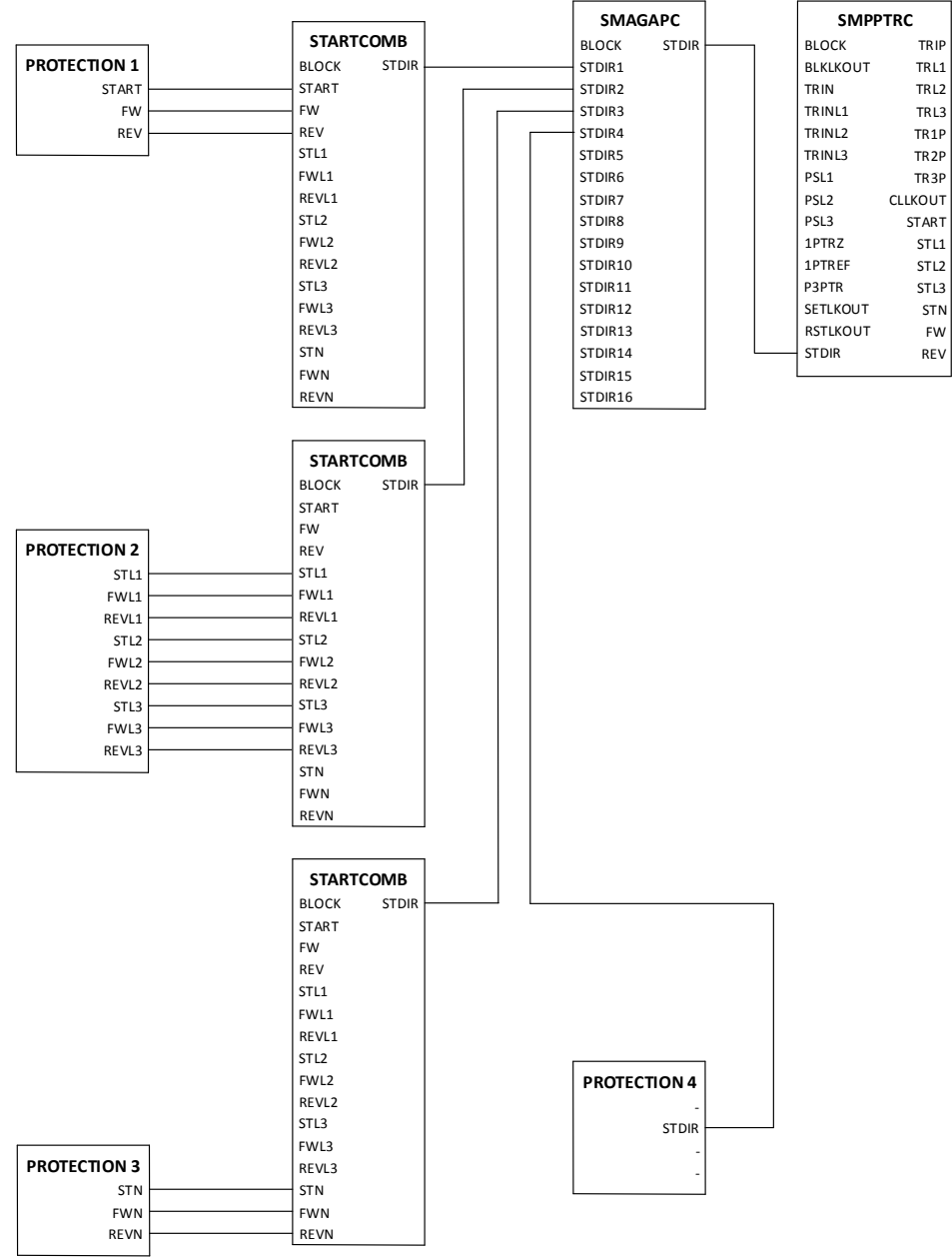
The lock-out can then be manually reset after checking the primary fault by activating the input reset lock-out RSTLKOUT.

If external conditions are required to initiate a closing circuit lock-out but not to lockout trip, this can be achieved by activating input SETLKOUT. The setting *AutoLock = Off* means that the internal trip will not activate lock-out so only initiation of the input SETLKOUT will result in lock-out. This is normally the case for overhead line protection where most faults are transient. Unsuccessful autoreclose and back-up zone tripping can in such cases be connected to initiate lock-out by activating the input SETLKOUT.

12.1.2.5

Example of directional data

An example how to connect the directional data from different application functions to the trip function is given below, see Figure [92](#):



IEC16000180-2-en.vsd

Figure 92: Example of the connection of directional start logic

The Start Matrix (SMAGAPC) merges start and directional output signals from different application functions and creates a common directional output signal (STDIR) to be connected to the Trip function (SMPPTRC). Protection functions connect their directional data via the STARTCOMB function to SMAGAPC and then to the SMPPTRC, or directly to SMAGAPC and then to the SMPPTRC.

The trip function (SMPPTRC) splits up the directional data as general output data for *START*, *STL1*, *STL2*, *STL3*, *STN*, *FW* and *REV*.

All start and directional outputs are mapped to the logical node data model of the trip function and provided via the IEC 61850 attributes `dirGeneral`, `DIRL1`, `DIRL2`, `DIRL3` and `DIRN`.

12.1.2.6 Blocking of the function block

Total block of the trip function is done by activating the input `BLOCK` and can be used to disable the outputs of the trip logic in the event of internal failures. Block of lock-out output is achieved by activating the input `BLKLKOUT`.

12.1.3 Setting guidelines

The parameters for tripping logic `SMPPTRC` are set via the local HMI or `PCM600`.

Operation: Sets the mode of operation. *Off* switches the tripping off. The normal selection is *On*.

Program: Sets the required tripping scheme. Normally *3 phase* or *1ph/3ph* is used.

TripLockout: Sets the scheme for lock-out. *Off* only activates the closing circuit lock-out output. *On* activates the closing circuit lock-out output and latches the TRIP related outputs. The normal selection is *Off*.

AutoLock: Sets the scheme for lock-out. *Off* only activates lock-out through the input `SETLKOUT`. *On* additionally allows lock-out activation via the trip inputs. The normal selection is *Off*.

tTripMin: Sets the required minimum duration of the trip pulse. It should be set to ensure that the circuit breaker is opened correctly. The normal setting is *0.150s*.

tEvolvingFault: Secures two- or three-pole tripping depending on *Program* selection during evolving faults.

12.2 Trip matrix logic TMAGAPC

12.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Trip matrix logic	TMAGAPC	-	-

12.2.2 Application

The trip matrix logic TMAGAPC function is used to route trip signals and other logical output signals to different output contacts on the IED.

The trip matrix logic function has 3 output signals and these outputs can be connected to physical tripping outputs according to the specific application needs for settable pulse or steady output.

12.2.3 Setting guidelines

Operation: Operation of function *On/Off*.

PulseTime: Defines the pulse time when in *Pulsed* mode. When used for direct tripping of circuit breaker(s) the pulse time delay shall be set to approximately 0.150 seconds in order to obtain satisfactory minimum duration of the trip pulse to the circuit breaker trip coils.

OnDelay: Used to prevent output signals to be given for spurious inputs. Normally set to 0 or a low value.

OffDelay: Defines a delay of the reset of the outputs after the activation conditions no longer are fulfilled. It is only used in *Steady* mode. When used for direct tripping of circuit breaker(s) the off delay time shall be set to at least 0.150 seconds in order to obtain a satisfactory minimum duration of the trip pulse to the circuit breaker trip coils.

ModeOutputx: Defines if output signal OUTPUT_x (where x=1-3) is *Steady* or *Pulsed*.

12.3 Logic for group alarm ALMCALH

12.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Logic for group alarm	ALMCALH	-	-

12.3.2 Application

Group alarm logic function ALMCALH is used to route alarm signals to different LEDs and/or output contacts on the IED.

ALMCALH output signal and the physical outputs allows the user to adapt the alarm signal to physical tripping outputs according to the specific application needs.

12.3.3 Setting guidelines

Operation: On or Off

12.4 Logic for group alarm WRNCALH

12.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Logic for group warning	WRNCALH	-	-

12.4.1.1 Application

Group warning logic function WRNCALH is used to route warning signals to LEDs and/or output contacts on the IED.

WRNCALH output signal WARNING and the physical outputs allows the user to adapt the warning signal to physical tripping outputs according to the specific application needs.

12.4.1.2 Setting guidelines

Operation: On or Off

12.5 Logic for group indication INDCALH

12.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Logic for group indication	INDCALH	-	-

12.5.1.1 Application

Group indication logic function INDCALH is used to route indication signals to different LEDs and/or output contacts on the IED.

INDCALH output signal IND and the physical outputs allows the user to adapt the indication signal to physical outputs according to the specific application needs.

12.5.1.2 Setting guidelines

Operation: On or Off

12.6 Configurable logic blocks

The configurable logic blocks are available in two categories:

- Configurable logic blocks that do not propagate the time stamp and the quality of signals. They do not have the suffix QT at the end of their function block name, for example, SRMEMORY. These logic blocks are also available as part of an extension logic package with the same number of instances.
- Configurable logic blocks that propagate the time stamp and the quality of signals. They have the suffix QT at the end of their function block name, for example, SRMEMORYQT.

12.6.1 Application

A set of standard logic blocks, like AND, OR etc, and timers are available for adapting the IED configuration to the specific application needs.

12.6.2 Setting guidelines

There are no settings for AND gates, OR gates, inverters or XOR gates.

For normal On/Off delay and pulse timers the time delays and pulse lengths are set from the local HMI or via the PST tool.

Both timers in the same logic block (the one delayed on pick-up and the one delayed on drop-out) always have a common setting value.

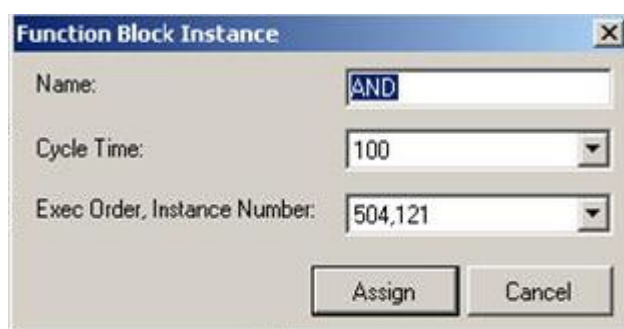
For controllable gates, settable timers and SR flip-flops with memory, the setting parameters are accessible via the local HMI or via the PST tool.

12.6.2.1 Configuration

Logic is configured using the ACT configuration tool in PCM600.

Execution of functions as defined by the configurable logic blocks runs according to a fixed sequence with different cycle times.

For each cycle time, the function block is given an serial execution number. This is shown when using the ACT configuration tool with the designation of the function block and the cycle time, see example below.



IEC09000695_2_en.vsd

Figure 93: Example designation, serial execution number and cycle time for logic function

The execution of different function blocks within the same cycle is determined by the order of their serial execution numbers. Always remember this when connecting two or more logical function blocks in series.



Always be careful when connecting function blocks with a fast cycle time to function blocks with a slow cycle time. Remember to design the logic circuits carefully and always check the execution sequence for different functions. In other cases, additional time delays must be introduced into the logic schemes to prevent errors, for example, race between functions.

12.7 Fixed signal function block FXDSIGN

12.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fixed signals	FXDSIGN	-	-

12.7.2 Application

The Fixed signals function (FXDSIGN) has nine pre-set (fixed) signals that can be used in the configuration of an IED, either for forcing the unused inputs in other function blocks to a certain level/value, or for creating certain logic. Boolean, integer, floating point, string types of signals are available.

One FXDSIGN function block is included in all IEDs.

Example for use of GRP_OFF signal in FXDSIGN

The Restricted earth fault function REFPDIF can be used both for auto-transformers and normal transformers.

When used for auto-transformers, information from both windings parts, together with the neutral point current, needs to be available to the function. This means that three inputs are needed.

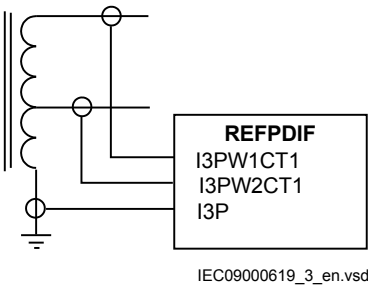


Figure 94: REFPDIF function inputs for autotransformer application

For normal transformers only one winding and the neutral point is available. This means that only two inputs are used. Since all group connections are mandatory to be connected, the third input needs to be connected to something, which is the GRP_OFF signal in FXDSIGN function block.

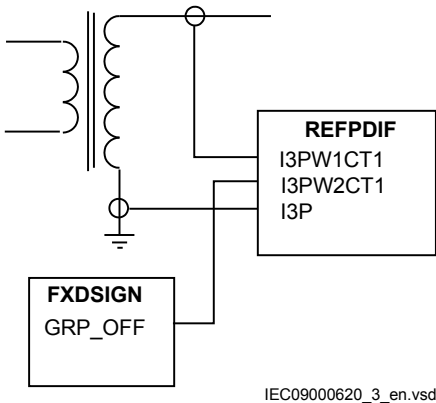


Figure 95: REFPDIF function inputs for normal transformer application

12.8

Boolean 16 to Integer conversion B16I

12.8.1

Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Boolean 16 to integer conversion	B16I	-	-

12.8.2

Application

Boolean 16 to integer conversion function B16I is used to transform a set of 16 binary (logical) signals into an integer. It can be used – for example, to connect logical output signals from a function (like distance protection) to integer inputs from another function (like line differential protection). B16I does not have a logical node mapping.

The Boolean 16 to integer conversion function (B16I) will transfer a combination of up to 16 binary inputs IN_x where $1 \leq x \leq 16$ to an integer. Each IN_x represents a value according to the table below from 0 to 32768. This follows the general formula: $IN_x = 2^{x-1}$ where $1 \leq x \leq 16$. The sum of all the values on the activated IN_x will be available on the output OUT as a sum of the values of all the inputs IN_x that are activated. OUT is an integer. When all IN_x where $1 \leq x \leq 16$ are activated that is = Boolean 1 it corresponds to that integer 65535 is available on the output OUT. B16I function is designed for receiving up to 16 booleans input locally. If the BLOCK input is activated, it will freeze the output at the last value.

Values of each of the different OUT_x from function block B16I for $1 \leq x \leq 16$.

The sum of the value on each IN_x corresponds to the integer presented on the output OUT on the function block B16I.

Name of input	Type	Default	Description	Value when activated	Value when deactivated
IN1	BOOLEAN	0	Input 1	1	0
IN2	BOOLEAN	0	Input 2	2	0
IN3	BOOLEAN	0	Input 3	4	0
IN4	BOOLEAN	0	Input 4	8	0
IN5	BOOLEAN	0	Input 5	16	0
IN6	BOOLEAN	0	Input 6	32	0
IN7	BOOLEAN	0	Input 7	64	0
IN8	BOOLEAN	0	Input 8	128	0
IN9	BOOLEAN	0	Input 9	256	0
IN10	BOOLEAN	0	Input 10	512	0
IN11	BOOLEAN	0	Input 11	1024	0
IN12	BOOLEAN	0	Input 12	2048	0
IN13	BOOLEAN	0	Input 13	4096	0
IN14	BOOLEAN	0	Input 14	8192	0
IN15	BOOLEAN	0	Input 15	16384	0
IN16	BOOLEAN	0	Input 16	32768	0

The sum of the numbers in column “Value when activated” when all IN_x (where $1 \leq x \leq 16$) are active that is=1; is 65535. 65535 is the highest boolean value that can be converted to an integer by the B16I function block.

12.9 Boolean to integer conversion with logical node representation, 16 bit BTIGAPC

12.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Boolean to integer conversion with logical node representation, 16 bit	BTIGAPC	-	-

12.9.2 Application

Boolean to integer conversion with logical node representation, 16 bit (BTIGAPC) is used to transform a set of 16 binary (logical) signals into an integer. BTIGAPC has a logical node mapping in IEC 61850.

The BTIGAPC function will transfer a combination of up to 16 binary inputs IN_x where $1 \leq x \leq 16$ to an integer. Each IN_x represents a value according to the table below from 0 to 32768. This follows the general formula: $IN_x = 2^{x-1}$ where $1 \leq x \leq 16$. The sum of all the values on the activated IN_x will be available on the output OUT as a sum of the values of all the inputs IN_x that are activated. OUT is an integer. When all IN_x where $1 \leq x \leq 16$ are activated that is = Boolean 1 it corresponds to that integer 65535 is available on the output OUT. BTIGAPC function is designed for receiving up to 16 booleans input locally. If the BLOCK input is activated, it will freeze the output at the last value.

Values of each of the different OUT_x from function block BTIGAPC for $1 \leq x \leq 16$.

The sum of the value on each IN_x corresponds to the integer presented on the output OUT on the function block BTIGAPC.

Name of input	Type	Default	Description	Value when activated	Value when deactivated
IN1	BOOLEAN	0	Input 1	1	0
IN2	BOOLEAN	0	Input 2	2	0
IN3	BOOLEAN	0	Input 3	4	0
IN4	BOOLEAN	0	Input 4	8	0
IN5	BOOLEAN	0	Input 5	16	0
IN6	BOOLEAN	0	Input 6	32	0
IN7	BOOLEAN	0	Input 7	64	0
IN8	BOOLEAN	0	Input 8	128	0
IN9	BOOLEAN	0	Input 9	256	0
IN10	BOOLEAN	0	Input 10	512	0
Table continues on next page					

Name of input	Type	Default	Description	Value when activated	Value when deactivated
IN11	BOOLEAN	0	Input 11	1024	0
IN12	BOOLEAN	0	Input 12	2048	0
IN13	BOOLEAN	0	Input 13	4096	0
IN14	BOOLEAN	0	Input 14	8192	0
IN15	BOOLEAN	0	Input 15	16384	0
IN16	BOOLEAN	0	Input 16	32768	0

The sum of the numbers in column “Value when activated” when all IN_x (where $1 \leq x \leq 16$) are active that is=1; is 65535. 65535 is the highest boolean value that can be converted to an integer by the BTIGAPC function block.

12.10 Integer to Boolean 16 conversion IB16

12.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Integer to boolean 16 conversion	IB16	-	-

12.10.2 Application

Integer to boolean 16 conversion function (IB16) is used to transform an integer into a set of 16 binary (logical) signals. It can be used – for example, to connect integer output signals from one function to binary (logical) inputs to another function. IB16 function does not have a logical node mapping.

The Boolean 16 to integer conversion function (IB16) will transfer a combination of up to 16 binary inputs IN_x where $1 \leq x \leq 16$ to an integer. Each IN_x represents a value according to the table below from 0 to 32768. This follows the general formula: $IN_x = 2^{x-1}$ where $1 \leq x \leq 16$. The sum of all the values on the activated IN_x will be available on the output OUT as a sum of the values of all the inputs IN_x that are activated. OUT is an integer. When all IN_x where $1 \leq x \leq 16$ are activated that is = Boolean 1 it corresponds to that integer 65535 is available on the output OUT. IB16 function is designed for receiving up to 16 booleans input locally. If the BLOCK input is activated, it will freeze the output at the last value.

Values of each of the different OUT_x from function block IB16 for $1 \leq x \leq 16$.

The sum of the value on each IN_x corresponds to the integer presented on the output OUT on the function block IB16.

Name of input	Type	Default	Description	Value when activated	Value when deactivated
IN1	BOOLEAN	0	Input 1	1	0
IN2	BOOLEAN	0	Input 2	2	0
IN3	BOOLEAN	0	Input 3	4	0
IN4	BOOLEAN	0	Input 4	8	0
IN5	BOOLEAN	0	Input 5	16	0
IN6	BOOLEAN	0	Input 6	32	0
IN7	BOOLEAN	0	Input 7	64	0
IN8	BOOLEAN	0	Input 8	128	0
IN9	BOOLEAN	0	Input 9	256	0
IN10	BOOLEAN	0	Input 10	512	0
IN11	BOOLEAN	0	Input 11	1024	0
IN12	BOOLEAN	0	Input 12	2048	0
IN13	BOOLEAN	0	Input 13	4096	0
IN14	BOOLEAN	0	Input 14	8192	0
IN15	BOOLEAN	0	Input 15	16384	0
IN16	BOOLEAN	0	Input 16	32768	0

The sum of the numbers in column “Value when activated” when all INx (where $1 \leq x \leq 16$) are active that is=1; is 65535. 65535 is the highest boolean value that can be converted to an integer by the IB16 function block.

12.11 Integer to Boolean 16 conversion with logic node representation ITBGAPC

12.11.1 Identification

Function description	IEC 61850 identification	ANSI/IEEE C37.2 device number	
Integer to boolean 16 conversion with logic node representation	ITBGAPC	-	-

12.11.2 Application

Integer to boolean 16 conversion with logic node representation function (ITBGAPC) is used to transform an integer into a set of 16 boolean signals. ITBGAPC function can receive an integer from a station computer – for example, over IEC 61850–8–1. This function is very useful when the user wants to generate

logical commands (for selector switches or voltage controllers) by inputting an integer number. ITBGAPC function has a logical node mapping in IEC 61850.

The Integer to Boolean 16 conversion with logic node representation function (ITBGAPC) will transfer an integer with a value between 0 to 65535 communicated via IEC 61850 and connected to the ITBGAPC function block to a combination of activated outputs OUTx where $1 \leq x \leq 16$.

The values of the different OUTx are according to the Table [32](#).

If the BLOCK input is activated, it freezes the logical outputs at the last value.

Table 32: *Output signals*

Name of OUTx	Type	Description	Value when activated	Value when deactivated
OUT1	BOOLEAN	Output 1	1	0
OUT2	BOOLEAN	Output 2	2	0
OUT3	BOOLEAN	Output 3	4	0
OUT4	BOOLEAN	Output 4	8	0
OUT5	BOOLEAN	Output 5	16	0
OUT6	BOOLEAN	Output 6	32	0
OUT7	BOOLEAN	Output 7	64	0
OUT8	BOOLEAN	Output 8	128	0
OUT9	BOOLEAN	Output 9	256	0
OUT10	BOOLEAN	Output 10	512	0
OUT11	BOOLEAN	Output 11	1024	0
OUT12	BOOLEAN	Output 12	2048	0
OUT13	BOOLEAN	Output 13	4096	0
OUT14	BOOLEAN	Output 14	8192	0
OUT15	BOOLEAN	Output 15	16384	0
OUT16	BOOLEAN	Output 16	32768	0

The sum of the numbers in column “Value when activated” when all OUTx ($1 \leq x \leq 16$) are active equals 65535. This is the highest integer that can be converted by the ITBGAPC function block.

12.12

Elapsed time integrator with limit transgression and overflow supervision TEIGAPC

12.12.1

Identification

Function Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Elapsed time integrator	TEIGAPC	-	-

12.12.2

Application

The function TEIGAPC is used for user-defined logics and it can also be used for different purposes internally in the IED. An application example is the integration of elapsed time during the measurement of neutral point voltage or neutral current at earth-fault conditions.

Settable time limits for warning and alarm are provided. The time limit for overflow indication is fixed to 999999.9 seconds.

12.12.3

Setting guidelines

The settings t_{Alarm} and $t_{Warning}$ are user settable limits defined in seconds. The achievable resolution of the settings depends on the level of the values defined.

A resolution of 10 ms can be achieved when the settings are defined within the range

$$1.00 \text{ second} \leq t_{Alarm} \leq 99\,999.99 \text{ seconds}$$

$$1.00 \text{ second} \leq t_{Warning} \leq 99\,999.99 \text{ seconds.}$$

If the values are above this range, the resolution becomes lower due to the 32 bit float representation

$$99\,999.99 \text{ seconds} < t_{Alarm} \leq 999\,999.0 \text{ seconds}$$

$$99\,999.99 \text{ seconds} < t_{Warning} \leq 999\,999.0 \text{ seconds}$$



Note that t_{Alarm} and $t_{Warning}$ are independent settings, that is, there is no check if $t_{Alarm} > t_{Warning}$.

The limit for the overflow supervision is fixed at 999999.9 seconds.

12.13

Comparator for integer inputs - INTCOMP

12.13.1

Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Comparison of integer values	INTCOMP	Int<=>	

12.13.2 Application

The function gives the possibility to monitor the level of integer values in the system relative to each other or to a fixed value. It is a basic arithmetic function that can be used for monitoring, supervision, interlocking and other logics.

12.13.3 Setting guidelines

For proper operation of comparison the set value should be set within the range of $\pm 2 \times 10^9$.

Setting procedure on the IED:

EnaAbs: This setting is used to select the comparison type between signed and absolute values.

- *Absolute*: Comparison is performed on absolute values of input and reference values
- *Signed*: Comparison is performed on signed values of input and reference values.

RefSource: This setting is used to select the reference source between input and setting for comparison.

- *Input REF*: The function will take reference value from input REF
- *Set Value*: The function will take reference value from setting *SetValue*

SetValue: This setting is used to set the reference value for comparison when setting *RefSource* is selected as *SetValue*.

12.13.4 Setting example

For absolute comparison between inputs:

Set the *EnaAbs* = *Absolute*

Set the *RefSource* = *Input REF*

Similarly for Signed comparison between inputs

Set the *EnaAbs* = *Signed*

Set the *RefSource* = *Input REF*

For absolute comparison between input and setting

Set the *EnaAbs* = *Absolute*

Set the *RefSource* = *Set Value*

SetValue shall be set between -2000000000 to 2000000000

Similarly for signed comparison between input and setting

Set the *EnaAbs* = *Signed*

Set the *RefSource* = *Set Value*

SetValue shall be set between -2000000000 to 2000000000

12.14 Comparator for real inputs - REALCOMP

12.14.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Comparator for real inputs	REALCOMP	Real<=>	

12.14.2 Application

The function gives the possibility to monitor the level of real values in the system relative to each other or to a fixed value. It is a basic arithmetic function that can be used for monitoring, supervision, interlocking and other logics.

12.14.3 Setting guidelines

Setting procedure on the IED:

EnaAbs: This setting is used to select the comparison type between signed and absolute values.

- *Absolute*: Comparison is performed with absolute values of input and reference.
- *Signed*: Comparison is performed with signed values of input and reference.

RefSource: This setting is used to select the reference source between input and setting for comparison.

- *Input REF*: The function will take reference value from input REF
- *Set Value*: The function will take reference value from setting *SetValue*

SetValue: This setting is used to set the reference value for comparison when setting *RefSource* is selected as *Set Value*. If this setting value is less than 0.2% of the set unit then the output INLOW will never pickup.

RefPrefix: This setting is used to set the unit of the reference value for comparison when setting *RefSource* is selected as *Set Value*. It has 5 unit selections and they are Milli, Unity, Kilo, Mega and Giga.

EqualBandHigh: This setting is used to set the equal condition high band limit in % of reference value. This high band limit will act as reset limit for INHIGH output when INHIGH.

EqualBandLow: This setting is used to set the equal condition low band limit in % of reference value. This low band limit will act as reset limit for INLOW output when INLOW.

12.14.4

Setting example

Let us consider a comparison is to be done between current magnitudes in the range of 90 to 110 with nominal rating is 100 and the order is kA.

For the above condition the comparator can be designed with settings as follows,

EnaAbs = *Absolute*

RefSource = *Set Value*

SetValue = 100

RefPrefix = *Kilo*

EqualBandHigh = 5.0 % of reference value

EqualBandLow = 5.0 % of reference value

Operation

The function will set the outputs for the following conditions,

INEQUAL will set when the INPUT is between the ranges of 95 to 105 kA.

INHIGH will set when the INPUT crosses above 105 kA.

INLOW will set when the INPUT crosses below 95 kA.

If the comparison should be done between two current magnitudes then those current signals need to be connected to function inputs, INPUT and REF. Then the settings should be adjusted as below,

EnaAbs = *Absolute*

RefSource = *Input REF*

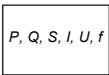
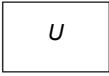
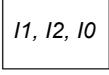
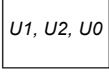
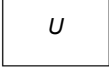
EqualBandHigh = 5.0 % of reference value

EqualBandLow = 5.0 % of reference value.

Section 13 Monitoring

13.1 Measurement

13.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Power system measurements			-
Phase current measurement	CMMXU		-
Phase-phase voltage measurement	VMMXU		-
Current sequence component measurement	CMSQI		-
Voltage sequence component measurement	VMSQI		-
Phase-neutral voltage measurement	VNMMXU		-

13.1.2 Application

Measurement functions are used for power system measurement, supervision and reporting to the local HMI, monitoring tool within PCM600 or to station level for example, via IEC 61850. The possibility to continuously monitor measured values of active power, reactive power, currents, voltages, frequency, power factor etc. is vital for efficient production, transmission and distribution of electrical energy. It

provides to the system operator fast and easy overview of the present status of the power system. Additionally, it can be used during testing and commissioning of protection and control IEDs in order to verify proper operation and connection of instrument transformers (CTs and VTs). During normal service by periodic comparison of the measured value from the IED with other independent meters the proper operation of the IED analog measurement chain can be verified. Finally, it can be used to verify proper direction orientation for distance or directional overcurrent protection function.



The available measured values from an IED are depending on the actual hardware (TRM) and the logic configuration made in PCM600.

All measured values can be supervised with four settable limits that is, low-low limit, low limit, high limit and high-high limit. A zero clamping reduction is also supported, that is, the measured value below a settable limit is forced to zero which reduces the impact of noise in the inputs.

Dead-band supervision can be used to report measured signal value to station level when change in measured value is above set threshold limit or time integral of all changes since the last time value updating exceeds the threshold limit. Measure value can also be based on periodic reporting.

The measurement function, , provides the following power system quantities:

- P, Q and S: three phase active, reactive and apparent power
- PF: power factor
- U: phase-to-phase voltage amplitude
- I: phase current amplitude
- F: power system frequency

The measuring functions CMMXU, VMMXU and VNMMXU provide physical quantities:

- I: phase currents (amplitude and angle) (CMMXU)
- U: voltages (phase-to-earth and phase-to-phase voltage, amplitude and angle) (VMMXU, VNMMXU)

The function calculates three-phase power quantities by using fundamental frequency phasors (DFT values) of the measured current and voltage signals. The measured power quantities are available either, as instantaneously calculated quantities or, averaged values over a period of time (low pass filtered) depending on the selected settings.

It is possible to calibrate the measuring function above to get better than class 0.5 presentation. This is accomplished by angle and amplitude compensation at 5, 30 and 100% of rated current and at 100% of rated voltage.



The power system quantities provided, depends on the actual hardware, (TRM) and the logic configuration made in PCM600.

The measuring functions CMSQI and VMSQI provide sequence component quantities:

- I: sequence currents (positive, zero, negative sequence, amplitude and angle)
- U: sequence voltages (positive, zero and negative sequence, amplitude and angle).

13.1.3

Zero clamping

Measuring functions CVMMXN, CMMXU, VMMXU and VNMMXU have no interconnections regarding any settings or parameters.

Zero clampings are also handled entirely by *ZeroDb* separately for each function's every output signal. For example, zero clamping of U12 is handled by *UL12ZeroDb* in VMMXU, zero clamping of I1 is handled by *IL1ZeroDb* in CMMXU, and so on.

Example of CVMMXN operation

Outputs seen on the local HMI under **Main menu/Measurements/Monitoring/Servicevalues(P_Q)/CVMMXN(P_Q)**:

S	Apparent three-phase power
P	Active three-phase power
Q	Reactive three-phase power
PF	Power factor
ILAG	I lagging U
ILEAD	I leading U
U	System mean voltage, calculated according to selected mode
I	System mean current, calculated according to selected mode
F	Frequency

Relevant settings and their values on the local HMI under **Main menu/Settings/IED settings/Monitoring/Servicevalues(P_Q)/CVMMXN(P_Q)**:

- When system voltage falls below *UGenZeroDB*, values for S, P, Q, PF, ILAG, ILEAD, U and F are forced to zero.
- When system current falls below *IGenZeroDB*, values for S, P, Q, PF, ILAG, ILEAD, U and F are forced to zero.
- When the value of a single signal falls below its set deadband, the value is forced to zero. For example, if the apparent three-phase power falls below *SZeroDb*, the value for S is forced to zero.

13.1.4

Setting guidelines

The available setting parameters of the measurement function, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU are depending on the actual hardware (TRM) and the logic configuration made in PCM600.

The parameters for the Measurement functions, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU are set via the local HMI or PCM600.

GlobalBaseSel: Selects the global base value group used by the function to define *IBase*, *UBase* and *SBase* as applicable.

Operation: *Off/On*. Every function instance (, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU) can be taken in operation (*On*) or out of operation (*Off*).

The following general settings can be set for the **Measurement function** (,).

PowAmpFact: Amplitude factor to scale power calculations.

PowAngComp: Angle compensation for phase shift between measured I & U.

Mode: Selection of measured current and voltage. There are 9 different ways of calculating monitored three-phase values depending on the available VT inputs connected to the IED. See parameter group setting table.

k: Low pass filter coefficient for power measurement, U and I.

UGenZeroDb: Minimum level of voltage in % of *UBase*, used as indication of zero voltage (zero point clamping). If measured value is below *UGenZeroDb* calculated S, P, Q and PF will be zero.

IGenZeroDb: Minimum level of current in % of *IBase*, used as indication of zero current (zero point clamping). If measured value is below *IGenZeroDb* calculated S, P, Q and PF will be zero.

UAmpCompY: Amplitude compensation to calibrate voltage measurements at Y% of U_r , where Y is equal to 5, 30 or 100.

IampCompY: Amplitude compensation to calibrate current measurements at Y% of I_r , where Y is equal to 5, 30 or 100.

IAngCompY: Angle compensation to calibrate angle measurements at Y% of I_r , where Y is equal to 5, 30 or 100.

The following general settings can be set for the **Phase current measurement** (CMMXU).

IampCompY: Amplitude compensation to calibrate current measurements at Y% of I_r , where Y is equal to 5, 30 or 100.

IAngCompY: Angle compensation to calibrate angle measurements at Y% of I_r , where Y is equal to 5, 30 or 100.

The following general settings can be set for the **Phase-phase voltage measurement** (VMMXU).

UAmpCompY: Amplitude compensation to calibrate voltage measurements at Y% of U_r , where Y is equal to 5, 30 or 100.

UAngCompY: Angle compensation to calibrate angle measurements at Y% of U_r , where Y is equal to 5, 30 or 100.

The following general settings can be set for **all monitored quantities** included in the functions (, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU) X in setting names below equals S, P, Q, PF, U, I, F, IL1-3, UL1-3UL12-31, I1, I2, 3I0, U1, U2 or 3U0.

Xmin: Minimum value for analog signal X set directly in applicable measuring unit. This forms the minimum limit of the range.

Xmax: Maximum value for analog signal X. This forms the maximum limit of the range.

XZeroDb: Zero point clamping. A signal value less than *XZeroDb* is forced to zero.

Observe the related zero point clamping settings in Setting group N for (*UGenZeroDb* and *IGenZeroDb*). If measured value is below *UGenZeroDb* and/or *IGenZeroDb* calculated S, P, Q and PF will be zero and these settings will override *XZeroDb*.

XRepTyp: Reporting type. Cyclic (*Cyclic*), amplitude deadband (*Dead band*), integral deadband (*Int deadband*) or Deadband and xx se cyclic (xx: 5 sec, 30 sec, 1 min). The reporting interval is controlled by the parameter *XDbRepInt*.

XDbRepInt: This setting handles all the reporting types. If setting is deadband in *XRepTyp*, *XDbRepInt* defines the deadband in m% of the measuring range. For cyclic reporting type (*XRepTyp* : *cyclic*), the setting value reporting interval is in seconds. Amplitude deadband is the setting value in m% of measuring range. Integral deadband setting is the integral area, that is, measured value in m% of measuring range multiplied by the time between two measured values.

XHiHiLim: High-high limit. Set as % of *YBase* (Y is *SBase* for S,P,Q *UBase* for Voltage measurement and *IBase* for current measurement).

XHiLim: High limit. Set as % of *YBase* (Y is *SBase* for S,P,Q *UBase* for Voltage measurement and *IBase* for current measurement).

XLowLim: Low limit. Set as % of *YBase* (Y is *SBase* for S,P,Q *UBase* for Voltage measurement and *IBase* for current measurement).

XLowLowLim: Low-low limit. Set as % of *YBase* (Y is *SBase* for S,P,Q *UBase* for Voltage measurement and *IBase* for current measurement).

XLimHyst: Hysteresis value in % of range and is common for all limits.

All phase angles are presented in relation to defined reference channel. The parameter *PhaseAngleRef* defines the reference, see Section [“Analog inputs”](#).

Calibration curves

It is possible to calibrate the functions (, CMMXU, VMMXU and VNMMXU) to get class 0.5 presentations of currents, voltages and powers. This is accomplished by amplitude and angle compensation at 5, 30 and 100% of rated current and voltage. The compensation curve will have the characteristic for amplitude and angle compensation of currents as shown in figure 96 (example). The first phase will be used as reference channel and compared with the curve for calculation of factors. The factors will then be used for all related channels.

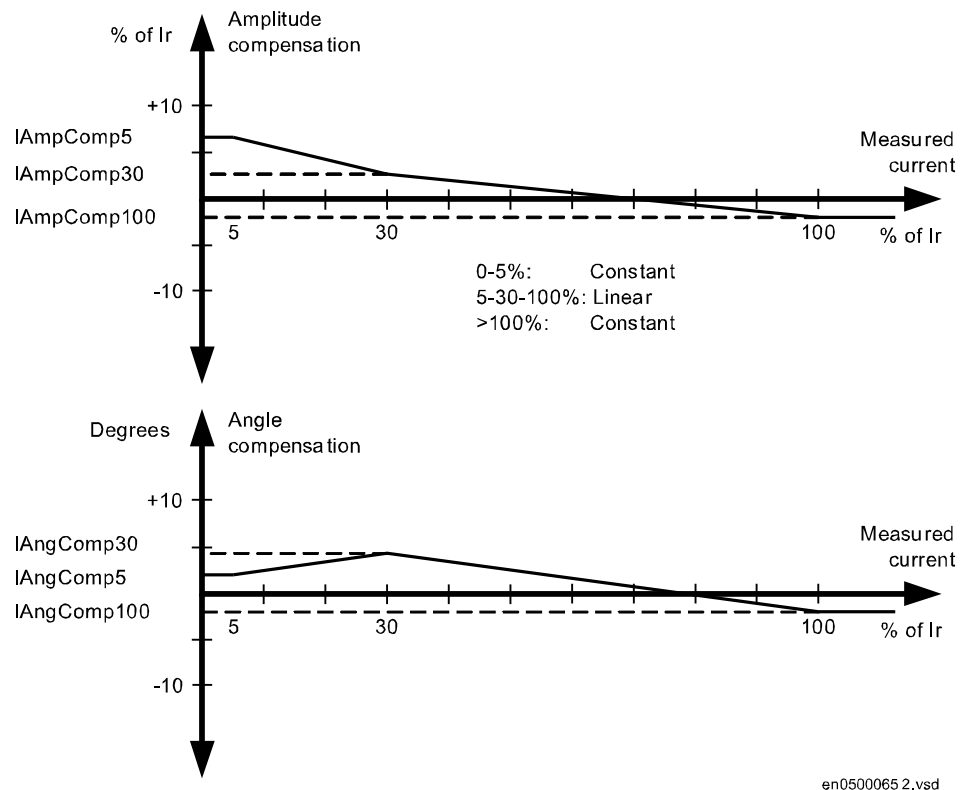


Figure 96: Calibration curves

13.1.4.1

Setting examples

Three setting examples, in connection to Measurement function (), are provided:

- Measurement function () application for a OHL
- Measurement function () application on the secondary side of a transformer
- Measurement function () application for a generator

For each of them detail explanation and final list of selected setting parameters values will be provided.



The available measured values of an IED are depending on the actual hardware (TRM) and the logic configuration made in PCM600.

Measurement function application for a 400kV OHL

Single line diagram for this application is given in figure 97:

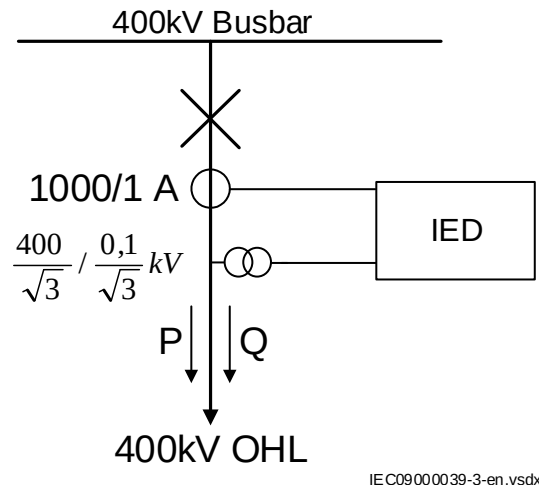


Figure 97: Single line diagram for 400kV OHL application

In order to monitor, supervise and calibrate the active and reactive power as indicated in figure 97 it is necessary to do the following:

1. Set correctly CT and VT data and phase angle reference channel *PhaseAngleRef* (see Section [“Setting of the phase reference channel”](#)) using PCM600 for analog input channels
2. Connect, in PCM600, measurement function to three-phase CT and VT inputs
3. Set under General settings parameters for the Measurement function:
 - general settings as shown in table 33.
 - level supervision of active power as shown in table 34.
 - calibration parameters as shown in table 35.

Table 33: General settings parameters for the Measurement function

Setting	Short Description	Selected value	Comments
Operation	Operation Off/On	On	Function must be <i>On</i>
PowAmpFact	Amplitude factor to scale power calculations	1.000	It can be used during commissioning to achieve higher measurement accuracy. Typically no scaling is required
PowAngComp	Angle compensation for phase shift between measured I & U	0.0	It can be used during commissioning to achieve higher measurement accuracy. Typically no angle compensation is required. As well here required direction of P & Q measurement is towards protected object (as per IED internal default direction)
Mode	Selection of measured current and voltage	L1, L2, L3	All three phase-to-earth VT inputs are available
k	Low pass filter coefficient for power measurement, U and I	0.00	Typically no additional filtering is required
UGenZeroDb	Zero point clamping in % of Ubase	25	Set minimum voltage level to 25%. Voltage below 25% will force S, P and Q to zero.
IGenZeroDb	Zero point clamping in % of Ibase	3	Set minimum current level to 3%. Current below 3% will force S, P and Q to zero.
UBase (set in Global base)	Base setting for voltage level in kV	400.00	Set rated OHL phase-to-phase voltage
IBase (set in Global base)	Base setting for current level in A	1000	Set rated primary CT current used for OHL
SBase (set in Global base)	Base Setting for power base in MVA	1000	Set based on rated Power

Table 34: Settings parameters for level supervision

Setting	Short Description	Selected value	Comments
<i>PMin</i>	Minimum value	-100	Minimum expected load
<i>PMax</i>	Minimum value	100	Maximum expected load
<i>PZeroDb</i>	Zero point clamping in 0.001% of range	3000	Set zero point clamping to 60 MW that is, 3% of 200 MW
<i>PRepTyp</i>	Reporting type	db	Select amplitude deadband supervision
<i>PDbReplnt</i>	Cycl: Report interval (s), Db: In 0.001% of range, Int Db: In 0.001% s	2000	Set $\pm\Delta db=40$ MW that is, 2% (larger changes than 40 MW will be reported)
<i>PHiHiLim</i>	High High limit (physical value), % of SBase	60	High alarm limit that is, extreme overload alarm, hence it will be 415 MW.
<i>PHiLim</i>	High limit (physical value), in % of SBase	50	High warning limit that is, overload warning, hence it will be 371 MW.
Table continues on next page			

Setting	Short Description	Selected value	Comments
<i>PLowLim</i>	Low limit (physical value), in % of SBase	-50	Low warning limit -500 MW
<i>PLowLowLim</i>	Low Low limit (physical value), in % of SBase	-60	Low alarm limit -600 MW
<i>PLimHyst</i>	Hysteresis value in % of range (common for all limits)	1	Set $\pm\Delta$ Hysteresis 20 MW that is, 1% of range (2000 MW)

Table 35: *Settings for calibration parameters*

Setting	Short Description	Selected value	Comments
<i>IAmpComp5</i>	Amplitude factor to calibrate current at 5% of Ir	0.00	
<i>IAmpComp30</i>	Amplitude factor to calibrate current at 30% of Ir	0.00	
<i>IAmpComp100</i>	Amplitude factor to calibrate current at 100% of Ir	0.00	
<i>UAmpComp5</i>	Amplitude factor to calibrate voltage at 5% of Ur	0.00	
<i>UAmpComp30</i>	Amplitude factor to calibrate voltage at 30% of Ur	0.00	
<i>UAmpComp100</i>	Amplitude factor to calibrate voltage at 100% of Ur	0.00	
<i>IAngComp5</i>	Angle calibration for current at 5% of Ir	0.00	
<i>IAngComp30</i>	Angle pre-calibration for current at 30% of Ir	0.00	
<i>IAngComp100</i>	Angle pre-calibration for current at 100% of Ir	0.00	

Measurement function application for a power transformer

Single line diagram for this application is given in figure [98](#).

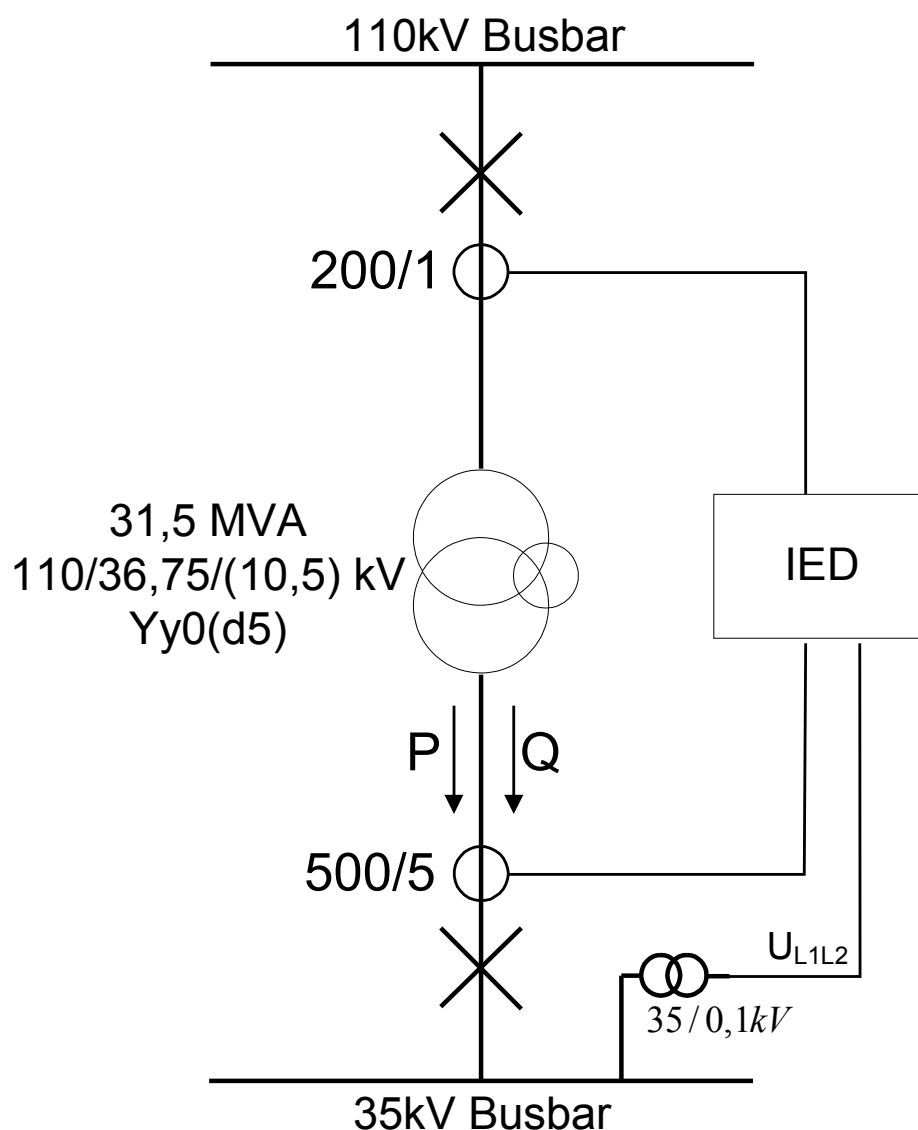


Figure 98: Single line diagram for transformer application

In order to measure the active and reactive power as indicated in figure 98, it is necessary to do the following:

1. Set correctly all CT and VT and phase angle reference channel *PhaseAngleRef* (see Section “[Setting of the phase reference channel](#)”) data using PCM600 for analog input channels
2. Connect, in PCM600, measurement function to LV side CT & VT inputs
3. Set the setting parameters for relevant Measurement function as shown in the following table 36:

Table 36: *General settings parameters for the Measurement function*

Setting	Short description	Selected value	Comment
<i>Operation</i>	Operation <i>Off/On</i>	<i>On</i>	Function must be <i>On</i>
<i>PowAmpFact</i>	Amplitude factor to scale power calculations	1.000	Typically no scaling is required
<i>PowAngComp</i>	Angle compensation for phase shift between measured I & U	180.0	Typically no angle compensation is required. However here the required direction of P & Q measurement is towards busbar (Not per IED internal default direction). Therefore angle compensation have to be used in order to get measurements in alignment with the required direction.
<i>Mode</i>	Selection of measured current and voltage	L1L2	Only UL1L2 phase-to-phase voltage is available
k	Low pass filter coefficient for power measurement, U and I	0.00	Typically no additional filtering is required
UGenZeroDb	Zero point clamping in % of Ubase	25	Set minimum voltage level to 25%
IGenZeroDb	Zero point clamping in % of Ibase	3	Set minimum current level to 3%
UBase (set in Global base)	Base setting for voltage level in kV	35.00	Set LV side rated phase-to-phase voltage
IBase (set in Global base)	Base setting for current level in A	495	Set transformer LV winding rated current
SBase (set in Global base)	Base setting for power in MVA	31.5	Set based on rated power

13.2 Gas medium supervision SSIMG

13.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Insulation gas monitoring function	SSIMG	-	63

13.2.2 Application

Gas medium supervision (SSIMG) is used for monitoring the circuit breaker condition. Proper arc extinction by the compressed gas in the circuit breaker is very important. When the pressure becomes too low compared to the required value, the circuit breaker operation shall be blocked to minimize the risk of internal failure. Binary information based on the gas pressure in the circuit breaker is used as an

input signal to the function. The function generates alarms based on the received information.

13.2.3 Setting guidelines

The parameters for Gas medium supervision SSIMG can be set via local HMI or Protection and Control Manager PCM600.

Operation: This is used to disable/enable the operation of gas medium supervision i.e. Off/On.

PresAlmLimit: This is used to set the limit for a pressure alarm condition in the circuit breaker.

PresLOLimit: This is used to set the limit for a pressure lockout condition in the circuit breaker.

TempAlarmLimit: This is used to set the limit for a temperature alarm condition in the circuit breaker.

TempLOLimit: This is used to set the limit for a temperature lockout condition in the circuit breaker.

tPressureAlarm: This is used to set the time delay for a pressure alarm indication, given in s.

tPressureLO: This is used to set the time delay for a pressure lockout indication, given in s.

tTempAlarm: This is used to set the time delay for a temperature alarm indication, given in s.

tTempLockOut: This is used to set the time delay for a temperature lockout indication, given in s.

tResetPressAlm: This is used for the pressure alarm indication to reset after a set time delay in s.

tResetPressLO: This is used for the pressure lockout indication to reset after a set time delay in s.

tResetTempLO: This is used for the temperature lockout indication to reset after a set time delay in s.

tResetTempAlm: This is used for the temperature alarm indication to reset after a set time delay in s.

13.3 Liquid medium supervision SSIML

13.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Insulation liquid monitoring function	SSIML	-	71

13.3.2 Application

Liquid medium supervision (SSIML) is used for monitoring the transformers and tap changers. When the level becomes too low compared to the required value, the operation is blocked to minimize the risk of internal failures. Binary information based on the oil level in the transformer and the tap changer is used as input signals to the function. In addition to that, the function generates alarms based on received information.

13.3.3 Setting guidelines

The parameters for Liquid medium supervision SSIML can be set via local HMI or Protection and Control Manager PCM600.

Operation: This is used to disable/enable the operation of liquid medium supervision i.e. *Off/On*.

LevelAlmLimit: This is used to set the limit for a level alarm condition in the transformer.

LevelLOLimit: This is used to set the limit for a level lockout condition in the transformer.

TempAlarmLimit: This is used to set the limit for a temperature alarm condition in the transformer.

TempLOLimit: This is used to set the limit for a temperature lockout condition in the transformer.

tLevelAlarm: This is used to set the time delay for a level alarm indication, given in s.

tLevelLockOut: This is used to set the time delay for a level lockout indication, given in s.

tTempAlarm: This is used to set the time delay for a temperature alarm indication, given in s.

tTempLockOut: This is used to set the time delay for a temperature lockout indication, given in s.

tResetLevelAlm: This is used for the level alarm indication to reset after a set time delay in s.

tResetLevelLO: This is used for the level lockout indication to reset after a set time delay in s.

tResetTempLO: This is used for the temperature lockout indication to reset after a set time delay in s.

tResetTempAlm: This is used for the temperature alarm indication to reset after a set time delay in s.

13.4 Breaker monitoring SSCBR

13.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Breaker monitoring	SSCBR	-	-

13.4.2 Application

The circuit breaker maintenance is usually based on regular time intervals or the number of operations performed. This has some disadvantages because there could be a number of abnormal operations or few operations with high-level currents within the predetermined maintenance interval. Hence, condition-based maintenance scheduling is an optimum solution in assessing the condition of circuit breakers.

Circuit breaker contact travel time

Auxiliary contacts provide information about the mechanical operation, opening time and closing time of a breaker. Detecting an excessive traveling time is essential to indicate the need for maintenance of the circuit breaker mechanism. The excessive travel time can be due to problems in the driving mechanism or failures of the contacts.

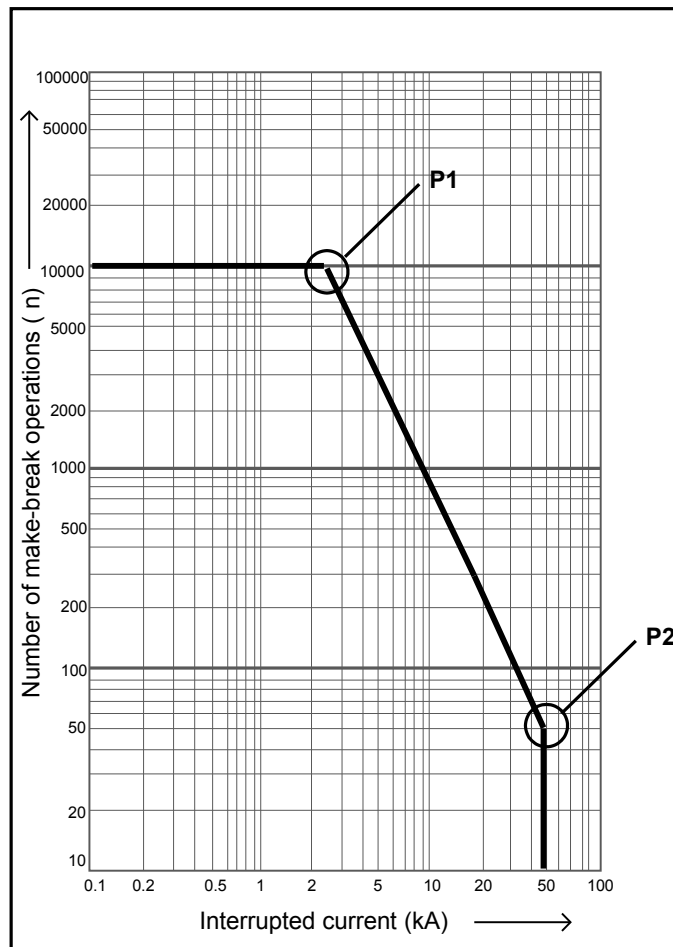
Circuit breaker status

Monitoring the breaker status ensures proper functioning of the features within the protection relay such as breaker control, breaker failure and autoreclosing. The breaker status is monitored using breaker auxiliary contacts. The breaker status is indicated by the binary outputs. These signals indicate whether the circuit breaker is in an open, closed or error state.

Remaining life of circuit breaker

Every time the breaker operates, the circuit breaker life reduces due to wear. The wear in a breaker depends on the interrupted current. For breaker maintenance or replacement at the right time, the remaining life of the breaker must be estimated. The remaining life of a breaker can be estimated using the maintenance curve provided by the circuit breaker manufacturer.

Circuit breaker manufacturers provide the number of make-break operations possible at various interrupted currents. An example is shown in figure 99.



IEC12000623_1_en.vsd

Figure 99: An example for estimating the remaining life of a circuit breaker

Calculation for estimating the remaining life

The graph shows that there are 10000 possible operations at the rated operating current and 900 operations at 10 kA and 50 operations at rated fault current. Therefore, if the interrupted current is 10 kA, one operation is equivalent to $10000/900 = 11$ operations at the rated current. It is assumed that prior to tripping, the remaining life of a breaker is 10000 operations. Remaining life calculation for three different interrupted current conditions is explained below.

- Breaker interrupts at and below the rated operating current, that is, 2 kA, the remaining life of the CB is decreased by 1 operation and therefore, 9999 operations remaining at the rated operating current.
- Breaker interrupts between rated operating current and rated fault current, that is, 10 kA, one operation at 10kA is equivalent to $10000/900 = 11$ operations at the rated current. The remaining life of the CB would be $(10000 - 10) = 9989$ at the rated operating current after one operation at 10 kA.
- Breaker interrupts at and above rated fault current, that is, 50 kA, one operation at 50 kA is equivalent to $10000/50 = 200$ operations at the rated operating current. The remaining life of the CB would become $(10000 - 200) = 9800$ operations at the rated operating current after one operation at 50 kA.

Accumulated energy

Monitoring the contact erosion and interrupter wear has a direct influence on the required maintenance frequency. Therefore, it is necessary to accurately estimate the erosion of the contacts and condition of interrupters using cumulative summation of I^y . The factor "y" depends on the type of circuit breaker. The energy values were accumulated using the current value and exponent factor for CB contact opening duration. When the next CB opening operation is started, the energy is accumulated from the previous value. The accumulated energy value can be reset to initial accumulation energy value by using the Reset accumulating energy input, RSTI POW.

Circuit breaker operation cycles

Routine breaker maintenance like lubricating breaker mechanism is based on the number of operations. A suitable threshold setting helps in preventive maintenance. This can also be used to indicate the requirement for oil sampling for dielectric testing in case of an oil circuit breaker.

Circuit breaker operation monitoring

By monitoring the activity of the number of operations, it is possible to calculate the number of days the breaker has been inactive. Long periods of inactivity degrade the reliability for the protection system.

Circuit breaker spring charge monitoring

For normal circuit breaker operation, the circuit breaker spring should be charged within a specified time. Detecting a long spring charging time indicates the time for circuit breaker maintenance. The last value of the spring charging time can be given as a service value.

Circuit breaker gas pressure indication

For proper arc extinction by the compressed gas in the circuit breaker, the pressure of the gas must be adequate. Binary input available from the pressure sensor is based on the pressure levels inside the arc chamber. When the pressure becomes too low compared to the required value, the circuit breaker operation is blocked.

13.4.3 Setting guidelines

The breaker monitoring function 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 also essential to monitor the circuit breaker operation, spring charge indication or breaker wear, travel time, number of operation cycles and accumulated energy during arc extinction.

13.4.3.1 Setting procedure on the IED

The parameters for breaker monitoring (SSCBR) can be set using the local HMI or Protection and Control Manager (PCM600).

Common base IED values for primary current (*IBase*), primary voltage (*UBase*) and primary power (*SBase*) are set in Global base values for settings function GBASVAL.

GlobalBaseSel: It is used to select a GBASVAL function for reference of base values.

Operation: On or Off.

IBase: Base phase current in primary A. This current is used as reference for current settings.

OpenTimeCorr: Correction factor for circuit breaker opening travel time.

CloseTimeCorr: Correction factor for circuit breaker closing travel time.

tTrOpenAlm: Setting of alarm level for opening travel time.

tTrCloseAlm: Setting of alarm level for closing travel time.

OperAlmLevel: Alarm limit for number of mechanical operations.

OperLOLevel: Lockout limit for number of mechanical operations.

CurrExponent: Current exponent setting for energy calculation. It varies for different types of circuit breakers. This factor ranges from 0.5 to 3.0.

AccStopCurr: RMS current setting below which calculation of energy accumulation stops. It is given as a percentage of *IBase*.

ContTrCorr: Correction factor for time difference in auxiliary and main contacts' opening time.

AlmAccCurrPwr: Setting of alarm level for accumulated energy.

LOAccCurrPwr: Lockout limit setting for accumulated energy.

SpChAlmTime: Time delay for spring charging time alarm.

tDGasPresAlm: Time delay for gas pressure alarm.

tDGasPresLO: Time delay for gas pressure lockout.

DirCoef: Directional coefficient for circuit breaker life calculation.

RatedOperCurr: Rated operating current of the circuit breaker.

RatedFltCurr: Rated fault current of the circuit breaker.

OperNoRated: Number of operations possible at rated current.

OperNoFault: Number of operations possible at rated fault current.

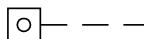
CBLifeAlmLevel: Alarm level for circuit breaker remaining life.

AccSelCal: Selection between the method of calculation of accumulated energy.

OperTimeDelay: Time delay between change of status of trip output and start of main contact separation.

13.5 Event function EVENT

13.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Event function	EVENT		-

13.5.2 Application

When using a Substation Automation system with LON or SPA communication, time-tagged events can be sent at change or cyclically from the IED to the station level. These events are created from any available signal in the IED that is connected to the Event function (EVENT). The EVENT function block is used for LON and SPA communication.

Analog, integer and double indication values are also transferred through the EVENT function.

13.5.3 Setting guidelines

The input parameters for the Event function (EVENT) can be set individually via the local HMI (**Main Menu/Settings / IED Settings / Monitoring / Event Function**) or via the Parameter Setting Tool (PST).

EventMask (Ch_1 - 16)

The inputs can be set individually as:

- *NoEvents*
- *OnSet*, at pick-up of the signal
- *OnReset*, at drop-out of the signal
- *OnChange*, at both pick-up and drop-out of the signal
- *AutoDetect*, the EVENT function makes the reporting decision (reporting criteria for integers have no semantic, prefer to be set by the user)

LONChannelMask or SPACchannelMask

Definition of which part of the event function block that shall generate events:

- *Off*
- *Channel 1-8*
- *Channel 9-16*
- *Channel 1-16*

MinReplntVal (1 - 16)

A time interval between cyclic events can be set individually for each input channel. This can be set between 0 s to 3600 s in steps of 1 s. It should normally be set to 0, that is, no cyclic communication.



It is important to set the time interval for cyclic events in an optimized way to minimize the load on the station bus.

13.6 Disturbance report DRPRDRE

13.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Disturbance report	DRPRDRE	-	-
Disturbance report	A1RADR - A4RADR	-	-
Disturbance report	B1RBDR - B22RBDR	-	-

13.6.2

Application

To get fast, complete and reliable information about disturbances in the primary and/or in the secondary system it is very important to gather information on fault currents, voltages and events. It is also important having a continuous event-logging to be able to monitor in an overview perspective. These tasks are accomplished by the disturbance report function DRPRDRE and facilitate a better understanding of the power system behavior and related primary and secondary equipment during and after a disturbance. An analysis of the recorded data provides valuable information that can be used to explain a disturbance, basis for change of IED setting plan, improve existing equipment, and so on. This information can also be used in a longer perspective when planning for and designing new installations, that is, a disturbance recording could be a part of Functional Analysis (FA).

Disturbance report DRPRDRE, always included in the IED, acquires sampled data of all selected analog and binary signals connected to the function blocks that is,

- Maximum 30 external analog signals,
- 10 internal derived analog signals, and
- 352 binary signals

Disturbance report function is a common name for several functions; Indications (IND), Event recorder (ER), Event list (EL), Trip value recorder (TVR), Disturbance recorder (DR) and Fault locator (FL).

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

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

If the IED is connected to a station bus (IEC 61850-8-1), the disturbance recorder (record made and fault number) and the fault locator information are available. The same information is obtainable if IEC 60870-5-103 is used.

13.6.3

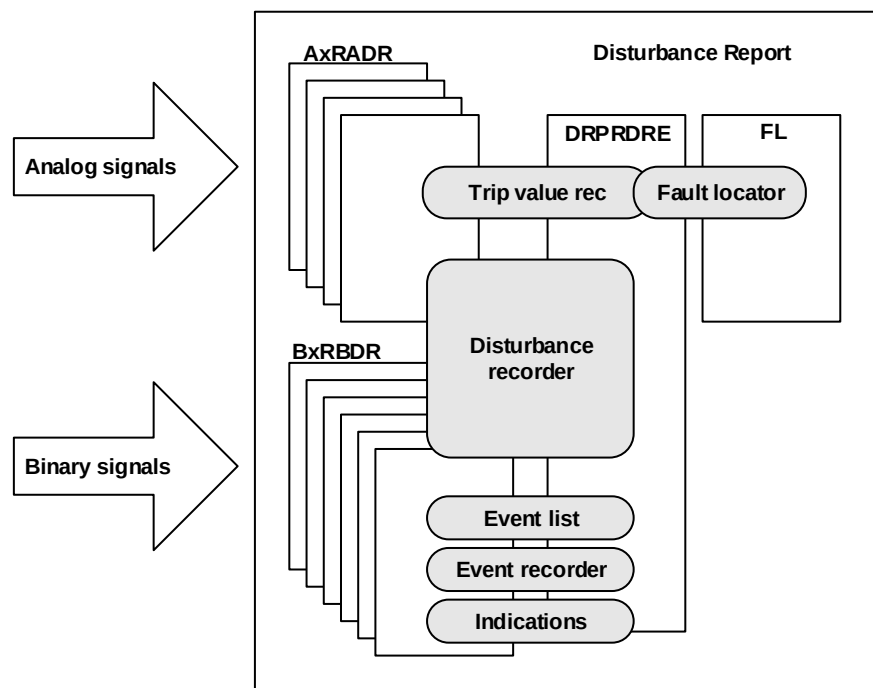
Setting guidelines

The setting parameters for the Disturbance report function DRPRDRE are set via the local HMI or PCM600.

It is possible to handle up to 40 analog and 352 binary signals, either internal signals or signals coming from external inputs. The binary signals are identical in all functions that is, Disturbance recorder (DR), Event recorder (ER), Indication (IND), Trip value recorder (TVR) and Event list (EL) function.

User-defined names of binary and analog input signals is set using PCM600. The analog and binary signals appear with their user-defined names. The name is used in all related functions (Disturbance recorder (DR), Event recorder (ER), Indication (IND), Trip value recorder (TVR) and Event list (EL)).

Figure 100 shows the relations between Disturbance report, included functions and function blocks. Event list (EL), Event recorder (ER) and Indication (IND) uses information from the binary input function blocks (BxRBDR). Trip value recorder (TVR) uses analog information from the analog input function blocks (AxRADR), which is used by Fault locator (FL) after estimation by Trip Value Recorder (TVR). Disturbance report function acquires information from both AxRADR and BxRBDR.



IEC09000336-3-en.vsdX

Figure 100: Disturbance report functions and related function blocks

For Disturbance report function there are a number of settings which also influences the sub-functions.

Three LED indications placed above the LCD screen makes it possible to get quick status information about the IED.

Green LED:	
Steady light	In Service
Flashing light	Internal failure
Dark	No power supply
Yellow LED:	
Steady light	Triggered on binary signal N with SetLEDx = Start (or Start and Trip)
Flashing light	The IED is in test mode
Red LED:	
Steady light	Triggered on binary signal N with SetLEDx = Trip (or Start and Trip)
Flashing	The IED is in configuration mode

Operation

The operation of Disturbance report function DRPRDRE has to be set *On* or *Off*. If *Off* is selected, note that no disturbance report is registered, and none sub-function will operate (the only general parameter that influences Event list (EL)).

Operation = Off:

- Disturbance reports are not stored.
- LED information (yellow - start, red - trip) is not stored or changed.

Operation = On:

- Disturbance reports are stored, disturbance data can be read from the local HMI and from a PC for example using PCM600.
- LED information (yellow - start, red - trip) is stored.

Every recording will get a number (0 to 999) which is used as identifier (local HMI, disturbance handling tool and IEC 61850). An alternative recording identification is date, time and sequence number. The sequence number is automatically increased by one for each new recording and is reset to zero at midnight. The maximum number of recordings stored in the IED is 100. The oldest recording will be overwritten when a new recording arrives (FIFO).



To be able to delete disturbance records, *Operation* parameter has to be *On*.



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



The IED flash disk should NOT be used to store any user files. This might cause disturbance recordings to be deleted due to lack of disk space.

13.6.3.1

Recording times

The different recording times for Disturbance report are set (the pre-fault time, post-fault time, and limit time). These recording times affect all sub-functions more or less but not the Event list (EL) function.

Prefault recording time (*PreFaultRecT*) is the recording time before the starting point of the disturbance. The setting should be at least 0.1 s to ensure enough samples for the estimation of pre-fault values in the Trip value recorder (TVR) function.

Postfault recording time (*PostFaultRecT*) is the maximum recording time after the disappearance of the trig-signal (does not influence the Trip value recorder (TVR) function).

Recording time limit (*TimeLimit*) is the maximum recording time after trig. The parameter limits the recording time if some triggering condition (fault-time) is very long or permanently set (does not influence the Trip value recorder (TVR) function).

Operation in test mode

If the IED is in test mode and *OpModeTest* = Off. Disturbance report function does not save any recordings and no LED information is displayed.

If the IED is in test mode and *OpModeTest* = On. Disturbance report function works in normal mode and the status is indicated in the saved recording.

Post Retrigger

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

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

When the retrig parameter is disabled (*PostRetrig* = Off), a new recording will not start until the post-fault (*PostFaultRecT* or *TimeLimit*) period is terminated. If a new trig occurs during the post-fault period and lasts longer than the proceeding recording a new complete recording will be started.

Disturbance report function can handle a maximum of 3 simultaneous disturbance recordings.

13.6.3.2

Binary input signals

Up to 352 binary signals can be selected among internal logical and binary input signals. The configuration tool is used to configure the signals.

For each of the 352 signals, it is also possible to select if the signal is to be used as a trigger for the start of the Disturbance report and if the trigger should be activated on positive (1) or negative (0) slope.

OperationN: Disturbance report may trig for binary input N (*On*) or not (*Off*).

TrigLevelN: Trig on positive (*Trig on 1*) or negative (*Trig on 0*) slope for binary input N.

Func103N: Function type number (0-255) for binary input N according to IEC-60870-5-103, that is, 128: Distance protection, 160: overcurrent protection, 176: transformer differential protection and 192: line differential protection.

Info103N: Information number (0-255) for binary input N according to IEC-60870-5-103, that is, 69-71: Trip L1-L3, 78-83: Zone 1-6.

See also description in the chapter IEC 60870-5-103.

13.6.3.3

Analog input signals

Up to 40 analog signals can be selected among internal analog and analog input signals. PCM600 is used to configure the signals.

The analog trigger of Disturbance report is not affected if analog input M is to be included in the disturbance recording or not (*OperationM* = *On/Off*).

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

If *OperationM* = *On*, waveform (samples) will also be recorded and reported in graph.

NomValueM: Nominal value for input M.

OverTrigOpM, *UnderTrigOpM*: Over or Under trig operation, Disturbance report may trig for high/low level of analog input M (*On*) or not (*Off*).

OverTrigLeM, *UnderTrigLeM*: Over or under trig level, Trig high/low level relative nominal value for analog input M in percent of nominal value.

13.6.3.4

Sub-function parameters

All functions are in operation as long as Disturbance report is in operation.

Indications

IndicationMaN: Indication mask for binary input N. If set (*Show*), a status change of that particular input, will be fetched and shown in the disturbance summary on local HMI. If not set (*Hide*), status change will not be indicated.

SetLEDN: Set red LED on local HMI in front of the IED if binary input N changes status.

Disturbance recorder

OperationM: Analog channel M is to be recorded by the disturbance recorder (*On*) or not (*Off*).

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

If *OperationM* = *On*, waveform (samples) will also be recorded and reported in graph.

Setting information

SetInfoInDrep: Parameter used to enable or disable the settings information in disturbance header.

Event recorder

Event recorder (ER) function has no dedicated parameters.

Trip value recorder

ZeroAngleRef: The parameter defines which analog signal that will be used as phase angle reference for all other analog input signals. This signal will also be used for frequency measurement and the measured frequency is used when calculating trip values. It is suggested to point out a sampled voltage input signal, for example, a line or busbar phase voltage (channel 1-30).

Event list

Event list (EL) (SOE) function has no dedicated parameters.

13.6.3.5**Consideration**

The density of recording equipment in power systems is increasing, since the number of modern IEDs, where recorders are included, is increasing. This leads to a vast number of recordings at every single disturbance and a lot of information has to be handled if the recording functions do not have proper settings. The goal is to optimize the settings in each IED to be able to capture just valuable disturbances and to maximize the number that is possible to save in the IED.

The recording time should not be longer than necessary (*PostFaultrecT* and *TimeLimit*).

- Should the function record faults only for the protected object or cover more?
- How long is the longest expected fault clearing time?
- Is it necessary to include reclosure in the recording or should a persistent fault generate a second recording (*PostRetrig*)?

Minimize the number of recordings:

- Binary signals: Use only relevant signals to start the recording that is, protection trip, carrier receive and/or start signals.
- Analog signals: The level triggering should be used with great care, since unfortunate settings will cause enormously number of recordings. If nevertheless analog input triggering is used, chose settings by a sufficient margin from normal operation values. Phase voltages are not recommended for triggering.



There is a risk of flash wear out if the disturbance report triggers too often.

Remember that values of parameters set elsewhere are linked to the information on a report. Such parameters are, for example, station and object identifiers, CT and VT ratios.

13.7 Logical signal status report BINSTATREP

13.7.1 Identification

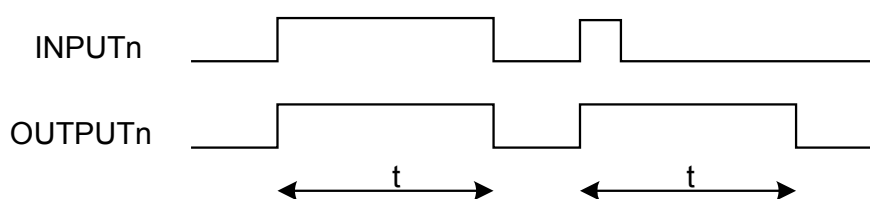
Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Logical signal status report	BINSTATREP	-	-

13.7.2 Application

The Logical signal status report (BINSTATREP) function makes it possible to poll signals from various other function blocks.

BINSTATREP has 16 inputs and 16 outputs. The output status follows the inputs and can be read from the local HMI or via SPA communication.

When an input is set, the respective output is set for a user defined time. If the input signal remains set for a longer period, the output will remain set until the input signal resets.



IEC09000732-1-en.vsd

Figure 101: BINSTATREP logical diagram

13.7.3 Setting guidelines

The pulse time t is the only setting for the Logical signal status report (BINSTATREP). Each output can be set or reset individually, but the pulse time will be the same for all outputs in the entire BINSTATREP function.

13.8 Limit counter L4UFCNT

13.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Limit counter	L4UFCNT		-

13.8.2 Application

Limit counter (L4UFCNT) is intended for applications where positive and/or negative flanks on a binary signal need to be counted.

The limit counter provides four independent limits to be checked against the accumulated counted value. The four limit reach indication outputs can be utilized to initiate proceeding actions. The output indicators remain high until the reset of the function.

It is also possible to initiate the counter from a non-zero value by resetting the function to the wanted initial value provided as a setting.

If applicable, the counter can be set to stop or rollover to zero and continue counting after reaching the maximum count value. The steady overflow output flag indicates the next count after reaching the maximum count value. It is also possible to set the counter to rollover and indicate the overflow as a pulse, which lasts up to the first count after rolling over to zero. In this case, periodic pulses will be generated at multiple overflow of the function.

13.8.3 Setting guidelines

The parameters for Limit counter L4UFCNT are set via the local HMI or PCM600.

13.9 Running hour-meter TEILGAPC

13.9.1 Identification

Function Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Running hour-meter	TEILGAPC	-	-

13.9.2 Application

The function is used for user-defined logics and it can also be used for different purposes internally in the IED. An application example is to accumulate the total running/energized time of the generator, transformer, reactor, capacitor bank or even line.

Settable time limits for warning and alarm are provided. The time limit for overflow indication is fixed to 99999.9 hours. At overflow the accumulated time resets and the accumulation starts from zero again.

13.9.3 Setting guidelines

The settings *tAlarm* and *tWarning* are user settable limits defined in hours. The achievable resolution of the settings is 0.1 hours (6 minutes).



tAlarm and *tWarning* are independent settings, that is, there is no check if $tAlarm > tWarning$.

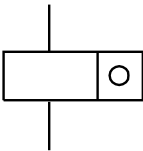
The limit for the overflow supervision is fixed at 99999.9 hours.

The setting *tAddToTime* is a user settable time parameter in hours.

Section 14 Metering

14.1 Pulse-counter logic PCFCNT

14.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Pulse-counter logic	PCFCNT		-

14.1.2 Application

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

The normal use for this function is the counting of energy pulses from external energy meters. An optional number of inputs from an arbitrary input module in IED can be used for this purpose with a frequency of up to 40 Hz. The pulse-counter logic PCFCNT can also be used as a general purpose counter.

14.1.3 Setting guidelines

Parameters that can be set individually for each pulse counter from PCM600:

- *Operation: Off/On*
- *tReporting: 0-3600s*
- *EventMask: NoEvents/ReportEvents*

Configuration of inputs and outputs of PCFCNT is made via PCM600.

On the Binary input module (BIM), the debounce filter default time is set to 5ms, that is, the counter suppresses pulses with a pulse length less than 5 ms. The input oscillation blocking frequency is preset to 40 Hz meaning that the counter detects the input to oscillate if the input frequency is greater than 40 Hz. Oscillation suppression is released at 30 Hz. Block/release values for oscillation can be changed on the local HMI and PCM600 under **Main menu/Configuration/I/O modules**.



The setting is common for all input channels on BIM, that is, if limit changes are made for inputs not connected to the pulse counter, the setting also influences the inputs on the same board used for pulse counting.

14.2 Function for energy calculation and demand handling ETPMMTR

14.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Function for energy calculation and demand handling	ETPMMTR	W_Varh	-

14.2.2 Application

Energy calculation and demand handling function (ETPMMTR) is intended for statistics of the forward and reverse active and reactive energy. It has a high accuracy basically given by the measurements function. This function has a site calibration possibility to further increase the total accuracy.

The function is connected to the instantaneous outputs of as shown in figure [102](#).

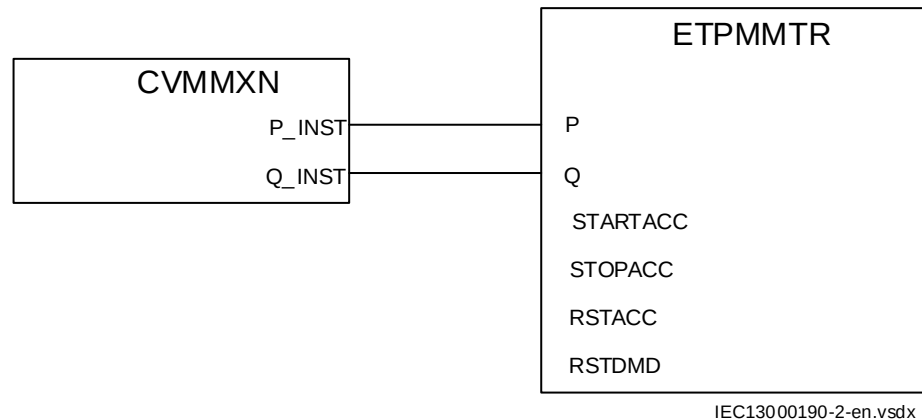


Figure 102: Connection of energy calculation and demand handling function ETPMMTR to the measurements function (CVMMXN)

The energy values can be read through communication in MWh and MVarh in monitoring tool of PCM600 and/or alternatively the values can be presented on the local HMI. The local HMI graphical display is configured with PCM600 Graphical Display Editor tool (GDE) with a measuring value which is selected to the active and reactive component as preferred. Also all Accumulated Active Forward, Active Reverse, Reactive Forward and Reactive Reverse energy values can be presented.

Maximum demand values are presented in MWh or MVarh in the same way.

Alternatively, the energy values can be presented with use of the pulse counters function (PCGGIO). The output energy values are scaled with the pulse output setting values *EAFAccPlsQty*, *EARAccPlsQty*, *ERFAccPlsQty* and *ERVAccPlsQty* of the energy metering function and then the pulse counter can be set-up to present the correct values by scaling in this function. Pulse counter values can then be presented on the local HMI in the same way and/or sent to the SA (Substation Automation) system through communication where the total energy then is calculated by summation of the energy pulses. This principle is good for very high values of energy as the saturation of numbers else will limit energy integration to about one year with 50 kV and 3000 A. After that the accumulation will start on zero again.

14.2.3

Setting guidelines

The parameters are set via the local HMI or PCM600.

The following settings can be done for the energy calculation and demand handling function ETPMMTR:

GlobalBaseSel: Selects the global base value group used by the function to define *IBase*, *UBase* and *SBase* as applicable.

Operation: Off/On

EnaAcc: Off/On is used to switch the accumulation of energy on and off.

tEnergy: Time interval when energy is measured.

tEnergyOnPls: gives the pulse length ON time of the pulse. It should be at least 100 ms when connected to the Pulse counter function block. Typical value can be 100 ms.

tEnergyOffPls: gives the OFF time between pulses. Typical value can be 100 ms.

EAFaccPlsQty and *EARaccPlsQty*: gives the MWh value in each pulse. It should be selected together with the setting of the Pulse counter (PCGGIO) settings to give the correct total pulse value.

ERFaccPlsQty and *ERVaccPlsQty* : gives the MVarh value in each pulse. It should be selected together with the setting of the Pulse counter (PCGGIO) settings to give the correct total pulse value.

For the advanced user there are a number of settings for direction, zero clamping, max limit, and so on. Normally, the default values are suitable for these parameters.

Section 15 Ethernet-based communication

15.1 Access point

15.1.1 Application

The access points are used to connect the IED to the communication buses (like the station bus) that use communication protocols. The access point can be used for single and redundant data communication. The access points are also used for communication with the merging units and for time synchronization using Precision Time Protocol (PTP).

15.1.2 Setting guidelines



The physical ports allocated to access points 2–4 have to be added in the hardware tool in PCM600 before the access points can be configured. The factory setting only includes the physical ports allocated to the front port and access point 1.

The settings for the access points are configured using the Ethernet configuration tool (ECT) in PCM600.

The access point is activated if the *Operation* checkbox is checked for the respective access point and a partial or common write to IED is performed.



To increase security, it is recommended to deactivate the access point when it is not in use.

Redundancy and *PTP* cannot be set for the front port (Access point 0) as redundant communication and PTP are only available for the rear optical Ethernet ports.

Subnetwork shows the SCL subnetwork to which the access point is connected. This column shows the SCL subnetworks available in the PCM600 project. SCL subnetworks can be created/deleted in the Subnetworks tab of IEC 61850 Configuration tool in PCM600.



When saving the ECT configuration after selecting a subnetwork, ECT creates the access point in the SCL model. Unselecting the subnetwork removes the access point from the SCL model. This column is editable for IEC61850 Ed2 IEDs and not editable for

IEC61850 Ed1 IEDs because in IEC61850 Ed1 only one access point can be modelled in SCL.

The IP address can be set in *IP address*. ECT validates the value, the access points have to be on separate subnetworks.

The subnetwork mask can be set in *Subnet mask*. This field will be updated to the SCL model based on the *Subnetwork* selection.

To select which communication protocols can be run on the respective access points, check or uncheck the check box for the relevant protocol. The protocols are not activated/deactivated in ECT, only filtered for the specific access point. For information on how to activate the individual communication protocols, see the communication protocol chapters.



To increase security it is recommended to uncheck protocols that are not used on the access point.

The default gateway can be selected by entering the IP address in *Default gateway*. The default gateway is the router that is used to communicate with the devices in the other subnetwork. By default this is set to *0.0.0.0* which means that no default gateway is selected. ECT validates the entered value, but the default gateway has to be in the same subnetwork as the access point. The default gateway is the router that is being used as default, that is when no route has been set up for the destination. If communication with a device in another subnetwork is needed, a route has to be set up. For more information on routes, see the *Routes* chapter in the *Technical manual* and the *Application manual*.

DHCP can be activated for the front port from the LHMI in **Main menu/Configuration/Communication/Ethernet configuration/Front port/DHCP:1**

15.2 Redundant communication

15.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
IEC 62439-3 Parallel redundancy protocol	PRP	-	-
IEC 62439-3 High-availability seamless redundancy	HSR	-	-
Access point diagnostic for redundant Ethernet ports	RCHLCCH	-	-

15.2.2

Application

Dynamic access point diagnostic (RCHLCCH) is used to supervise and assure redundant Ethernet communication over two channels. This will secure data transfer even though one communication channel might not be available for some reason

Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR) provides redundant communication over station bus running the available communication protocols. The redundant communication uses two Ethernet ports.

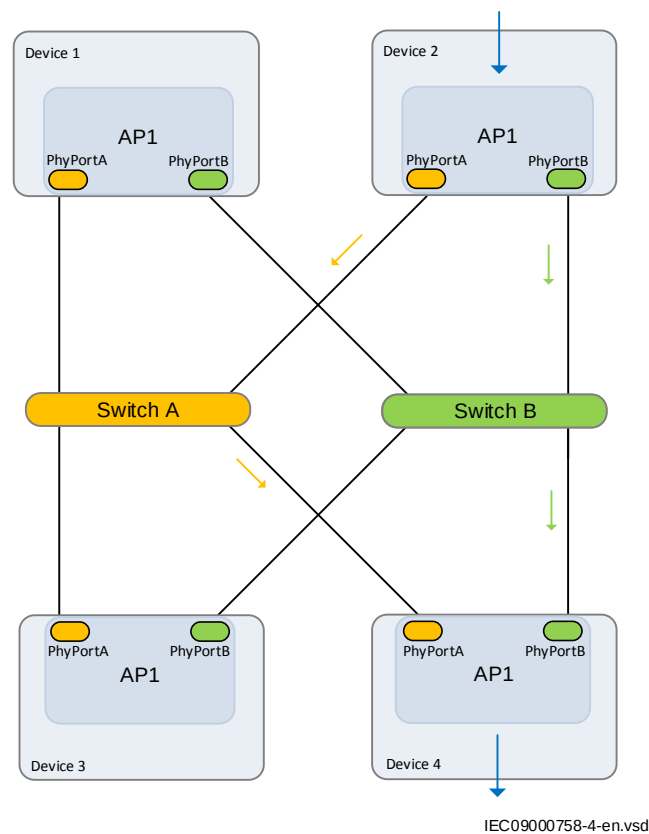


Figure 103: Parallel Redundancy Protocol (PRP)

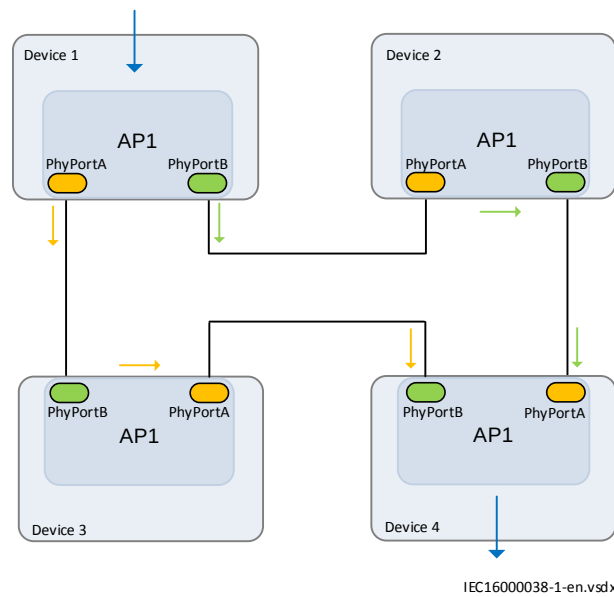


Figure 104: High-availability Seamless Redundancy (HSR)

15.2.3

Setting guidelines

Redundant communication is configured with the Ethernet configuration tool in PCM600.

Redundancy: redundant communication is activated when the parameter is set to *PRP-0*, *PRP-1* or *HSR*. The settings for the next access point will be hidden and PhyPortB will show the second port information. Redundant communication is activated after a common write to IED is done.

PRP-1 should be used primarily, *PRP-0* is intended only for use in existing PRP-networks. PRP-1 and HSR can be combined in a mixed network.

If the access point is not taken into operation, the write option in Ethernet Configuration Tool can be used to activate the access point.

Access points					
Merging units					
Routes					
Access point	Description	Operation	Redundancy	Physical port A	Physical port B
0	FrontPort	☒	None	ETH_Front	
1	Station bus	☒	PRP-1	SFP_301	SFP_302
3	Accesspoint 3	☒	HSR	SFP_303	SFP_304

IEC16000039-1-en.vsd

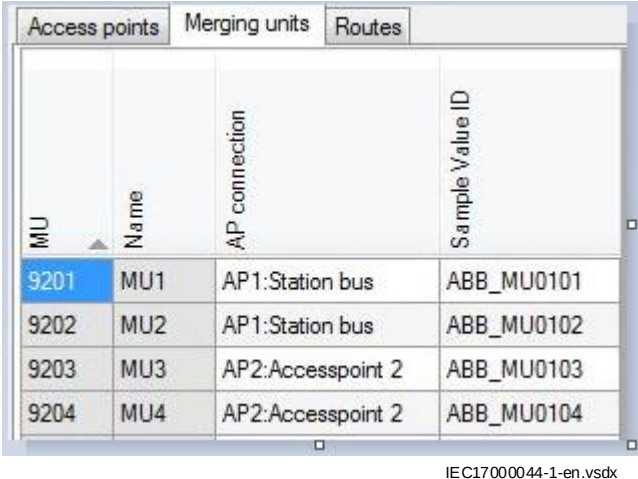
Figure 105: ECT screen with Redundancy set to PRP-1 on Access point 1 and HSR Access point 3

15.3 Merging unit

15.3.1 Application

The IEC/UCA 61850-9-2LE process bus communication protocol enables an IED to communicate with devices providing measured values in digital format, commonly known as Merging Units (MU). The rear access points are used for the communication.

The merging units (MU) are called so because they can gather analog values from one or more measuring transformers, sample the data and send the data over process bus to other clients (or subscribers) in the system. Some merging units are able to get data from classical measuring transformers, others from non-conventional measuring transducers and yet others can pick up data from both types.



Access points			
Merging units			
Routes			
MU	Name	AP connection	Sample Value ID
9201	MU1	AP1:Station bus	ABB_MU0101
9202	MU2	AP1:Station bus	ABB_MU0102
9203	MU3	AP2:Accesspoint 2	ABB_MU0103
9204	MU4	AP2:Accesspoint 2	ABB_MU0104

IEC17000044-1-en.vsdX

Figure 106: Merging unit

15.3.2 Setting guidelines

For information on the merging unit setting guidelines, see section [IEC/UCA 61850-9-2LE communication protocol](#).

15.4 Routes

15.4.1 Application

Setting up a route enables communication to a device that is located in another subnetwork. Routing is used when the destination device is not in the same subnetwork as the default gateway.

The route specifies that when a package is sent to the destination device it should be sent through the selected router. If no route is specified the source device will not find the destination device.

15.4.2 Setting guidelines

Routes are configured using the Ethernet configuration tool in PCM600.

Operation for the route can be set to *On/Off* by checking and unchecking the check-box in the operation column.

Gateway specifies the address of the gateway.

Destination specifies the destination.

Destination subnet mask specifies the subnetwork mask of the destination.

Section 16 Station communication

16.1 Communication protocols

Each IED is provided with several communication interfaces enabling it to connect to one or many substation level systems or equipment, either on the Substation Automation (SA) bus or Substation Monitoring (SM) bus.

Available communication protocols are:

- IEC 61850-8-1 communication protocol
- IEC/UCA 61850-9-2LE communication protocol
- LON communication protocol
- SPA communication protocol
- IEC 60870-5-103 communication protocol
- DNP 3.0 communication protocol

Several protocols can be combined in the same IED.

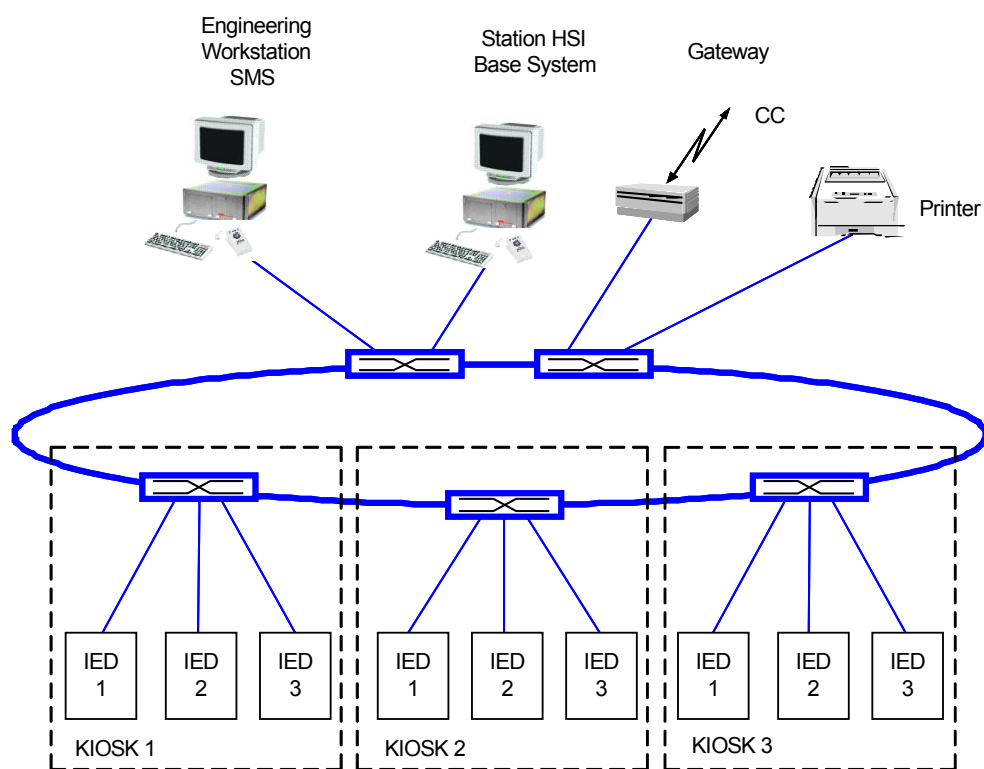
16.2 IEC 61850-8-1 communication protocol

16.2.1 Application IEC 61850-8-1

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

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

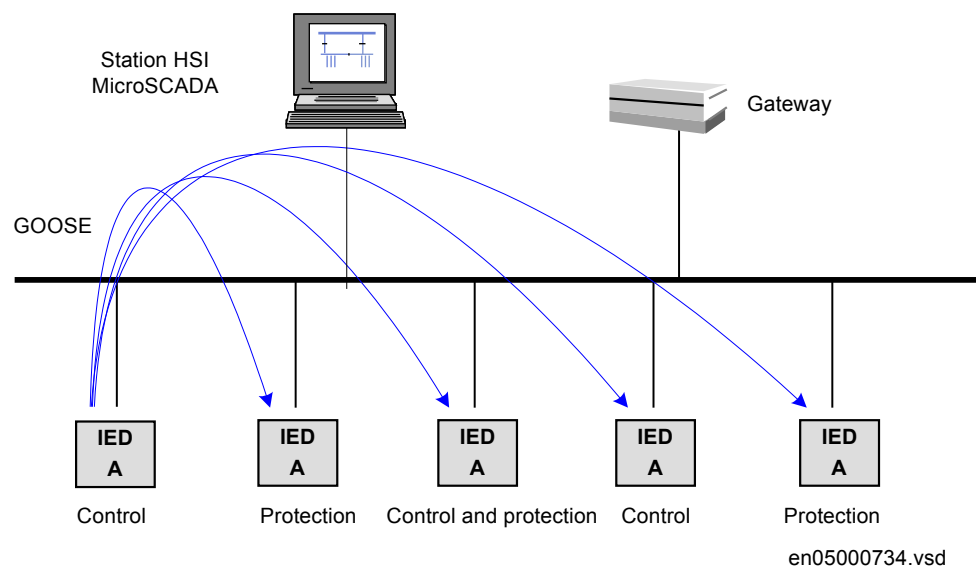
Figure [107](#) shows the topology of an IEC 61850-8-1 configuration. IEC 61850-8-1 specifies only the interface to the substation LAN. The LAN itself is left to the system integrator.



IEC09000135_en.v
sd

Figure 107: SA system with IEC 61850-8-1

Figure 108 shows the GOOSE peer-to-peer communication.



en05000734.vsd

Figure 108: Example of a broadcasted GOOSE message

16.2.2 Setting guidelines

There are two settings related to the IEC 61850–8–1 protocol:

Operation: User can set IEC 61850 communication to *On* or *Off*.

GOOSEPortEd1: Selection of the Ethernet link where GOOSE traffic shall be sent and received. This is only valid for Edition 1 and can be ignored if Edition 2 is used. For Edition 2, the Ethernet link selection is done with the Ethernet Configuration Tool (ECT) in PCM600.

16.2.3 Horizontal communication via GOOSE

16.2.3.1 Sending data

In addition to the data object and data attributes of the logical nodes, it is possible to send the outputs of the function blocks using the generic communication blocks. The outputs of this function can be set in a dataset and be sent in a GOOSE Control Block to other subscriber IEDs. There are different function blocks for different type of sending data.

Generic communication function for Single Point indication SPGAPC, SP16GAPC

Application

Generic communication function for Single Point Value (SPGAPC) function is used to send one single logical output to other systems or equipment in the substation. SP16GAPC can be used to send up to 16 single point values from the application functions running in the same cycle time. SPGAPC has one visible input and SPGAPC16 has 16 visible inputs that should be connected in the ACT tool.

Setting guidelines

There are no settings available for the user for SPGAPC.

Generic communication function for Measured Value MVGAPC

Application

Generic communication function for measured values (MVGAPC) function is used to send the instantaneous value of an analog signal to other systems or equipment in the substation. It can also be used inside the same IED, to attach a RANGE aspect to an analog value and to permit measurement supervision on that value.

Setting guidelines

The settings available for Generic communication function for Measured Value (MVGAPC) function allows the user to choose a deadband and a zero deadband for the monitored signal. Values within the zero deadband are considered as zero.

The high and low limit settings provides limits for the high-high-, high, normal, low and low-low ranges of the measured value. The actual range of the measured value is shown on the range output of MVGAPC function block. When a Measured value expander block (RANGE_XP) is connected to the range output, the logical outputs of the RANGE_XP are changed accordingly.

16.2.3.2

Receiving data

The GOOSE data must be received at function blocks. There are different GOOSE receiving function blocks depending on the type of the received data. Refer to the Engineering manual for more information about how to configure GOOSE.

Function block type	Data Type
GOOSEBINRCV	16 single point
GOOSEINTLKRCV	2 single points 16 double points
GOOSEDPRCV	Double point
GOOSEINTRCV	Integer
GOOSEMVRCV	Analog value
GOOSESRCV	Single point
GOOSEXLNRCV	Switch status

Application

The GOOSE receive function blocks are used to receive subscribed data from the GOOSE protocol. The validity of the data value is exposed as outputs of the function block as well as the validity of the communication. It is recommended to use these outputs to ensure that only valid data is handled on the subscriber IED. An example could be to control the external reservation before operating on a bay. In the figure below, the GOOSESRCV is used to receive the status of the bay reservation. The validity of the received data is used in additional logic to guarantee that the value has good quality before operation on that bay.

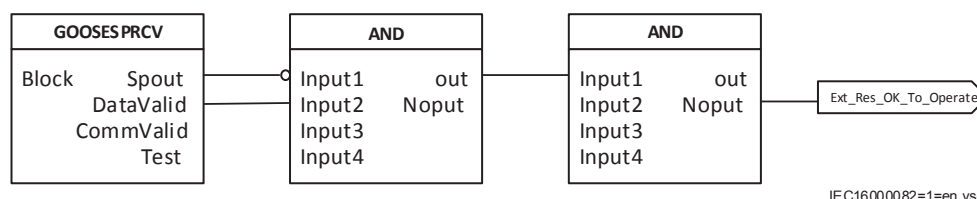


Figure 109: GOOSESRCV and AND function blocks - checking the validity of the received data

16.3 IEC/UCA 61850-9-2LE communication protocol

16.3.1 Introduction

Every IED can be provided with communication interfaces enabling it to connect to the process buses in order to get data from analog data acquisition units close to the process (primary apparatus), commonly known as Merging Units (MU). The protocol used in this case is the IEC/UCA 61850-9-2LE communication protocol.

The IEC/UCA 61850-9-2LE standard does not specify the quality of the sampled values. Thus, the accuracy of the current and voltage inputs to the merging unit and the inaccuracy added by the merging unit must be coordinated with the requirement for the actual type of protection function.

Factors influencing the accuracy of the sampled values from the merging unit are, for example, anti aliasing filters, frequency range, step response, truncating, A/D conversion inaccuracy, time tagging accuracy etc.

In principle, the accuracy of the current and voltage transformers, together with the merging unit, will have the same quality as the direct input of currents and voltages.

The process bus physical layout can be arranged in several ways, described in Annex B of the standard, depending on what are the needs for sampled data in a substation.

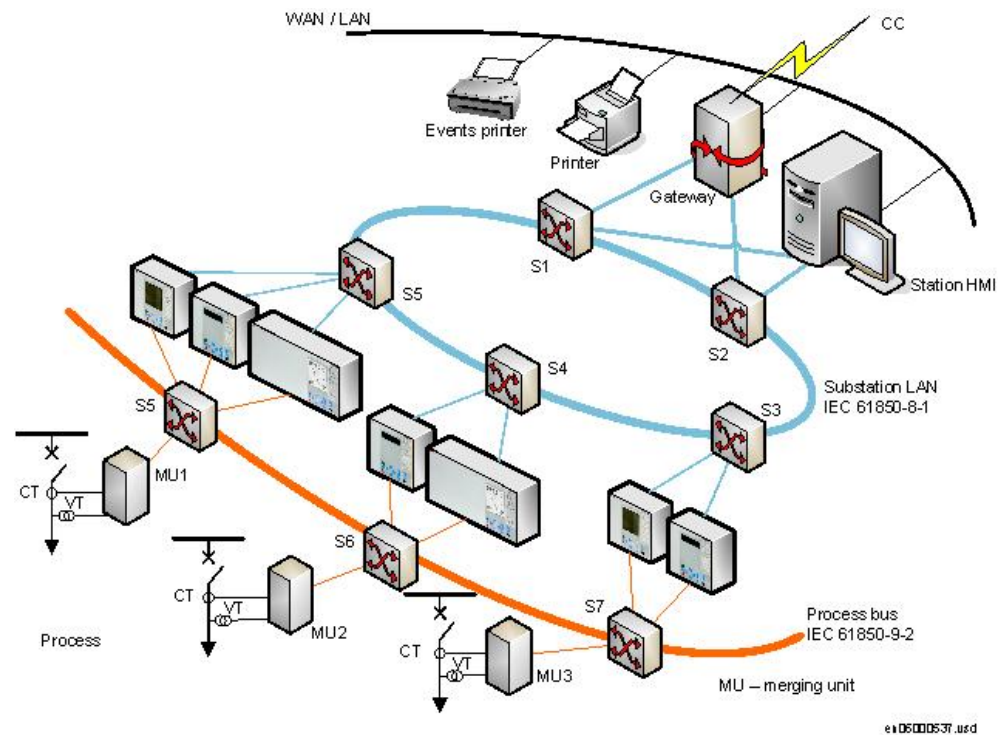


Figure 110: Example of a station configuration with separated process bus and station bus

The IED can get analog values simultaneously from a classical CT or VT and from a Merging Unit, like in this example:

The merging units (MU) are called so because they can gather analog values from one or more measuring transformers, sample the data and send the data over process bus to other clients (or subscribers) in the system. Some merging units are able to get data from classical measuring transformers, others from non-conventional measuring transducers and yet others can pick up data from both types. The electronic part of a non-conventional measuring transducer (like a Rogowski coil or a capacitive divider) can represent a MU by itself as long as it can send sampled data over process bus.

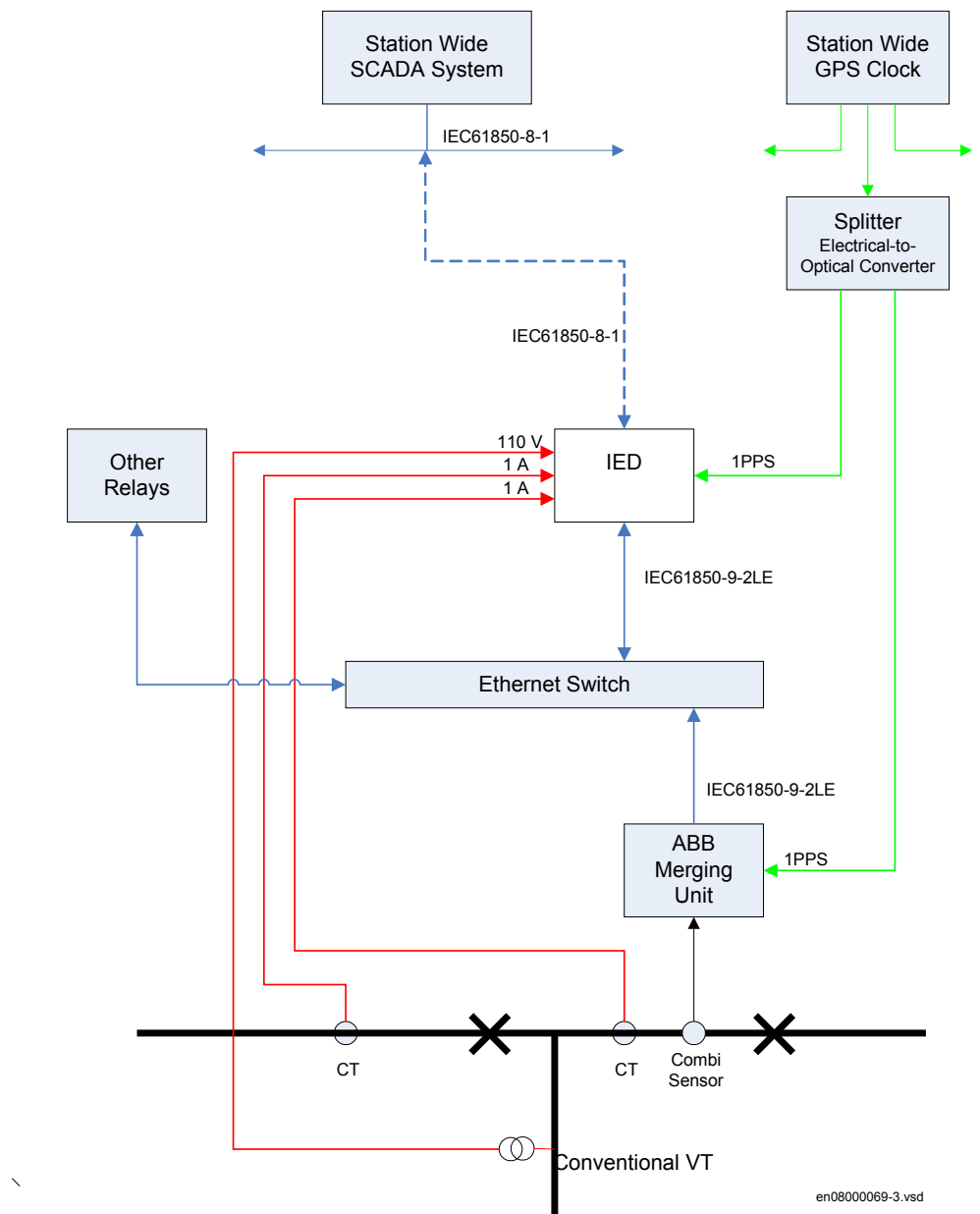


Figure 111: Example of a station configuration with the IED receiving analog values from both classical measuring transformers and merging units.

16.3.2

Setting guidelines

Merging Units (MUs) have several settings on local HMI under:

- **Main menu/Configuration/Analog modules/MUx:92xx.** The corresponding settings are also available in PST (PCM600).
- **Main menu/Configuration/Communication/Merging units configuration/MUx:92xx.** The corresponding settings are also available in ECT (PCM600).

Xx can take value 1–4.

16.3.2.1

Specific settings related to the IEC/UCA 61850-9-2LE communication

The process bus communication IEC/UCA 61850-9-2LE has specific settings, similar to the analog inputs modules.

If there are more than one sample group involved, time synch is mandatory. If there is no time synchronization, the protection functions will be blocked due to condition blocking.

CTStarPointx: These parameters specify the direction to or from object. See also section ["Setting of current channels"](#).

SyncLostMode: If this parameter is set to *Block* and the IED hardware time synchronization is lost or the synchronization to the MU time is lost, the protection functions in the list [37](#) will be blocked due to conditional blocking. If this parameter is set to *BlockOnLostUTC*, the protection functions in list [37](#) are blocked if the IED hardware time synchronization is lost or the synchronization of the MU time is lost or the IED has lost global common synchronization (i.e. GPS, IRIG-B or PTP). *SYNCH* output will be set if IED hardware time synchronization is lost. *MUSYNCH* output will be set if either of MU or IED hardware time synchronization is lost.

16.3.2.2

Loss of communication when used with LDCM

If IEC/UCA 61850-9-2LE communication is lost, see examples in figures [112](#), [113](#) and [114](#), the protection functions in table [37](#) are blocked as per graceful degradation.

Case 1:

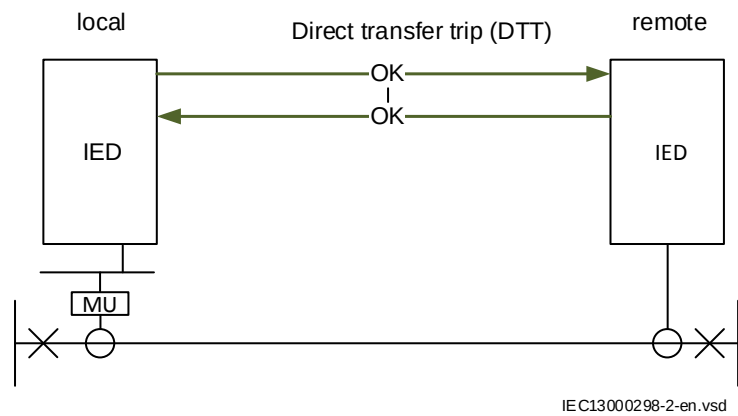


Figure 112: Normal operation

Case 2:

Failure of the MU (sample lost) blocks the sending of binary signals through LDCM. The received binary signals are not blocked and processed normally.

→DTT from the remote end is still processed.

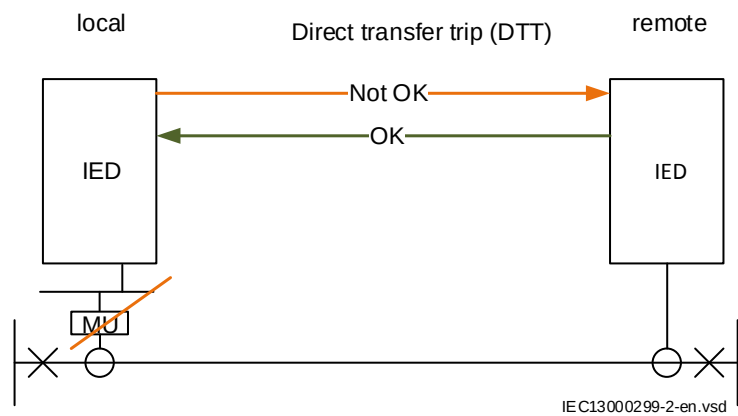


Figure 113: MU failed, mixed system

Case 3:

Failure of one MU (sample lost) blocks the sending and receiving of binary signals through LDCM.

→DTT from the remote end is not working.

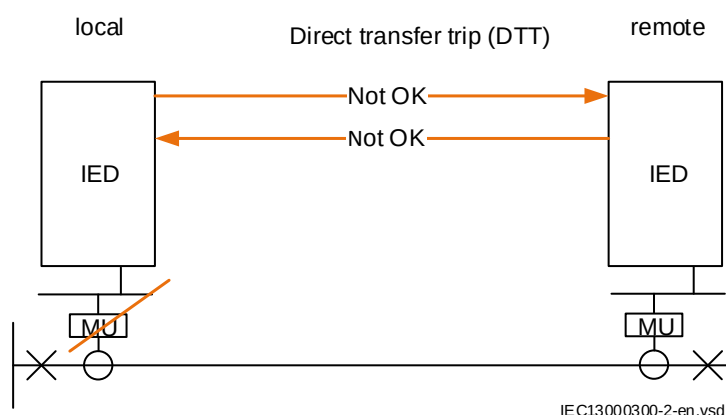


Figure 114: MU failed, 9-2 system

Table 37: Blocked protection functions if IEC/UCA 61850-9-2LE communication is interrupted and functions are connected to specific MUs

Function description	IEC 61850 identification	Function description	IEC 61850 identification
Accidental energizing protection for synchronous generator	AEGPVOC	Two step overvoltage protection	OV2PTOV
Broken conductor check	BRCPTOC	Four step single phase overcurrent protection	PH4SPTOC
Capacitor bank protection	CBPGAPC	Radial feeder protection	PAPGAPC
Pole discordance protection	CCPDSC	Instantaneous phase overcurrent protection	PHPIOC
Breaker failure protection	CCRBRF	PoleSlip/Out-of-step protection	PSPPPAM
Breaker failure protection, single phase version	CCSRBRF	Restricted earth fault protection, low impedance	REFPDIF
Current circuit supervision	CCSSPVC	Two step residual overvoltage protection	ROV2PTOV
Compensated over- and undervoltage protection	COUVGAPC	Rate-of-change frequency protection	SAPFRC
General current and voltage protection	CVGAPC	Overfrequency protection	SAPTOF
Current reversal and weakend infeed logic for residual overcurrent protection	ECRWPSCH	Underfrequency protection	SAPTUF
Four step residual overcurrent protection	EF4PTOC	Sudden change in current variation	SCCVPTOC
Instantaneous residual overcurrent protection	EFPIOC	Sensitive Directional residual over current and power protection	SDEPSDE
Table continues on next page			

Function description	IEC 61850 identification	Function description	IEC 61850 identification
Phase selection, quadrilateral characteristic with fixed angle	FDPSPDIS	Synchrocheck, energizing check, and synchronizing	SESRSYN
Faulty phase identification with load encroachment	FMPSPDIS	Circuit breaker condition monitoring	SSCBR
Phase selection, quadrilateral characteristic with settable angle	FRPSPDIS	Insulation gas monitoring	SSIMG
Frequency time accumulation protection	FTAQFVR	Insulation liquid monitoring	SSIML
Fuse failure supervision	FUFSPVC	Stub protection	STBPTOC
Generator differential protection	GENPDIF	Transformer differential protection, two winding	T2WPDIF
Directional Overpower protection	GOPPDOP	Transformer differential protection, three winding	T3WPDIF
Generator rotor overload protection	GRPTTR	Automatic voltage control for tapchanger, single control	TR1ATCC
Generator stator overload protection	GSPTTR	Automatic voltage control for tapchanger, parallel control	TR8ATCC
Directional Underpower protection	GUPPDUP	Thermal overload protection, two time constants	TRPTTR
1Ph High impedance differential protection	HZPDIF	Two step undervoltage protection	UV2PTUV
Line differential protection, 3 CT sets, 2-3 line ends	L3CPDIF	Voltage differential protection	VDCPTOV
Line differential protection, 6 CT sets, 3-5 line ends	L6CPDIF	Fuse failure supervision	VDRFUF
Low active power and power factor protection	LAPPGAPC	Voltage-restrained time overcurrent protection	VRPVOC
Negative sequence overcurrent protection	LCNSPTOC	Local acceleration logic	ZCLCPSCH
Negative sequence overvoltage protection	LCNSPTOV	Scheme communication logic for distance or overcurrent protection	ZCPSCH
Three phase overcurrent	LCP3PTOC	Current reversal and weak-end infeed logic for distance protection	ZCRWPSCH
Table continues on next page			

Function description	IEC 61850 identification	Function description	IEC 61850 identification
Three phase undercurrent	LCP3PTUC	Automatic switch onto fault logic, voltage and current based	ZCVPSOF
Thermal overload protection, one time constant	LCPTTR	Under impedance protection for generator	ZGVDPDIS
Zero sequence overcurrent protection	LCZSPTOC	Fast distance protection	ZMFCPDIS
Zero sequence overvoltage protection	LCZSPTOV	High speed distance protection	ZMFPDIS
Line differential coordination	LDLPSCH	Distance measuring zone, quadrilateral characteristic for series compensated lines	ZMCPDIS
Additional security logic for differential protection	LDRGFC	Distance measuring zone, quadrilateral characteristic for series compensated lines	ZMCPDIS
Loss of excitation	LEXPDIS	Fullscheme distance protection, mho characteristic	ZMHPDIS
Thermal overload protection, one time constant	LFPTTR	Fullscheme distance protection, quadrilateral for earth faults	ZMMAPDIS
Loss of voltage check	LOVPTUV	Fullscheme distance protection, quadrilateral for earth faults	ZMMPDIS
Line differential protection 3 CT sets, with inzone transformers, 2-3 line ends	LT3CPDIF	Distance protection zone, quadrilateral characteristic	ZMQAPDIS
Line differential protection 6 CT sets, with inzone transformers, 3-5 line ends	LT6CPDIF	Distance protection zone, quadrilateral characteristic	ZMQPDIS
Negativ sequence time overcurrent protection for machines	NS2PTOC	Distance protection zone, quadrilateral characteristic, separate settings	ZMRAPDIS
Four step directional negative phase sequence overcurrent protection	NS4PTOC	Distance protection zone, quadrilateral characteristic, separate settings	ZMRPDIS
Four step phase overcurrent protection	OC4PTOC	Power swing detection	ZMRPSB
Overexcitation protection	OEXPVPH	Mho Impedance supervision logic	ZSMGAPC
Out-of-step protection	OOSPPAM	Transformer tank overcurrent protection	TPPIOC

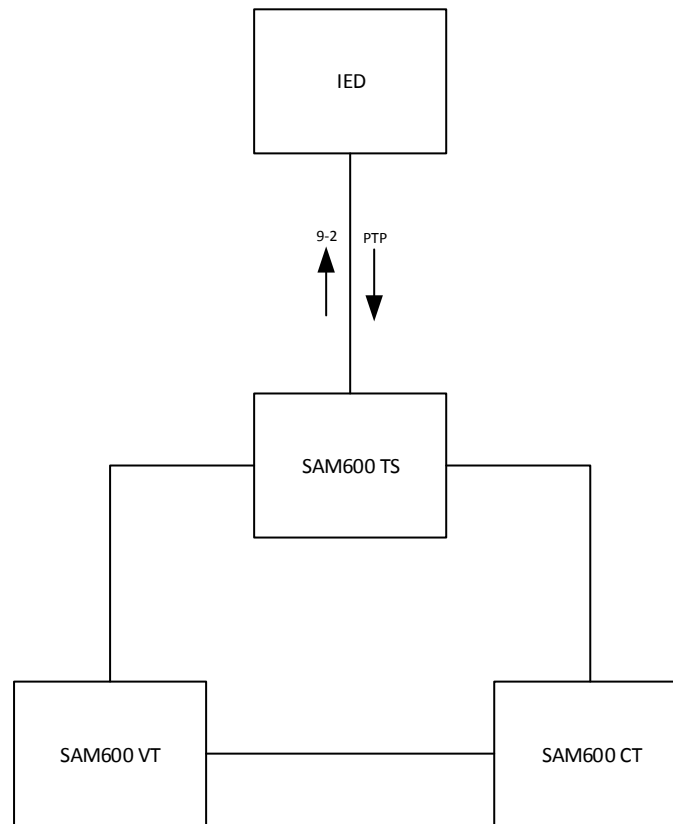
16.3.2.3**Setting examples for IEC/UCA 61850-9-2LE and time synchronization**

The IED and the Merging Units (MU) should use the same time reference especially if analog data is used from several sources, for example from an internal TRM and an MU, or if several physical MUs are used. Having the same time reference is important to correlate data so that channels from different sources refer to the correct phase angle.

When only one MU is used as an analog source, it is theoretically possible to do without time synchronization. However, this would mean that timestamps for analog and binary data/events become uncorrelated. If the IED has no time synchronization source configured, then the binary data/events will be synchronized with the merging unit. However, the global/complete time might not be correct. Disturbance recordings then appear incorrect since analog data is timestamped by MU, and binary events use the internal IED time. It is thus recommended to use time synchronization also when analog data emanate from only one MU.

An external time source can be used to synchronize both the IED and the MU. It is also possible to use the MU as a clock master to synchronize the IED from the MU. When using an external clock, it is possible to set the IED to be synchronized via PPS, IRIG-B or PTP. It is also possible to use an internal GPS receiver in the IED (if the external clock is using GPS).

Using PTP for synchronizing the MU



IEC17000040-1-en.vsdX

Figure 115: Setting example with PTP synchronization

Settings on the local HMI under **Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/IEC61850-9-2:**

- *HwSyncSrc*: is not used as the SW-time and HW-time are connected with each other due to PTP
- *SyncLostMode* : set to *Block* to block protection functions if time synchronization is lost or set to *BlockOnLostUTC* if the protection functions are to be blocked when global common synchronization is lost
- *SyncAccLevel*: can be set to $1\mu\text{s}$ since this corresponds to a maximum phase angle error of 0.018 degrees at 50Hz

Settings on the local HMI under **Main menu/Configuration/Communication/Ethernet configuration/Access point/AP_X:**

- Operation: On
- PTP: On

Two status monitoring signals can be:

- SYNCH signal on the MUX function block indicates that protection functions are blocked due to loss of internal time synchronization to the IED
- MUSYNCH signal on the MUX function block monitors the synchronization flag *smpSynch* in the datastream and IED hardware time synchronization.

Using MU for time synchronization via PPS



This example is not valid when GPS time is used for differential protection or when PTP is enabled.

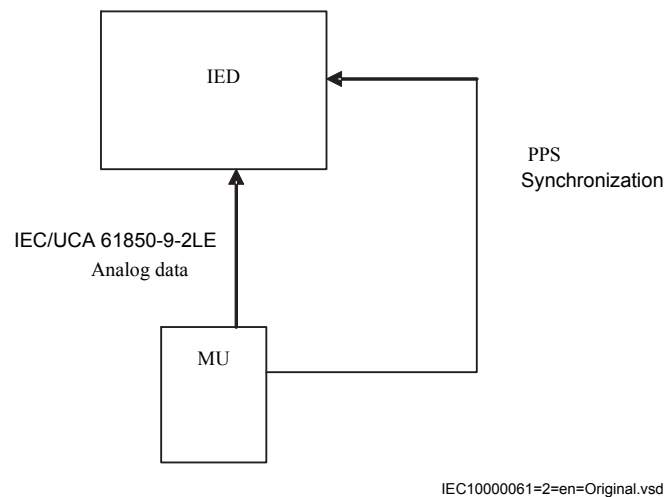


Figure 116: Setting example when MU is the synchronizing source

Settings on the local HMI under **Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/IEC61850-9-2:**

- *HwSyncSrc*: set to *PPS* as generated by the MU (ABB MU)
- *SyncLostMode*: set to *Block* to block protection functions if time synchronization is lost
- *SyncAccLevel*: can be set to $4\mu\text{s}$ since this corresponds to a maximum phase angle error of 0.072 degrees at 50Hz

Settings on the local HMI under **Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/General:**

- *fineSyncSource* can be set to something different to correlate events and data to other IEDs in the station.

Two status monitoring signals can be:

- SYNCH signal on the MUx function block indicates that protection functions are blocked due to loss of internal time synchronization to the IED.
- MUSYNCH signal on the MUx function block monitors the synchronization flag *smpSynch* in the datastream and IED hardware time synchronization.

SMPLLOST indicates that merging unit data are generated by internal substitution or one/more channel's Quality is not good or merging unit is in Testmode/detailed quality=Test, IED is not in test mode.

Using external clock for time synchronization



This example is not valid when GPS time is used for differential protection or when PTP is enabled.

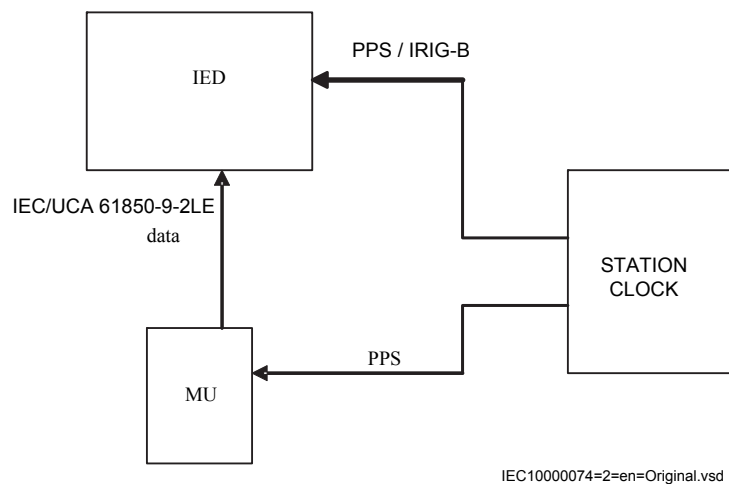


Figure 117: Setting example with external synchronization

Settings on the local HMI under **Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/IEC61850-9-2:**

- *HwSyncSrc*: set to *PPS/IRIG-B* depending on available outputs on the clock.
- *SyncLostMode*: set to *Block* to block protection functions if time synchronization is lost.
- *SyncAccLevel*: can be set to $4\mu\text{s}$ since this corresponds to a maximum phase angle error of 0.072 degrees at 50Hz.
- *fineSyncSource*: should be set to *IRIG-B* if available from the clock. If *PPS* is used for *HwSyncSrc*, “full-time” has to be acquired from another source. If station clock is on the local area network (LAN) and has an snntp-server, this is one option.

Two status monitoring signals can be:

- SYNCH signal on the MUX function block indicates that protection functions are blocked due to loss of internal time synchronization to the IED (that is loss of the hardware *synchSrc*).
- MUSYNCH signal on the MUX function block monitors the synchronization flag *smpSynch* in the datastream and IED hardware time synchronization.

No time synchronization



This example is not valid when GPS time is used for differential protection or when PTP is enabled.

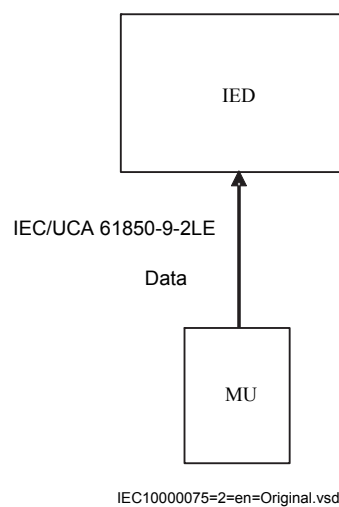


Figure 118: Setting example without time synchronization

It is also possible to use IEC/UCA 61850-9-2LE communication without time synchronization.

Settings on the local HMI under **Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/IEC61850-9-2:**

- *HwSyncSrc*: set to *Off*
- *SyncLostMode*: set to *No block* to indicate that protection functions are not blocked
- *SyncAccLevel*: set to *unspecified*

Two status monitoring signals with no time synchronization:

- SYNCH signal on the MUx function block indicates that protection functions are blocked due to loss of internal time synchronization to the IED. Since *SyncLostMode* is set to *No block*, this signal is not set.
- MUSYNCH signal on the MUx function block is set if the datastream indicates time synchronization loss. However, protection functions are not blocked.

To get higher availability in protection functions, it is possible to avoid blocking during time synchronization loss if there is a single source of analog data. This means that if there is only one physical MU and no TRM, parameter *SyncLostMode* is set to *No block* but parameter *HwSyncSrc* is still set to *PPS*. This maintains analog and binary data correlation in disturbance recordings without blocking protection functions if PPS is lost.

16.3.3

IEC 61850 quality expander QUALEXP

The quality expander component is used to display the detailed quality of an IEC/UCA 61850-9-2LE analog channel. The component expands the channel quality output of a Merging Unit analog channel received in the IED as per the IEC 61850-7-3 standard. This component can be used during the ACT monitoring to get the particular channel quality of the Merging Unit.

Figure 119 depicts the usage of the quality expander block in ACT.

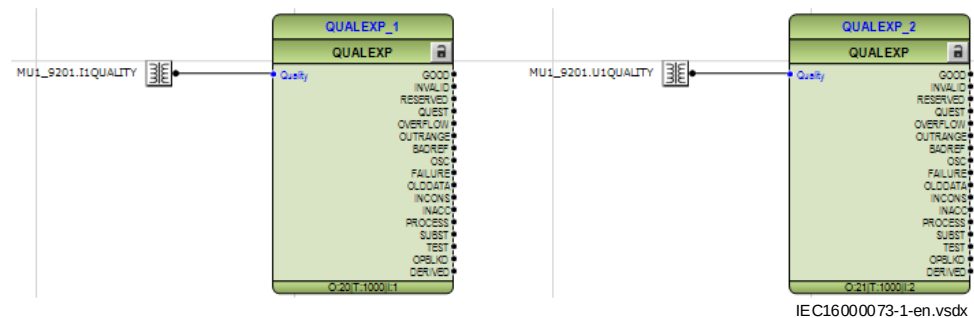


Figure 119: Quality expander block in ACT

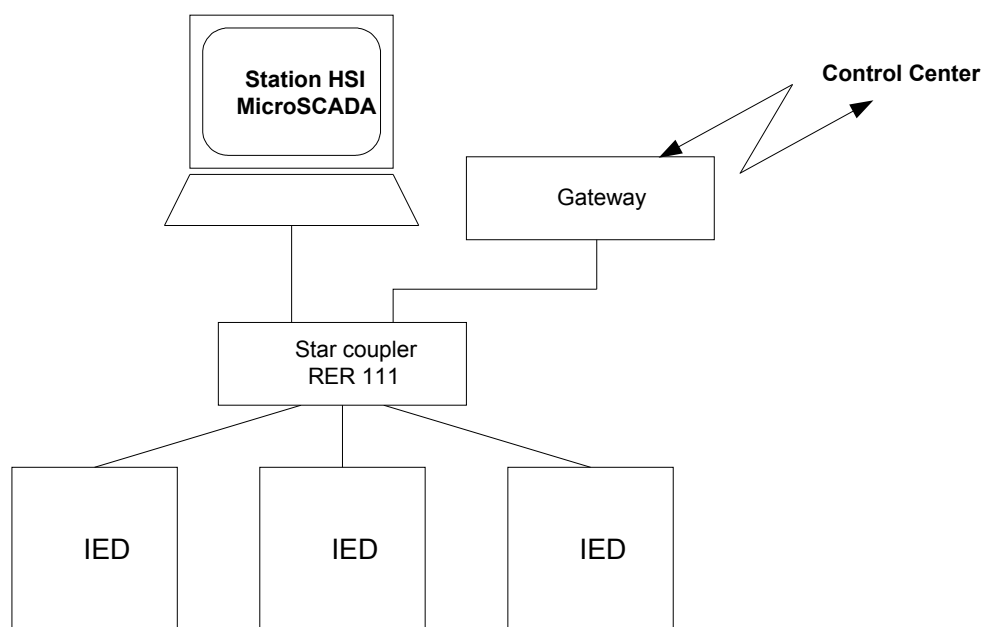
The expanded quality bits are visible on the outputs as per IEC 61850-7-3 standard. When written to IED, the configuration will show the expanded form of the respective MU channel quality information during the online monitoring in the ACT.



The quality expander function is intended for monitoring purposes, not for being used in a logic controlling the behaviour of the protection or control functions in the IED. The function outputs are updated once every second and, therefore, do not reflect the quality bits in real time.

16.4 LON communication protocol

16.4.1 Application



IEC05000663-1-en.vsd

Figure 120: Example of LON communication structure for a station automation system

An optical network can be used within the station automation system. This enables communication with the IEDs through the LON bus from the operator's workplace, from the control center and also from other IEDs via bay-to-bay horizontal communication. For LON communication an SLM card should be ordered for the IEDs.

The fibre optic LON bus is implemented using either glass core or plastic core fibre optic cables.

Table 38: *Specification of the fibre optic connectors*

	Glass fibre	Plastic fibre
Cable connector	ST-connector	snap-in connector
Cable diameter	62.5/125 m	1 mm
Max. cable length	1000 m	10 m
Wavelength	820-900 nm	660 nm
Transmitted power	-13 dBm (HFBR-1414)	-13 dBm (HFBR-1521)
Receiver sensitivity	-24 dBm (HFBR-2412)	-20 dBm (HFBR-2521)

The LON Protocol

The LON protocol is specified in the LonTalkProtocol Specification Version 3 from Echelon Corporation. This protocol is designed for communication in control networks and is a peer-to-peer protocol where all the devices connected to the network can communicate with each other directly. For more information of the bay-to-bay communication, refer to the section Multiple command function.

Hardware and software modules

The hardware needed for applying LON communication depends on the application, but one very central unit needed is the LON Star Coupler and optical fibres connecting the star coupler to the IEDs. To interface the IEDs from the MicroSCADA with Classic Monitor, application library LIB520 is required.

The HV Control 670 software module is included in the LIB520 high-voltage process package, which is a part of the Application Software Library in MicroSCADA applications.

The HV Control 670 software module is used for control functions in the IEDs. The module contains a process picture, dialogues and a tool to generate a process database for the control application in MicroSCADA.

When using MicroSCADA Monitor Pro instead of the Classic Monitor, SA LIB is used together with 670 series Object Type files.



The HV Control 670 software module and 670 series Object Type files are used with both 650 and 670 series IEDs.

Use the LON Network Tool (LNT) to set the LON communication. This is a software tool applied as one node on the LON bus. To communicate via LON, the IEDs need to know

- The node addresses of the other connected IEDs.
- The network variable selectors to be used.

This is organized by LNT.

The node address is transferred to LNT via the local HMI by setting the parameter *ServicePinMsg* = *Yes*. The node address is sent to LNT via the LON bus, or LNT can scan the network for new nodes.

The communication speed of the LON bus is set to the default of 1.25 Mbit/s. This can be changed by LNT.

16.4.2

MULTICMDRCV and MULTICMDSND

16.4.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Multiple command and receive	MULTICMDRCV	-	-
Multiple command and send	MULTICMDSND	-	-

16.4.2.2 Application

The IED provides two function blocks enabling several IEDs to send and receive signals via the interbay bus. The sending function block, MULTICMDSND, takes 16 binary inputs. LON enables these to be transmitted to the equivalent receiving function block, MULTICMDRCV, which has 16 binary outputs.

16.4.2.3 Setting guidelines

Settings

The parameters for the multiple command function are set via PCM600.

The *Mode* setting sets the outputs to either a *Steady* or *Pulsed* mode.

16.5 SPA communication protocol

16.5.1 Application

SPA communication protocol is an alternative to IEC 60870-5-103, and they use the same rear communication port.

When communicating with a PC connected to the utility substation LAN via WAN and the utility office LAN (see Figure [121](#)), and when using the rear optical Ethernet port, the only hardware required for a station monitoring system is:

- Optical fibres from the IED to the utility substation LAN
- PC connected to the utility office LAN

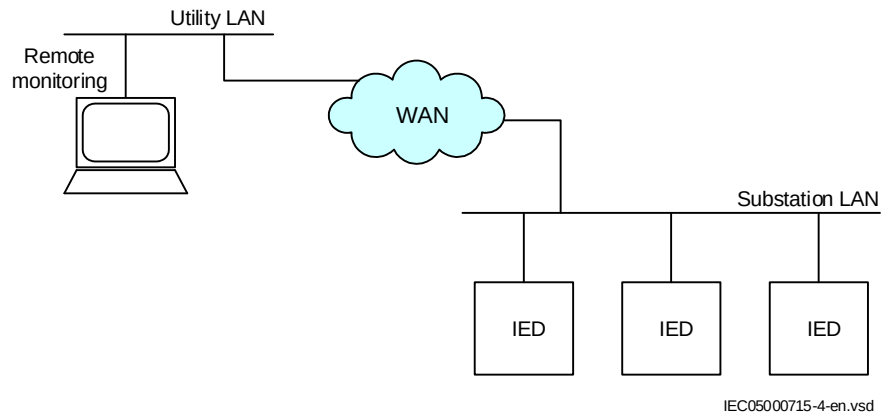


Figure 121: SPA communication structure for a remote monitoring system via a substation LAN, WAN and utility LAN

SPA communication is mainly used for the Station Monitoring System. It can include different IEDs with remote communication possibilities. Connection to a PC can be made directly (if the PC is located in the substation), via a telephone modem through a telephone network with ITU (former CCITT) characteristics or via a LAN/WAN connection.

glass	<1000 m according to optical budget
plastic	<25 m (inside cubicle) according to optical budget

Functionality

The SPA protocol V2.5 is an ASCII-based protocol for serial communication. The communication is based on a master-slave principle, where the IED is a slave and the PC is the master. Only one master can be applied on each fibre optic loop. A program is required in the master computer for interpretation of the SPA-bus codes and for translation of the data that should be sent to the IED.

For the specification of the SPA protocol V2.5, refer to SPA-bus Communication Protocol V2.5.

16.5.2

Setting guidelines

SPA, IEC 60870-5-103 and DNP3 use the same rear communication port. This port can be set for SPA use on the local HMI under **Main menu /Configuration / Communication /Station communication/Port configuration/SLM optical serial port/PROTOCOL:1**. When the communication protocol is selected, the IED is automatically restarted, and the port then operates as a SPA port.

The SPA communication setting parameters are set on the local HMI under **Main menu/Configuration/Communication/Station communication/SPA/SPA:1**.

The most important SPA communication setting parameters are *SlaveAddress* and *BaudRate*. They are essential for all communication contact to the IED. *SlaveAddress* and *BaudRate* can be set only on the local HMI for rear and front channel communication.

SlaveAddress can be set to any value between 1–899 as long as the slave number is unique within the used SPA loop. *BaudRate* (communication speed) can be set between 300–38400 baud. *BaudRate* should be the same for the whole station although different communication speeds in a loop are possible. If different communication speeds are used in the same fibre optical loop or RS485 network, take this into account when making the communication setup in the communication master (the PC).

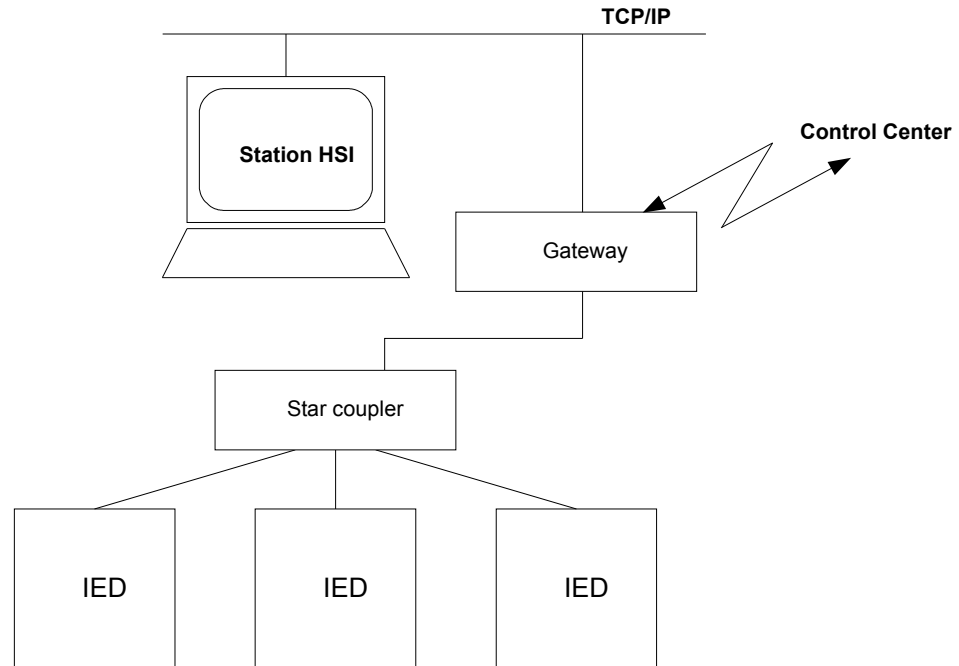
With local fibre optic communication, communication speed is usually set to 19200 or 38400 baud. With telephone communication, the speed setting depends on the quality of the connection and the type of modem used. Refer to technical data to determine the rated communication speed for the selected communication interfaces.



The IED does not adapt its speed to the actual communication conditions because the communication speed is set on the local HMI.

16.6 IEC 60870-5-103 communication protocol

16.6.1 Application



IEC05000660-4-en.vsd

Figure 122: Example of IEC 60870-5-103 communication structure for a substation automation system

IEC 60870-5-103 communication protocol is mainly used when a protection IED communicates with a third party control or monitoring system. This system must have software that can interpret the IEC 60870-5-103 communication messages.

When communicating locally in the station using a Personal Computer (PC) or a Remote Terminal Unit (RTU) connected to the Communication and processing module, the only hardware needed is optical fibres and an opto/electrical converter for the PC/RTU, or a RS-485 connection depending on the used IED communication interface.

16.6.1.1 Functionality

IEC 60870-5-103 is an unbalanced (master-slave) protocol for coded-bit serial communication exchanging information with a control system. In IEC terminology a primary station is a master and a secondary station is a slave. The communication is based on a point-to-point principle. The master must have software that can interpret the IEC 60870-5-103 communication messages. For detailed information about IEC 60870-5-103, refer to IEC 60870 standard part 5: Transmission

protocols, and to the section 103, Companion standard for the informative interface of protection equipment.

16.6.1.2

Design

General

The protocol implementation consists of the following functions:

- Event handling
- Report of analog service values (measurands)
- Fault location
- Command handling
 - Autorecloser ON/OFF
 - Teleprotection ON/OFF
 - Protection ON/OFF
 - LED reset
 - Characteristics 1 - 4 (Setting groups)
- File transfer (disturbance files)
- Time synchronization

Hardware

When communicating locally with a Personal Computer (PC) or a Remote Terminal Unit (RTU) in the station, using the SPA/IEC port, the only hardware needed is:

- Optical fibres, glass/plastic
- Opto/electrical converter for the PC/RTU

Commands

The commands defined in the IEC 60870-5-103 protocol are represented in dedicated function blocks. These blocks have output signals for all available commands according to the protocol. For more information, refer to the *Communication protocol manual, IEC 60870-5-103*.

- IED commands in control direction

Function block with defined IED functions in control direction, I103IEDCMD. This block use PARAMETR as FUNCTION TYPE, and INFORMATION NUMBER parameter is defined for each output signal.

- Function commands in control direction

Function block with pre-defined functions in control direction, I103CMD. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each output signal.

- Function commands in control direction

Function block with user defined functions in control direction, I103UserCMD. These function blocks include the FUNCTION TYPE parameter for each block in the private range, and the INFORMATION NUMBER parameter for each output signal.

Status



For more information on the function blocks below, refer to the *Communication protocol manual, IEC 60870-5-103*.

The events created in the IED available for the IEC 60870-5-103 protocol are based on the:

- IED status indication in monitor direction

Function block with defined IED functions in monitor direction, I103IED. This block use PARAMETER as FUNCTION TYPE, and INFORMATION NUMBER parameter is defined for each input signal.

- Function status indication in monitor direction, user-defined

Function blocks with user defined input signals in monitor direction, I103UserDef. These function blocks include the FUNCTION TYPE parameter for each block in the private range, and the INFORMATION NUMBER parameter for each input signal.

- Supervision indications in monitor direction

Function block with defined functions for supervision indications in monitor direction, I103Superv. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each output signal.

- Earth fault indications in monitor direction

Function block with defined functions for earth fault indications in monitor direction, I103EF. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each output signal.

- Fault indications in monitor direction

Function block with defined functions for fault indications in monitor direction, I103FLTPROT. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each input signal.

This block is suitable for distance protection, line differential, transformer differential, over-current and earth-fault protection functions.

- Autorecloser indications in monitor direction

Function block with defined functions for autorecloser indications in monitor direction, I103AR. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each output signal.

Measurands

The measurands can be included as type 3.1, 3.2, 3.3, 3.4 and type 9 according to the standard.

- Measurands in public range

Function block that reports all valid measuring types depending on connected signals, I103Meas.

- Measurands in private range

Function blocks with user defined input measurands in monitor direction, I103MeasUsr. These function blocks include the FUNCTION TYPE parameter for each block in the private range, and the INFORMATION NUMBER parameter for each block.

Fault location

The fault location is expressed in reactive ohms. In relation to the line length in reactive ohms, it gives the distance to the fault in percent. The data is available and reported when the fault locator function is included in the IED.

Disturbance recordings

- The transfer functionality is based on the Disturbance recorder function. The analog and binary signals recorded will be reported to the master by polling. The eight last disturbances that are recorded are available for transfer to the master. A file that has been transferred and acknowledged by the master cannot be transferred again.
- The binary signals that are included in the disturbance recorder are those that are connected to the disturbance function blocks B1RBDR to B22RBDR. These function blocks include the function type and the information number for each signal. For more information on the description of the Disturbance report in the Technical reference manual. The analog channels, that are reported, are those connected to the disturbance function blocks A1RADR to A4RADR. The eight first ones belong to the public range and the remaining ones to the private range.

16.6.2

Settings

16.6.2.1

Settings for RS485 and optical serial communication

General settings

SPA, DNP and IEC 60870-5-103 can be configured to operate on the SLM optical serial port while DNP and IEC 60870-5-103 additionally can utilize the RS485 port. A single protocol can be active on a given physical port at any time.

Two different areas in the HMI are used to configure the IEC 60870-5-103 protocol.

1. The port specific IEC 60870-5-103 protocol parameters are configured under:
Main menu/Configuration/Communication/Station Communication/IEC60870-5-103/
 - <config-selector>
 - SlaveAddress
 - BaudRate
 - RevPolarity (optical channel only)
 - CycMeasRepTime
 - MasterTimeDomain
 - TimeSyncMode
 - EvalTimeAccuracy
 - EventRepMode
 - CmdMode
 - RepIntermediatePos

<config-selector> is:

 - “OPTICAL103:1” for the optical serial channel on the SLM
 - “RS485103:1” for the RS485 port
2. The protocol to activate on a physical port is selected under:
Main menu/Configuration/Communication/Station Communication/Port configuration/
 - RS485 port
 - RS485PROT:1 (off, DNP, IEC103)
 - SLM optical serial port
 - PROTOCOL:1 (off, DNP, IEC103, SPA)

Operation		Off			
SlaveAddress		1		1	254
BaudRate		9600 Bd			
RevPolarity		On			
CycMeasRepTime		5,0	s	1,0	1800,0
MasterTimeDomain		UTC			
TimeSyncMode		IEDTime			
✓ EvalTimeAccuracy		5ms			
EventRepMode		SeqOfEvent			

Figure 123: Settings for IEC 60870-5-103 communication

The general settings for IEC 60870-5-103 communication are the following:

- *SlaveAddress* and *BaudRate*: Settings for slave number and communication speed (baud rate).
The slave number can be set to any value between 1 and 254. The communication speed, can be set either to 9600 bits/s or 19200 bits/s.
- *RevPolarity*: Setting for inverting the light (or not). Standard IEC 60870-5-103 setting is *On*.
- *CycMeasRepTime*: See I103MEAS function block for more information.
- *EventRepMode*: Defines the mode for how events are reported. The event buffer size is 1000 events.

Event reporting mode

If *EventRepMode* = *SeqOfEvent*, all GI and spontaneous events will be delivered in the order they were generated by BSW. The most recent value is the latest value delivered. All GI data from a single block will come from the same cycle.

If *EventRepMode* = *HiPriSpont*, spontaneous events will be delivered prior to GI event. To prevent old GI data from being delivered after a new spontaneous event, the pending GI event is modified to contain the same value as the spontaneous event. As a result, the GI dataset is not time-correlated.

16.6.2.2

Settings from PCM600

I103USEDEF

For each input of the I103USEDEF function there is a setting for the information number of the connected signal. The information number can be set to any value between 0 and 255. To get proper operation of the sequence of events the event masks in the event function is to be set to ON_CHANGE. For single-command signals, the event mask is to be set to ON_SET.

In addition there is a setting on each event block for function type. Refer to description of the Main Function type set on the local HMI.

Commands

As for the commands defined in the protocol there is a dedicated function block with eight output signals. Use PCM600 to configure these signals. To realize the BlockOfInformation command, which is operated from the local HMI, the output BLKINFO on the IEC command function block ICOM has to be connected to an input on an event function block. This input must have the information number 20 (monitor direction blocked) according to the standard.

Disturbance Recordings

For each input of the Disturbance recorder function there is a setting for the information number of the connected signal. The function type and the information number can be set to any value between 0 and 255. To get INF and FUN for the recorded binary signals, there are parameters on the disturbance recorder for each input. The user must set these parameters to whatever he connects to the corresponding input.

Refer to description of Main Function type set on the local HMI.

Recorded analog channels are sent with ASDU26 and ASDU31. One information element in these ASDUs is called ACC, and it indicates the actual channel to be processed. The channels on disturbance recorder are sent with an ACC as shown in Table 39.

Table 39: Channels on disturbance recorder sent with a given ACC

DRA#-Input	ACC	IEC 60870-5-103 meaning
1	1	IL1
2	2	IL2
3	3	IL3
4	4	IN
5	5	UL1
6	6	UL2
7	7	UL3
8	8	UN
9	64	Private range
10	65	Private range
11	66	Private range
12	67	Private range
13	68	Private range
14	69	Private range
15	70	Private range
16	71	Private range
17	72	Private range
18	73	Private range
19	74	Private range
20	75	Private range
Table continues on next page		

DRA#-Input	ACC	IEC 60870-5-103 meaning
21	76	Private range
22	77	Private range
23	78	Private range
24	79	Private range
25	80	Private range
26	81	Private range
27	82	Private range
28	83	Private range
29	84	Private range
30	85	Private range
31	86	Private range
32	87	Private range
33	88	Private range
34	89	Private range
35	90	Private range
36	91	Private range
37	92	Private range
38	93	Private range
39	94	Private range
40	95	Private range

16.6.3 Function and information types

Product type IEC103mainFunType value Comment:

REL 128 Compatible range

REC 242 Private range, use default

RED 192 Compatible range

RET 176 Compatible range

REB 207 Private range

REQ 245 Private range

Refer to the tables in the Technical reference manual /Station communication, specifying the information types supported by the communication protocol IEC 60870-5-103.

To support the information, corresponding functions must be included in the protection IED.

There is no representation for the following parts:

-
- Generating events for test mode
 - Cause of transmission: Info no 11, Local operation

Glass or plastic fibre should be used. BFOC/2.5 is the recommended interface to use (BFOC/2.5 is the same as ST connectors). ST connectors are used with the optical power as specified in standard.

For more information, refer to IEC standard IEC 60870-5-103.

16.7 DNP3 Communication protocol

16.7.1 Application

For more information on the application and setting guidelines for the DNP3 communication protocol refer to the DNP3 Communication protocol manual.

Section 17 Security

17.1 Authority status ATHSTAT

17.1.1 Application

Authority status (ATHSTAT) function is an indication function block, which informs about two events related to the IED and the user authorization:

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

The two outputs of ATHSTAT function can be used in the configuration for different indication and alarming reasons, or can be sent to the station control for the same purpose.

17.2 Self supervision with internal event list INTERRSIG

17.2.1 Application

The protection and control IEDs have many functions included. The included self-supervision with internal event list function block provides good supervision of the IED. The fault signals make it easier to analyze and locate a fault.

Both hardware and software supervision is included and it is also possible to indicate possible faults through a hardware contact on the power supply module and/or through the communication.

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

Apart from the built-in supervision of the various modules, events are also generated when the status changes for the:

- built-in real time clock (in operation/out of order).
- external time synchronization (in operation/out of order).

Events are also generated:

- whenever any setting in the IED is changed.

The internal events are time tagged with a resolution of 1 ms and stored in a list. The list can store up to 40 events. The list is based on the FIFO principle, that is, when it is full, the oldest event is overwritten. The list contents cannot be modified, but the whole list can be cleared using the Reset menu in the LHMI.

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

The information can, in addition to be viewed on the built in HMI, also be retrieved with the aid of a PC with PCM600 installed and by using the Event Monitoring Tool. The PC can either be connected to the front port, or to the port at the back of the IED.

17.3 Change lock CHNGLCK

17.3.1 Application

Change lock function CHNGLCK is used to block further changes to the IED configuration once the commissioning is complete. The purpose is to make it impossible to perform inadvertent IED configuration and setting changes.

However, when activated, CHNGLCK will still allow the following actions that does not involve reconfiguring of the IED:

- Monitoring
- Reading events
- Resetting events
- Reading disturbance data
- Clear disturbances
- Reset LEDs
- Reset counters and other runtime component states
- Control operations
- Set system time
- Enter and exit from test mode
- Change of active setting group

The binary input controlling the function is defined in ACT or SMT. The CHNGLCK function is configured using ACT.

LOCK	Binary input signal that will activate/deactivate the function, defined in ACT or SMT.



When CHNGLCK has a logical one on its input, then all attempts to modify the IED configuration and setting will be denied and the message "Error: Changes blocked" will be displayed on the local HMI; in PCM600 the message will be "Operation denied by active ChangeLock". The CHNGLCK function should be configured so that it is controlled by a signal from a binary input card. This guarantees that by setting that signal to a logical zero, CHNGLCK is deactivated. If any logic is included in the signal path to the CHNGLCK input, that logic must be designed so that it cannot permanently issue a logical one to the CHNGLCK input. If such a situation would occur in spite of these precautions, then please contact the local ABB representative for remedial action.

17.4 Denial of service SCHLCCH/RCHLCCH

17.4.1 Application

The denial of service functionality is designed to limit the CPU load that can be produced by Ethernet network traffic on the IED. The communication facilities must not be allowed to compromise the primary functionality of the device. All inbound network traffic will be quota controlled so that too heavy network loads can be controlled. Heavy network load might for instance be the result of malfunctioning equipment connected to the network.

The functions Access point diagnostics function block measure the IED load from communication and, if necessary, limit it for not jeopardizing the IEDs control and protection functionality due to high CPU load. The function has the following denial of service related outputs:

- LINKSTS indicates the Ethernet link status for the rear ports (single communication)
- CHALISTS and CHBLISTS indicates the Ethernet link status for the rear ports channel A and B (redundant communication)
- LinkStatus indicates the Ethernet link status for the front port

17.4.2 Setting guidelines

The function does not have any parameters available in the local HMI or PCM600.

Section 18 Basic IED functions

18.1 IED identifiers TERMINALID

18.1.1 Application

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



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

18.2 Product information PRODINF

18.2.1 Application

Product information contains unchangeable data that uniquely identifies the IED.

Product information data is visible on the local HMI under **Main menu/Diagnostics/IED status/Product identifiers** and under **Main menu/Diagnostics/IED Status/Identifiers**:

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

This information is very helpful when interacting with ABB product support (for example during repair and maintenance).

18.2.2 Factory defined settings

The factory defined settings are very useful for identifying a specific version and very helpful in the case of maintenance, repair, interchanging IEDs between different Substation Automation Systems and upgrading. The factory made settings can not be changed by the customer. They can only be viewed. The settings are

found in the local HMI under **Main menu/Diagnostics/IED status/Product identifiers**

The following identifiers are available:

- IEDProdType
 - Describes the type of the IED. Example: *REL650*
- ProductDef
 - Describes the release number from the production. Example: *2.1.0*
- FirmwareVer
 - Describes the firmware version.
 - The firmware version can be checked from **Main menu/Diagnostics/IED status/Product identifiers**
 - Firmware version numbers run independently from the release production numbers. For every release number there can be one or more firmware versions depending on the small issues corrected in between releases.
- ProductVer
 - Describes the product version. Example: *2.1.0*

1	is the Major version of the manufactured product this means, new platform of the product
2	is the Minor version of the manufactured product this means, new functions or new hardware added to the product
3	is the Major revision of the manufactured product this means, functions or hardware is either changed or enhanced in the product

- IEDMainFunType
 - Main function type code according to IEC 60870-5-103. Example: 128 (meaning line protection).
- SerialNo
- OrderingNo
- ProductionDate

18.3 Measured value expander block RANGE_XP

18.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Measured value expander block	RANGE_XP	-	-

18.3.2 Application

The current and voltage measurements functions (CVMMXN, CMMXU, VMMXU and VNMMXU), current and voltage sequence measurement functions (CMSQI and VMSQI) and IEC 61850 generic communication I/O functions (MVGAPC) are provided with measurement supervision functionality. All measured values can be supervised with four settable limits, that is low-low limit, low limit, high limit and high-high limit. The measure value expander block (RANGE_XP) has been introduced to be able to translate the integer output signal from the measuring functions to 5 binary signals, that is below low-low limit, below low limit, normal, above high-high limit or above high limit. The output signals can be used as conditions in the configurable logic.

18.3.3 Setting guidelines

There are no settable parameters for the measured value expander block function.

18.4 Parameter setting groups

18.4.1 Application

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

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

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

A function block, SETGRPS, defines how many setting groups are used. Setting is done with parameter *MAXSETGR* and shall be set to the required value for each IED. Only the number of setting groups set will be available in the Parameter Setting tool for activation with the ActiveGroup function block.

18.4.2 Setting guidelines

The setting *ActiveSetGrp*, is used to select which parameter group to be active. The active group can also be selected with configured input to the function block SETGRPS.

The length of the pulse, sent out by the output signal SETCHGD when an active group has changed, is set with the parameter *t*.

The parameter *MAXSETGR* defines the maximum number of setting groups in use to switch between. Only the selected number of setting groups will be available in the Parameter Setting tool (PST) for activation with the ActiveGroup function block.

18.5 Rated system frequency PRIMVAL

18.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Primary system values	PRIMVAL	-	-

18.5.2 Application

The rated system frequency and phase rotation direction are set under **Main menu/ Configuration/ Power system/ Primary Values** in the local HMI and PCM600 parameter setting tree.

18.5.3 Setting guidelines

Set the system rated frequency. Refer to section ["Signal matrix for analog inputs SMAI"](#) for description on frequency tracking.

18.6 Summation block 3 phase 3PHSUM

18.6.1 Application

The analog summation block 3PHSUM function block is used in order to get the sum of two sets of 3 phase analog signals (of the same type) for those IED functions that might need it.

18.6.2 Setting guidelines

The summation block receives the three-phase signals from SMAI blocks. The summation block has several settings.

SummationType: Summation type (*Group 1 + Group 2*, *Group 1 - Group 2*, *Group 2 - Group 1* or $-(Group\ 1 + Group\ 2)$).

DFTReference: The reference DFT block (*InternalDFT Ref*, *DFTRefGrp1* or *External DFT ref*).

FreqMeasMinVal: The minimum value of the voltage for which the frequency is calculated, expressed as percent of *UBase* voltage setting (for each instance x).

GlobalBaseSel: Selects the global base value group used by the function to define (*IBase*), (*UBase*) and (*SBase*).

18.7 Global base values GBASVAL

18.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Global base values	GBASVAL	-	-

18.7.2 Application

Global base values function (GBASVAL) is used to provide global values, common for all applicable functions within the IED. One set of global values consists of values for current, voltage and apparent power and it is possible to have twelve different sets.

This is an advantage since all applicable functions in the IED use a single source of base values. This facilitates consistency throughout the IED and also facilitates a single point for updating values when necessary.

Each applicable function in the IED has a parameter, *GlobalBaseSel*, defining one out of the twelve sets of GBASVAL functions.

18.7.3 Setting guidelines

UBase: Phase-to-phase voltage value to be used as a base value for applicable functions throughout the IED.

IBase: Phase current value to be used as a base value for applicable functions throughout the IED.

SBase: Standard apparent power value to be used as a base value for applicable functions throughout the IED, typically $SBase = \sqrt{3} \cdot UBase \cdot IBase$.

18.8 Signal matrix for binary inputs SMBI

18.8.1 Application

The Signal matrix for binary inputs function SMBI is used within the Application Configuration tool in direct relation with the Signal Matrix tool. SMBI represents the way binary inputs are brought in for one IED configuration.

18.8.2 Setting guidelines

There are no setting parameters for the Signal matrix for binary inputs SMBI available to the user in Parameter Setting tool. However, the user shall give a name to SMBI instance and the SMBI inputs, directly in the Application Configuration tool. These names will define SMBI function in the Signal Matrix tool. The user defined name for the input or output signal will also appear on the respective output or input signal.

18.9 Signal matrix for binary outputs SMBO

18.9.1 Application

The Signal matrix for binary outputs function SMBO is used within the Application Configuration tool in direct relation with the Signal Matrix tool. SMBO represents the way binary outputs are sent from one IED configuration.

18.9.2 Setting guidelines

There are no setting parameters for the Signal matrix for binary outputs SMBO available to the user in Parameter Setting tool. However, the user must give a name to SMBO instance and SMBO outputs, directly in the Application Configuration tool. These names will define SMBO function in the Signal Matrix tool.

18.10 Signal matrix for analog inputs SMAI

18.10.1 Application

Signal matrix for analog inputs (SMAI), also known as the preprocessor function block, analyses the connected four analog signals (three phases and neutral) and calculates all relevant information from them like the phasor magnitude, phase angle, frequency, true RMS value, harmonics, sequence components and so on. This information is then used by the respective functions connected to this SMAI block in ACT (for example protection, measurement or monitoring functions).

18.10.2 Frequency values

The SMAI function includes a functionality based on the level of positive sequence voltage, *MinValFreqMeas*, to validate if the frequency measurement is valid or not. If the positive sequence voltage is lower than *MinValFreqMeas*, the function freezes the frequency output value for 500 ms and after that the frequency output is set to the nominal value. A signal is available for the SMAI function to prevent operation due to non-valid frequency values. *MinValFreqMeas* is set as % of $U_{Base}/\sqrt{3}$

If SMAI setting *ConnectionType* is *Ph-Ph*, at least two of the inputs GRPxL1, GRPxL2 and GRPxL3, where $1 \leq x \leq 12$, must be connected in order to calculate the positive sequence voltage. Note that phase to phase inputs shall always be connected as follows: L1-L2 to GRPxL1, L2-L3 to GRPxL2, L3-L1 to GRPxL3. If SMAI setting *ConnectionType* is *Ph-N*, all three inputs GRPxL1, GRPxL2 and GRPxL3 must be connected in order to calculate the positive sequence voltage.

If only one phase-phase voltage is available and SMAI setting *ConnectionType* is *Ph-Ph*, the user is advised to connect two (not three) of the inputs GRPxL1, GRPxL2 and GRPxL3 to the same voltage input as shown in figure 124 to make SMAI calculate a positive sequence voltage.

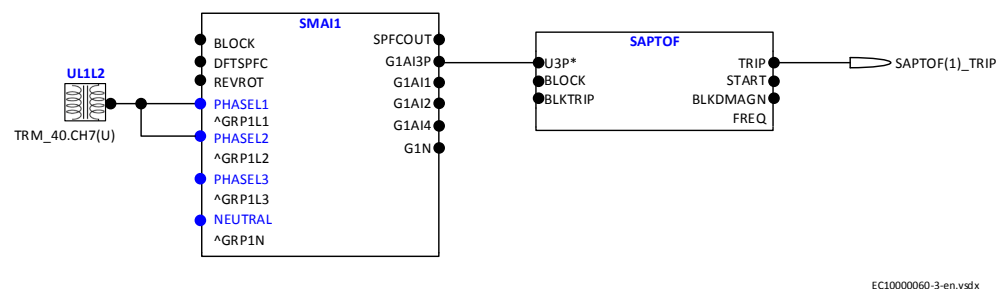


Figure 124: Connection example



The above described scenario does not work if SMAI setting *ConnectionType* is *Ph-N*. If only one phase-earth voltage is available, the same type of connection can be used but the SMAI *ConnectionType* setting must still be *Ph-Ph* and this has to be accounted for when setting *MinValFreqMeas*. If SMAI setting *ConnectionType* is *Ph-N* and the same voltage is connected to all three SMAI inputs, the positive sequence voltage will be zero and the frequency functions will not work properly.



The outputs from the above configured SMAI block shall only be used for Overfrequency protection (SAPTOF), Underfrequency protection (SAPTUF) and Rate-of-change frequency protection (SAPFRC) due to that all other information except frequency and positive sequence voltage might be wrongly calculated.

18.10.3

Setting guidelines

The parameters for the signal matrix for analog inputs (SMAI) functions are set via the local HMI or PCM600.

Every SMAI function block can receive four analog signals (three phases and one neutral value), either voltage or current. SMAI outputs give information about every aspect of the 3ph analog signals acquired (phase angle, RMS value, frequency and frequency derivatives, and so on – 244 values in total). Besides the block “group name”, the analog inputs type (voltage or current) and the analog input names that can be set directly in ACT.

Application functions should be connected to a SMAI block with same task cycle as the application function, except for e.g. measurement functions that run in slow cycle tasks.

DFTRefExtOut: Parameter valid only for function block SMAI1 .

Reference block for external output (SPFCOUT function output).

DFTReference: Reference DFT for the SMAI block use.

These DFT reference block settings decide DFT reference for DFT calculations. The setting *InternalDFTRef* will use fixed DFT reference based on set system frequency. *DFTRefGrp(n)* will use DFT reference from the selected group block, when own group is selected, an adaptive DFT reference will be used based on calculated signal frequency from own group. The setting *ExternalDFTRef* will use reference based on what is connected to input DFTSPFC.

The setting *ConnectionType*: Connection type for that specific instance (n) of the SMAI (if it is *Ph-N* or *Ph-Ph*). Depending on connection type setting the not connected *Ph-N* or *Ph-Ph* outputs will be calculated as long as they are possible to

calculate. E.g. at *Ph-Ph* connection L1, L2 and L3 will be calculated for use in symmetrical situations. If N component should be used respectively the phase component during faults I_N/U_N must be connected to input 4.

Negation: If the user wants to negate the 3ph signal, it is possible to choose to negate only the phase signals *Negate3Ph*, only the neutral signal *NegateN* or both *Negate3Ph+N*. negation means rotation with 180° of the vectors.

GlobalBaseSel: Selects the global base value group used by the function to define (*IBase*), (*UBase*) and (*SBase*).

MinValFreqMeas: The minimum value of the voltage for which the frequency is calculated, expressed as percent of *UBase* (for each instance n).



Settings *DFTRefExtOut* and *DFTReference* shall be set to default value *InternalDFTRef* if no VT inputs are available.



Even if the user sets the *AnalogInputType* of a SMAI block to “*Current*”, the *MinValFreqMeas* is still visible. However, using the current channel values as base for frequency measurement is **not recommendable** for a number of reasons, not last among them being the low level of currents that one can have in normal operating conditions.

Examples of adaptive frequency tracking



Preprocessing block shall only be used to feed functions within the same execution cycles (e.g. use preprocessing block with cycle 1 to feed transformer differential protection). The only exceptions are measurement functions (CVMMXN, CMMXU, VMMXU, etc.) which shall be fed by preprocessing blocks with cycle 8.



When two or more preprocessing blocks are used to feed one protection function (e.g. over-power function GOPPDOP), it is of outmost importance that parameter setting *DFTReference* has the same set value for all of the preprocessing blocks involved

Task time group 1	
SMAI instance	3 phase group
SMAI1:1	1
SMAI2:2	2
SMAI3:3	3
SMAI4:4	4
SMAI5:5	5
SMAI6:6	6
SMAI7:7	7
SMAI8:8	8
SMAI9:9	9
SMAI10:10	10
SMAI11:11	11
SMAI12:12	12

AdDFTRefCh7

Task time group 2	
SMAI instance	3 phase group
SMAI1:13	1
SMAI2:14	2
SMAI3:15	3
SMAI4:16	4
SMAI5:17	5
SMAI6:18	6
SMAI7:19	7
SMAI8:20	8
SMAI9:21	9
SMAI10:22	10
SMAI11:23	11
SMAI12:24	12

AdDFTRefCh4

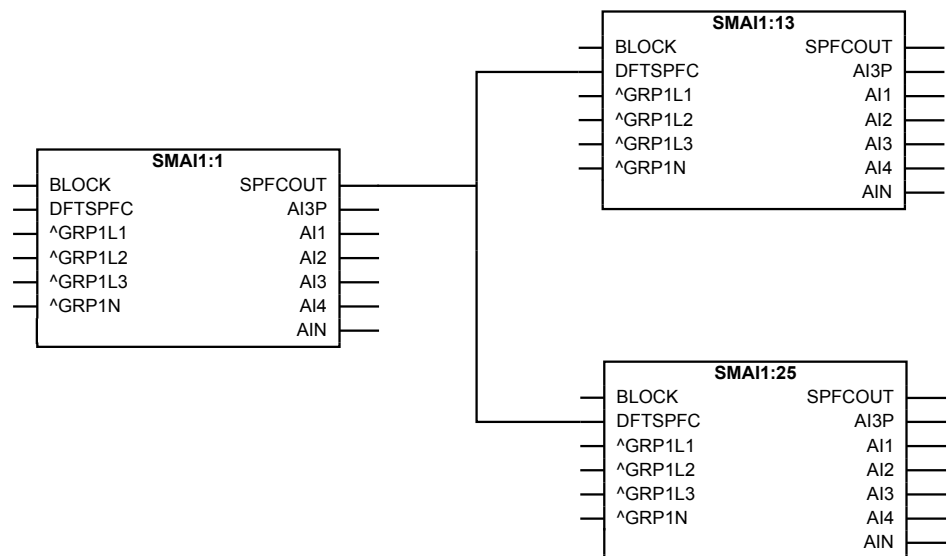
Task time group 3	
SMAI instance	3 phase group
SMAI1:25	1
SMAI2:26	2
SMAI3:27	3
SMAI4:28	4
SMAI5:29	5
SMAI6:30	6
SMAI7:31	7
SMAI8:32	8
SMAI9:33	9
SMAI10:34	10
SMAI11:35	11
SMAI12:36	12

IEC07000197.vsd

Figure 125: Twelve SMAI instances are grouped within one task time. SMAI blocks are available in three different task times in the IED. Two pointed instances are used in the following examples.

The examples shows a situation with adaptive frequency tracking with one reference selected for all instances. In practice each instance can be adapted to the needs of the actual application. The adaptive frequency tracking is needed in IEDs that belong to the protection system of synchronous machines and that are active during run-up and shut-down of the machine. In other application the usual setting of the parameter *DFTReference* of SMAI is *InternalDFTRef*.

Example 1



IEC07000198-2-en.vsd

Figure 126: Configuration for using an instance in task time group 1 as DFT reference

Assume instance SMAI7:7 in task time group 1 has been selected in the configuration to control the frequency tracking. Observe that the selected reference instance (i.e. frequency tracking master) must be a voltage type. Observe that positive sequence voltage is used for the frequency tracking feature.

For task time group 1 this gives the following settings (see Figure 125 for numbering):

SMAI1:1: $DFTRefExtOut = DFTRefGrp7$ to route SMAI7:7 reference to the SPFCOUT output, $DFTReference = DFTRefGrp7$ for SMAI1:1 to use SMAI7:7 as reference (see Figure 126) SMAI2:2 – SMAI12:12: $DFTReference = DFTRefGrp7$ for SMAI2:2 – SMAI12:12 to use SMAI7:7 as reference.

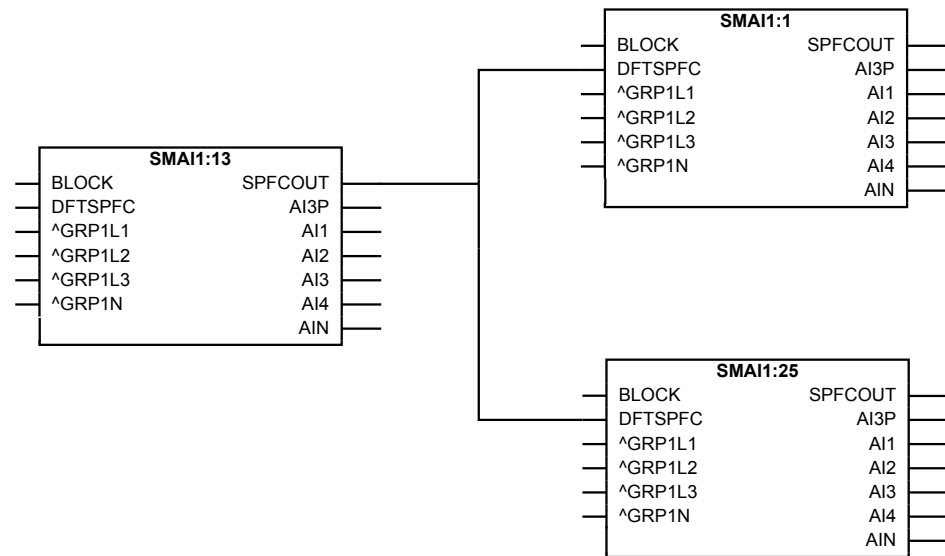
For task time group 2 this gives the following settings:

SMAI1:13 – SMAI12:24: $DFTReference = ExternalDFTRef$ to use DFTSPFC input of SMAI1:13 as reference (SMAI7:7)

For task time group 3 this gives the following settings:

SMAI1:25 – SMAI12:36: $DFTReference = ExternalDFTRef$ to use DFTSPFC input as reference (SMAI7:7)

Example 2



IEC07000199-2-en.vsd

Figure 127: Configuration for using an instance in task time group 2 as DFT reference.

Assume instance SMAI4:16 in task time group 2 has been selected in the configuration to control the frequency tracking for all instances. Observe that the selected reference instance (i.e. frequency tracking master) must be a voltage type. Observe that positive sequence voltage is used for the frequency tracking feature.

For task time group 1 this gives the following settings (see Figure 125 for numbering):

SMAI1:1 – SMAI12:12: *DFTReference* = *ExternalDFTRef* to use DFTSPFC input as reference (SMAI4:16)

For task time group 2 this gives the following settings:

SMAI1:13: *DFTRefExtOut* = *DFTRefGrp4* to route SMAI4:16 reference to the SPFCOUT output, *DFTReference* = *DFTRefGrp4* for SMAI1:13 to use SMAI4:16 as reference (see Figure 127) SMAI2:14 – SMAI12:24: *DFTReference* = *DFTRefGrp4* to use SMAI4:16 as reference.

For task time group 3 this gives the following settings:

SMAI1:25 – SMAI12:36: *DFTReference* = *ExternalDFTRef* to use DFTSPFC input as reference (SMAI4:16)

18.11 Test mode functionality TESTMODE

18.11.1 Application

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

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

18.11.1.1 IEC 61850 protocol test mode

The IEC 61850 Test Mode has improved testing capabilities for IEC 61850 systems. Operator commands sent to the IEC 61850 Mod determine the behavior of the functions. The command can be given from the LHMI under the **Main menu/Test/Function test modes** menu or remotely from an IEC 61850 client. The possible values of IEC 61850 Mod are described in *Communication protocol manual, IEC 61850 Edition 1* and *Edition 2*.



To be able to set the IEC 61850 Mod the parameter remotely, the PST setting *RemoteModControl* may not be set to *Off*. The possible values are *Off*, *Maintenance* or *All levels*. The *Off* value denies all access to data object Mod from remote, *Maintenance* requires that the category of the originator (orCat) is *Maintenance* and *All levels* allow any orCat.

The mod of the Root LD.LNN0 can be configured under **Main menu/Test/Function test modes/Communication/Station communication/IEC61850 LD0LLN0/LD0LLN0:1**

When the Mod is changed at this level, all components under the logical device update their own behavior according to IEC 61850-7-4. The supported values of IEC 61850 Mod are described in *Communication protocol manual, IEC 61850 Edition 2*. The IEC 61850 test mode is indicated with the Start LED on the LHMI.

The mod of an specific component can be configured under **Main menu/Test/Function test modes/Communication/Station Communication**

It is possible that the behavior is also influenced by other sources as well, independent of the mode, such as the insertion of the test handle, loss of SV, and IED configuration or LHMI. If a function of an IED is set to *Off*, the related *Beh* is set to *Off* as well. The related mod keeps its current state.

When the setting *Operation* is set to *Off*, the behavior is set to *Off* and it is not possible to override it. When a behavior of a function is *Off* the function will not execute.



When IEC 61850 Mod of a function is set to *Off* or *Blocked*, the Start LED on the LHMI will be set to flashing to indicate the abnormal operation of the IED.

The IEC 61850-7-4 gives a detailed overview over all aspects of the test mode and other states of mode and behavior.

- When the *Beh* of a component is set to *Test*, the component is not blocked and all control commands with a test bit are accepted.
- When the *Beh* of a component is set to *Test/blocked*, all control commands with a test bit are accepted. Outputs to the process via a non-IEC 61850 link data are blocked by the LN. Only process-related outputs on LNs related to primary equipment are blocked. If there is an XCBR, the outputs *EXC_Open* and *EXC_Close* are blocked.
- When the *Beh* of a component is set to *Blocked*, all control commands with a test bit are accepted. Outputs to the process via a non-IEC 61850 link data are blocked by the LN. In addition, the components can be blocked when their *Beh* is *blocked*. This can be done if the component has a block input. The block status of a component is shown as the *Blk* output under the **Test/Function status** menu. If the *Blk* output is not shown, the component cannot be blocked.

18.11.2

Setting guidelines

There are two possible ways to place the IED in the *TestMode= On* state. If, the IED is set to normal operation (*TestMode = Off*), but the functions are still shown being in the test mode, the input signal INPUT on the TESTMODE function block might be activated in the configuration.

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

18.12

Time synchronization TIMESYNCHGEN

18.12.1

Application

Use time synchronization to achieve a common time base for the IEDs in a protection and control system. This makes it possible to compare events and disturbance data between all IEDs in the system.

Time-tagging of internal events and disturbances are an excellent help when evaluating faults. Without time synchronization, only the events within one IED

can be compared with each other. With time synchronization, events and disturbances within the whole network, can be compared and evaluated.

In the IED, the internal time can be synchronized from the following sources:

- BIN (Binary Minute Pulse)
- DNP
- IEC103
- SNTP
- IRIG-B
- SPA
- LON
- PPS
- IEEE 1588 (PTP)

Out of these, LON and SPA contains two types of synchronization messages:

- Coarse time messages are sent every minute and contain complete date and time, that is year, month, day, hour, minute, second and millisecond.
- Fine time messages are sent every second and comprise only seconds and milliseconds.

The selection of the time source is done via the corresponding setting.

If PTP is activated, the device with the best accuracy within the synchronizing group will be selected as the source. For more information about PTP, see the Technical manual.

IEEE 1588 (PTP)

PTP according to IEEE 1588-2008 and specifically its profile IEC/IEEE 61850-9-3 for power utility automation is a synchronization method that can be used to maintain a common time within a station. This time can be synchronized to the global time using, for instance, a GPS receiver. If PTP is enabled on the IEDs and the switches that connect the station are compatible with IEEE 1588, the station will become synchronized to one common time with an accuracy of under 1µs. Using an IED as a boundary clock between several networks will keep 1µs accuracy on three levels or when using an HSR, 15 IEDs can be connected in a ring without losing a single microsecond in accuracy.

18.12.2

Setting guidelines

All the parameters related to time are divided into two categories: System time and Synchronization.

18.12.2.1

System time

The time is set with years, month, day, hour, minute, second and millisecond.

18.12.2.2

Synchronization

The setting parameters for the real-time clock with external time synchronization are set via local HMI or PCM600. The path for Time Synchronization parameters on local HMI is **Main menu/Configuration/Time/Synchronization**. The parameters are categorized as Time Synchronization (TIMESYNCHGEN) and IRIG-B settings (IRIG-B:1) in case that IRIG-B is used as the external time synchronization source.

TimeSynch

When the source of the time synchronization is selected on the local HMI, the parameter is called *TimeSynch*. The time synchronization source can also be set from PCM600. The setting alternatives are:

FineSyncSource which can have the following values:

- *Off*
- *SPA*
- *LON*
- *BIN* (Binary Minute Pulse)
- *SNTP*
- *IRIG-B*
- *PPS*

CoarseSyncSrc which can have the following values:

- *Off*
- *SPA*
- *LON*
- *DNP*
- *IEC 60870-5-103*

The function input to be used for minute-pulse synchronization is called BININPUT. For a description of the BININPUT settings, see the *Technical Manual*.

The system time can be set manually, either via the local HMI or via any of the communication ports. The time synchronization fine tunes the clock (seconds and milliseconds).

The parameter *SyncMaster* defines if the IED is a master, or not a master for time synchronization within a Substation Automation System, for IEDs connected in a communication network (IEC 61850-8-1). The *SyncMaster* can have the following values:

- *Off*
- *SNTP -Server*

IEEE 1588 (PTP)

Precision Time Protocol (PTP) is enabled/disabled using the Ethernet configuration tool /ECT) in PCM600.

PTP can be set to *On*, *Off* or *Slave only*. When set to *Slave only* the IED is connected to the PTP-group and will synchronize to the grandmaster but cannot function as the grandmaster.

A PTP-group is set up by connecting the IEDs to a network and enabling PTP. To set one IED as the grandmaster change Priority2 to 127 instead of the default 128.

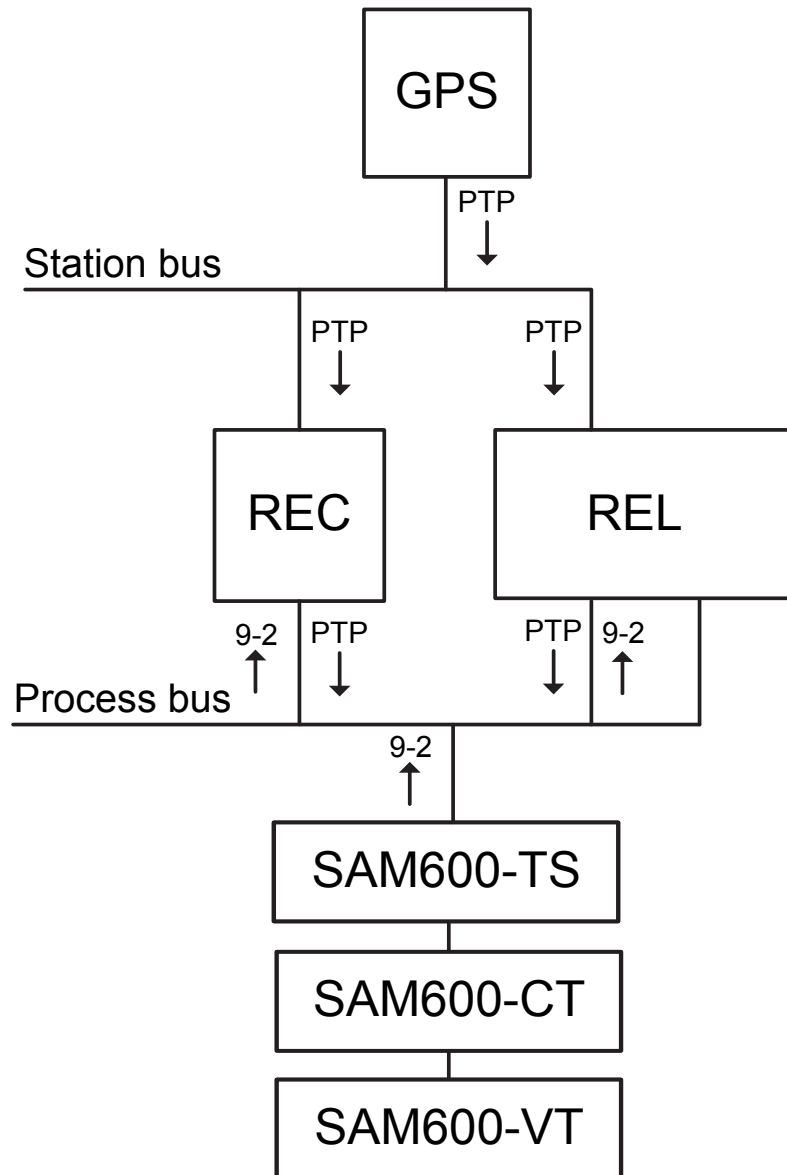
[illegible]

Figure 128: Enabling PTP in ECT

The *PTP VLAN* tag must have the same value in station clock and in the IED. The default value is set to 0.

The *PTP VLAN* tag does not need to be the same on all access points in one IED. It is possible to mix as long as they are the same for all devices on each subnet.

Setting example



IEC17000069=1=en.vsdX

Figure 129: Example system

Figure 129 describes an example system. The REC and REL are both using the 9-2 stream from the SAM600, and gets its synch from the GPS. Moreover, the REL and REC both acts as a boundary clock to provide synch to the SAM600.

On all access points, the *PTP* parameter is “ON”.

18.12.2.3**Process bus IEC/UCA 61850-9-2LE synchronization**

When process bus communication (IEC/UCA 61850-9-2LE protocol) is used, it is essential that the merging units are synchronized with the hardware time of the IED (see Technical manual, section *Design of the time system (clock synchronization)*). To achieve this, PTP, PPS or IRIG-B can be used depending of the facilities of the merging unit.

If the merging unit supports PTP, use PTP. If PTP is used in the IED and the merging unit cannot be synchronized from the IED, then use GPS-based clocks to provide PTP synch as well as sync to the merging unit.

If synchronization of the IED and the merging unit is based on GPS, set the parameter *LostSyncMode* to *BlockOnLostUTC* in order to provide a block of protection functions whenever the global common time is lost.

If PTP is not used, use the same synchronization method for the *HwSyncSrc* as the merging unit provides. For instance, if the merging unit provides PPS as synchronization, use PPS as *HwSyncSrc*. If LDCM in GPS-mode is used, that is, the hardware and software clocks are connected to each other, *HwSyncSrc* is not used and other means to synchronize the merging unit to the IED is required. For instance, *FineSyncSource* is set to the same source that the merging unit uses.

Section 19 Requirements

19.1 Current transformer requirements

The performance of a protection function will depend on the quality of the measured current signal. Saturation of the current transformers (CTs) will cause distortion of the current signals and can result in a failure to operate or cause unwanted operations of some functions. Consequently CT saturation can have an influence on both the dependability and the security of the protection. This protection IED has been designed to permit heavy CT saturation with maintained correct operation.

19.1.1 Current transformer basic classification and requirements

To guarantee correct operation, the current transformers (CTs) must be able to correctly reproduce the current for a minimum time before the CT will begin to saturate. To fulfill the requirement on a specified time to saturation the CTs must fulfill the requirements of a minimum secondary e.m.f. that is specified below.

CTs are specified according to many different classes and standards. In principle, there are three different types of protection CTs. These types are related to the design of the iron core and the presence of airgaps. Airgaps affects the properties of the remanent flux.

The following three different types of protection CTs have been specified:

- The High Remanence type with closed iron core and no specified limit of the remanent flux
- The Low Remanence type with small airgaps in the iron core and the remanent flux limit is specified to be maximum 10% of the saturation flux
- The Non Remanence type with big airgaps in the iron core and the remanent flux can be neglected

Even though no limit of the remanent flux is specified in the IEC standard for closed core CTs, it is a common opinion that the remanent flux is normally limited to maximum 75 - 80 % of the saturation flux.

Since approximately year 2000 some CT manufactures have introduced new core materials that gradually have increased the possible maximum levels of remanent flux even up to 95 % related to the hysteresis curve. Corresponding level of actual remanent flux is 90 % of the saturation flux (Ψ_{sat}). As the present CT standards have no limitation of the level of remanent flux, these CTs are also classified as for example, class TPX, P and PX according to IEC. The IEC TR 61869-100, Edition

1.0 2017-01, Instrument transformers – Guidance for application of current transformers in power system protection, is the first official document that highlighted this development. So far remanence factors of maximum 80% have been considered when CT requirements have been decided for ABB IEDs. Even in the future this level of remanent flux probably will be the maximum level that will be considered when decided the CT requirements. If higher remanence levels should be considered, it should often lead to unrealistic CT sizes.

Thus, now there is a need to limit the acceptable level of remanent flux. To be able to guarantee the performance of protection IEDs, we need to introduce the following classification of CTs.

There are many different standards and a lot of classes but fundamentally there are four different types of CTs:

- Very High Remanence type CT
- High Remanence type CT
- Low Remanence type CT
- Non Remanence type CT

The Very High Remanence (VHR) type is a CT with closed iron core (for example, protection classes TPX, P, PX according to IEC, class C, K according to ANSI/IEEE) and with an iron core material (new material, typically new alloy based magnetic materials) that gives a remanent flux higher than 80 % of the saturation flux.

The High Remanence (HR) type is a CT with closed iron core (for example, protection classes TPX, P, PX according to IEC, class C, K according to ANSI/IEEE) but with an iron core material (traditional material) that gives a remanent flux that is limited to maximum 80 % of the saturation flux.

The Low Remanence (LR) type is a CT with small airgaps in the iron core (for example, TPY, PR, PXR according to IEC) and the remanent flux limit is specified to be maximum 10% of the saturation flux.

The Non Remanence (NR) type is a CT with big airgaps in the core (for example, TPZ according to IEC) and the remanent flux can be neglected.

It is also possible that different CT classes of HR and LR type may be mixed.

CT type VHR (using new material) should not be used for protection CT cores. This means that it is important to specify that the remanence factor must not exceed 80 % when ordering for example, class P, PX or TPX CTs. If CT manufacturers are using new core material and are not able to fulfill this requirement, the CTs shall be specified with small airgaps and therefore will be CTs of LR type (for example, class PR, TPY or PXR). Very high remanence level in a protection core CT can cause the following problems for protection IEDs:

1. Unwanted operation of differential (i.e. unit) protections for external faults
2. Unacceptably delayed or even missing operation of all types of protections (for example, distance, differential, overcurrent, etc.) which can result in losing protection selectivity in the network

No information is available about how frequent the use of the new iron core material is for protection CT cores, but it is known that some CT manufacturers are using the new material while other manufacturers continue to use the old traditional core material for protection CT cores. In a case where VHR type CTs have been already installed, the calculated values of E_{al} for HR type CTs, for which the formulas are given in this document, must be multiplied by factor two-and-a-half in order for VHR type CTs (i.e. with new material) to be used together with ABB protection IEDs. However, this may result in unacceptably big CT cores, which can be difficult to manufacture and fit in available space.

Different standards and classes specify the saturation e.m.f. in different ways but it is possible to approximately compare values from different classes. The rated equivalent limiting secondary e.m.f. E_{al} according to the IEC 61869–2 standard is used to specify the CT requirements for the IED. The requirements are also specified according to other standards.

19.1.2

Conditions

The requirements are a result of investigations performed in our network simulator. The current transformer models are representative for current transformers of high remanence and low remanence type. The results may not always be valid for non remanence type CTs (TPZ).

The performances of the protection functions have been checked in the range from symmetrical to fully asymmetrical fault currents. Primary time constants of at least 120 ms have been considered at the tests. The current requirements below are thus applicable both for symmetrical and asymmetrical fault currents.

Depending on the protection function phase-to-earth, phase-to-phase and three-phase faults have been tested for different relevant fault positions for example, close in forward and reverse faults, zone 1 reach faults, internal and external faults. The dependability and security of the protection was verified by checking for example, time delays, unwanted operations, directionality, overreach and stability.

The remanence in the current transformer core can cause unwanted operations or minor additional time delays for some protection functions. As unwanted operations are not acceptable at all maximum remanence has been considered for fault cases critical for the security, for example, faults in reverse direction and external faults. Because of the almost negligible risk of additional time delays and the non-existent risk of failure to operate the remanence have not been considered for the dependability cases. The requirements below are therefore fully valid for all normal applications.

It is difficult to give general recommendations for additional margins for remanence to avoid the minor risk of an additional time delay. They depend on the performance and economy requirements. When current transformers of low remanence type (for example, TPY, PR) are used, normally no additional margin is needed. For current transformers of high remanence type (for example, P, PX, TPX) the small probability of fully asymmetrical faults, together with high remanence in the same direction as the flux generated by the fault, has to be kept in mind at the decision of an additional margin. Fully asymmetrical fault current will be achieved when the fault occurs at approximately zero voltage (0°).

Investigations have shown that 95% of the faults in the network will occur when the voltage is between 40° and 90° . In addition fully asymmetrical fault current will not exist in all phases at the same time.

19.1.3 Fault current

The current transformer requirements are based on the maximum fault current for faults in different positions. Maximum fault current will occur for three-phase faults or single phase-to-earth faults. The current for a single phase-to-earth fault will exceed the current for a three-phase fault when the zero sequence impedance in the total fault loop is less than the positive sequence impedance.

When calculating the current transformer requirements, maximum fault current for the relevant fault position should be used and therefore both fault types have to be considered.

19.1.4 Secondary wire resistance and additional load

The voltage at the current transformer secondary terminals directly affects the current transformer saturation. This voltage is developed in a loop containing the secondary wires and the burden of all relays in the circuit. For earth faults the loop includes the phase and neutral wire, normally twice the resistance of the single secondary wire. For three-phase faults the neutral current is zero and it is just necessary to consider the resistance up to the point where the phase wires are connected to the common neutral wire. The most common practice is to use four wires secondary cables so it normally is sufficient to consider just a single secondary wire for the three-phase case.

The conclusion is that the loop resistance, twice the resistance of the single secondary wire, must be used in the calculation for phase-to-earth faults and the phase resistance, the resistance of a single secondary wire, may normally be used in the calculation for three-phase faults.

As the burden can be considerable different for three-phase faults and phase-to-earth faults it is important to consider both cases. Even in a case where the phase-to-earth fault current is smaller than the three-phase fault current the phase-to-earth fault can be dimensioning for the CT depending on the higher burden.

In isolated or high impedance earthed systems the phase-to-earth fault is not the dimensioning case. Therefore, the resistance of the single secondary wire can always be used in the calculation for this kind of power systems.

19.1.5 General current transformer requirements

The current transformer ratio is mainly selected based on power system data for example, maximum load and/or maximum fault current. It should be verified that the current to the protection is higher than the minimum operating value for all faults that are to be detected with the selected CT ratio. It should also be verified that the maximum possible fault current is within the limits of the IED.

The current error of the current transformer can limit the possibility to use a very sensitive setting of a sensitive residual overcurrent protection. If a very sensitive setting of this function will be used it is recommended that the current transformer should have an accuracy class which have an current error at rated primary current that is less than $\pm 1\%$ (for example, 5P). If current transformers with less accuracy are used it is advisable to check the actual unwanted residual current during the commissioning.

19.1.6 Rated equivalent secondary e.m.f. requirements

With regard to saturation of the current transformer all current transformers of high remanence and low remanence type that fulfill the requirements on the rated equivalent limiting secondary e.m.f. E_{al} below can be used. The characteristic of the non remanence type CT (TPZ) is not well defined as far as the phase angle error is concerned. If no explicit recommendation is given for a specific function we therefore recommend contacting ABB to confirm that the non remanence type can be used.

The CT requirements for the different functions below are specified as a rated equivalent limiting secondary e.m.f. E_{al} according to the IEC 61869-2 standard. Requirements for CTs specified according to other classes and standards are given at the end of this section.

19.1.6.1 Transformer differential protection

The current transformers must have a rated equivalent limiting secondary e.m.f. E_{al} that is larger than the maximum of the required rated equivalent limiting secondary e.m.f. E_{alreq} below:

$$E_{al} \geq E_{alreq} = 30 \cdot I_{rt} \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 58)

$$E_{al} \geq E_{alreq} = 2 \cdot I_{tf} \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 59)

where:

I_{rt}	The rated primary current of the power transformer (A)
I_{tf}	Maximum primary fundamental frequency current that passes two main CTs and the power transformer (A)
I_{pr}	The rated primary CT current (A)
I_{sr}	The rated secondary CT current (A)
I_r	The rated current of the protection IED (A)
R_{ct}	The secondary resistance of the CT (Ω)
R_L	The resistance of the secondary wire and additional load (Ω). The loop resistance containing the phase and neutral wires must be used for faults in solidly earthed systems. The resistance of a single secondary wire should be used for faults in high impedance earthed systems.
S_R	The burden of an IED current input channel (VA). $S_R=0.020$ VA/channel for $I_r=1$ A and $S_R=0.150$ VA/channel for $I_r=5$ A

In substations with breaker-and-a-half or double-busbar double-breaker arrangement, the fault current may pass two main CTs for the transformer differential protection without passing the power transformer. In such cases and if both main CTs have equal ratios and magnetization characteristics the CTs must satisfy equation 58 and equation 60.

$$E_{al} \geq E_{alreq} = I_f \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 60)

where:

I_f	Maximum primary fundamental frequency current that passes two main CTs without passing the power transformer (A)

19.1.6.2

Distance protection

The current transformers must have a rated equivalent limiting secondary e.m.f. E_{al} that is larger than the maximum of the required rated equivalent limiting secondary e.m.f. E_{alreq} below:

$$E_{al} \geq E_{alreq} = \frac{I_{kmax} \cdot I_{sr}}{I_{pr}} \cdot a \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 61)

$$E_{al} \geq E_{alreq} = \frac{I_{kzone1} \cdot I_{sr}}{I_{pr}} \cdot k \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 62)

where:

I_{kmax}	Maximum primary fundamental frequency current for close-in forward and reverse faults (A)
I_{kzone1}	Maximum primary fundamental frequency current for faults at the end of zone 1 reach (A)
I_{pr}	The rated primary CT current (A)
I_{sr}	The rated secondary CT current (A)
I_r	The rated current of the protection IED (A)
R_{ct}	The secondary resistance of the CT (Ω)
R_L	The resistance of the secondary wire and additional load (Ω). In solidly earthed systems the loop resistance containing the phase and neutral wires should be used for phase-to-earth faults and the resistance of the phase wire should be used for three-phase faults. In isolated or high impedance earthed systems the resistance of the single secondary wire can always be used.
S_R	The burden of an IED current input channel (VA). $S_R=0.020$ VA/channel for $I_r=1$ A and $S_R=0.150$ VA/channel for $I_r=5$ A
a	This factor depends on the design of the protection function and can be a function of the primary DC time constant of the close-in fault current.
k	This factor depends on the design of the protection function and can be a function of the primary DC time constant of the fault current for a fault at the set reach of zone 1.

The a- and k-factors have the following values for the different types of distance function:

High speed distance: (ZMFPDIS and ZMFCPDIS)

Quadrilateral characteristic:

$a = 1$ for primary time constant $T_p \leq 400$ ms

$k = 3$ for primary time constant $T_p \leq 200$ ms

Mho characteristic:

$a = 2$ for primary time constant $T_p \leq 400$ ms (For $a = 1$ the delay in operation due to saturation is still under 1.5 cycles)

$k = 3$ for primary time constant $T_p \leq 200$ ms

Quadrilateral distance: (ZMQPDIS, ZMQAPDIS and ZMCPDIS, ZMCAPDIS and ZMMPDIS, ZMMAPDIS)

$a = 1$ for primary time constant $T_p \leq 100$ ms

$a = 3$ for primary time constant $T_p > 100$ and ≤ 400 ms

$k = 4$ for primary time constant $T_p \leq 50$ ms

$k = 5$ for primary time constant $T_p > 50$ and ≤ 150 ms

Mho distance: (ZMHPDIS)

$a = 1$ for primary time constant $T_p \leq 100$ ms

$a = 3$ for primary time constant $T_p > 100$ and ≤ 400 ms

$k = 4$ for primary time constant $T_p \leq 40$ ms

$k = 5$ for primary time constant $T_p > 40$ and ≤ 150 ms

19.1.6.3 Breaker failure protection

The CTs must have a rated equivalent limiting secondary e.m.f. E_{al} that is larger than or equal to the required rated equivalent limiting secondary e.m.f. E_{alreq} below:

$$E_{al} \geq E_{alreq} = 5 \cdot I_{op} \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 63)

where:

I_{op}	The primary operate value (A)
I_{pr}	The rated primary CT current (A)
I_{sr}	The rated secondary CT current (A)
I_r	The rated current of the protection IED (A)
R_{ct}	The secondary resistance of the CT (Ω)
R_L	The resistance of the secondary cable and additional load (Ω). The loop resistance containing the phase and neutral wires, must be used for faults in solidly earthed systems. The resistance of a single secondary wire should be used for faults in high impedance earthed systems.
S_R	The burden of an IED current input channel (VA). $S_R=0.020$ VA/channel for $I_r=1$ A and $S_R=0.150$ VA/channel for $I_r=5$ A

19.1.6.4 Restricted earth fault protection (low impedance differential)

The requirements are specified separately for solidly earthed and impedance earthed transformers. For impedance earthed transformers the requirements for the phase CTs are depending whether it is three individual CTs connected in parallel or it is a cable CT enclosing all three phases.

Neutral CTs and phase CTs for solidly earthed transformers

The neutral CT and the phase CTs must have a rated equivalent limiting secondary e.m.f. E_{al} that is larger than or equal to the maximum of the required rated equivalent limiting secondary e.m.f. E_{alreq} below:

$$E_{al} \geq E_{alreq} = 30 \cdot I_{rt} \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 64)

$$E_{al} \geq E_{alreq} = 2 \cdot I_{etf} \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 65)

Where:

I_{rt}	The rated primary current of the power transformer (A)
I_{etf}	Maximum primary fundamental frequency phase-to-earth fault current that passes the CTs and the power transformer neutral (A)
I_{pr}	The rated primary CT current (A)
I_{sr}	The rated secondary CT current (A)
I_r	The rated current of the protection IED (A)
R_{ct}	The secondary resistance of the CT (Ω)
R_L	The resistance of the secondary wire and additional load (Ω). The loop resistance containing the phase and neutral wires shall be used.
S_R	The burden of a REx670 current input channel (VA). $S_R=0.020$ VA / channel for $I_R = 1$ A and $S_R = 0.150$ VA / channel for $I_R = 5$ A

In substations with breaker-and-a-half or double-busbar double-breaker arrangement, the fault current may pass two main phase CTs for the restricted earth fault protection without passing the power transformer. In such cases and if both main CTs have equal ratios and magnetization characteristics the CTs must satisfy Requirement [64](#) and the Requirement [65](#):

$$E_{al} \geq E_{alreq} = I_{ef} \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 66)

Where:

I_{ef}	Maximum primary fundamental frequency phase-to-earth fault current that passes two main CTs without passing the power transformer neutral (A)

Neutral CTs and phase CTs for impedance earthed transformers

The neutral CT and phase CTs must have a rated equivalent limiting secondary e.m.f. E_{al} that is larger than or equal to the required rated equivalent limiting secondary e.m.f. E_{alreq} below:

$$E_{al} \geq E_{alreq} = 3 \cdot I_{etf} \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 67)

Where:

I_{etf}	Maximum primary fundamental frequency phase-to-earth fault current that passes the CTs and the power transformer neutral (A)
I_{pr}	The rated primary CT current (A)
I_{sr}	The rated secondary CT current (A)

Table continues on next page

I_r	The rated current of the protection IED (A)
R_{ct}	The secondary resistance of the CT (Ω)
R_L	The resistance of the secondary wire and additional load (Ω). The loop resistance containing the phase and neutral wires shall be used.
S_R	The burden of a REx670 current input channel (VA). $S_R = 0.020$ VA / channel for $I_r = 1$ A and $S_R = 0.150$ VA / channel for $I_r = 5$ A

In case of three individual CTs connected in parallel (Holmgren connection) on the phase side the following additional requirements must also be fulfilled.

The three individual phase CTs must have a rated equivalent limiting secondary e.m.f. E_{al} that is larger than or equal to the maximum of the required rated equivalent limiting secondary e.m.f. E_{alreq} below:

$$E_{al} \geq E_{alreq} = 2 \cdot I_{ff} \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_{Lsw} + \frac{S_R}{I_r^2} \right)$$

(Equation 68)

Where:

I_{ff}	Maximum primary fundamental frequency three-phase fault current that passes the CTs and the power transformer (A).
R_{Lsw}	The resistance of the single secondary wire and additional load (Ω).

In impedance earthed systems the phase-to-earth fault currents often are relatively small and the requirements might result in small CTs. However, in applications where the zero sequence current from the phase side of the transformer is a summation of currents from more than one CT (cable CTs or groups of individual CTs in Holmgren connection) for example, in substations with breaker-and-a-half or double-busbar double-breaker arrangement or if the transformer has a T-connection to different busbars, there is a risk that the CTs can be exposed for higher fault currents than the considered phase-to-earth fault currents above. Examples of such cases can be cross-country faults or phase-to-phase faults with high fault currents and unsymmetrical distribution of the phase currents between the CTs. The zero sequence fault current level can differ much and is often difficult to calculate or estimate for different cases. To cover these cases, with summation of zero sequence currents from more than one CT, the phase side CTs must fulfill the Requirement [69](#) below:

$$E_{al} \geq E_{alreq} = I_f \cdot \frac{I_{sr}}{I_{pr}} \cdot \left(R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 69)

Where:

I_f	Maximum primary fundamental frequency three-phase fault current that passes the CTs (A)
R_L	The resistance of the secondary wire and additional load (Ω). The loop resistance containing the phase and neutral wires shall be used.

19.1.7 Current transformer requirements for CTs according to other standards

All kinds of conventional magnetic core CTs are possible to use with the IEDs if they fulfill the requirements corresponding to the above specified expressed as the rated equivalent limiting secondary e.m.f. E_{al} according to the IEC 61869-2 standard. From different standards and available data for relaying applications it is possible to approximately calculate a secondary e.m.f. of the CT comparable with E_{al} . By comparing this with the required rated equivalent limiting secondary e.m.f. E_{alreq} it is possible to judge if the CT fulfills the requirements. The requirements according to some other standards are specified below.

19.1.7.1 Current transformers according to IEC 61869-2, class P, PR

A CT according to IEC 61869-2 is specified by the secondary limiting e.m.f. E_{ALF} . The value of the E_{ALF} is approximately equal to the corresponding E_{al} . Therefore, the CTs according to class P and PR must have a secondary limiting e.m.f. E_{ALF} that fulfills the following:

$$E_{ALF} > \max E_{alreq}$$

(Equation 70)

19.1.7.2 Current transformers according to IEC 61869-2, class PX, PXR (and old IEC 60044-6, class TPS and old British Standard, class X)

CTs according to these classes are specified approximately in the same way by a rated knee point e.m.f. E_{knee} (E_k for class PX and PXR, E_{kneeBS} for class X and the limiting secondary voltage U_{al} for TPS). The value of the E_{knee} is lower than the corresponding E_{al} according to IEC 61869-2. It is not possible to give a general relation between the E_{knee} and the E_{al} but normally the E_{knee} is approximately 80 % of the E_{al} . Therefore, the CTs according to class PX, PXR, X and TPS must have a rated knee point e.m.f. E_{knee} that fulfills the following:

$$E_{knee} \approx E_k \approx E_{kneeBS} \approx U_{al} > 0.8 \cdot (\text{maximum of } E_{alreq})$$

(Equation 71)

19.1.7.3

Current transformers according to ANSI/IEEE

Current transformers according to ANSI/IEEE are partly specified in different ways. A rated secondary terminal voltage U_{ANSI} is specified for a CT of class C. U_{ANSI} is the secondary terminal voltage the CT will deliver to a standard burden at 20 times rated secondary current without exceeding 10 % ratio correction. There are a number of standardized U_{ANSI} values for example, U_{ANSI} is 400 V for a C400 CT. A corresponding rated equivalent limiting secondary e.m.f. E_{alANSI} can be estimated as follows:

$$E_{\text{alANSI}} = |20 \cdot I_{\text{sr}} \cdot R_{\text{ct}} + U_{\text{ANSI}}| = |20 \cdot I_{\text{sr}} \cdot R_{\text{ct}} + 20 \cdot I_{\text{sr}} \cdot Z_{\text{bANSI}}|$$

(Equation 72)

where:

Z_{bANSI} The impedance (that is, with a complex quantity) of the standard ANSI burden for the specific C class (Ω)

U_{ANSI} The secondary terminal voltage for the specific C class (V)

The CTs according to class C must have a calculated rated equivalent limiting secondary e.m.f. E_{alANSI} that fulfils the following:

$$E_{\text{alANSI}} > \text{maximum of } E_{\text{alreq}}$$

(Equation 73)

A CT according to ANSI/IEEE is also specified by the knee point voltage U_{kneeANSI} that is graphically defined from an excitation curve. The knee point voltage U_{kneeANSI} normally has a lower value than the knee-point e.m.f. according to IEC and BS. U_{kneeANSI} can approximately be estimated to 75 % of the corresponding E_{al} according to IEC 61869-2. Therefore, the CTs according to ANSI/IEEE must have a knee point voltage U_{kneeANSI} that fulfils the following:

$$V_{\text{kneeANSI}} > 0.75 \cdot (\text{maximum of } E_{\text{alreq}})$$

(Equation 74)

19.2

Voltage transformer requirements

The performance of a protection function will depend on the quality of the measured input signal. Transients caused by capacitive voltage transformers (CVTs) can affect some protection functions.

Magnetic or capacitive voltage transformers can be used.

The capacitive voltage transformers (CVTs) should fulfill the requirements according to the IEC 61869-5 standard regarding ferro-resonance and transients. The ferro-resonance requirements of the CVTs are specified in chapter 6.502 of the standard.

The transient responses for three different standard transient response classes, T1, T2 and T3 are specified in chapter 6.503 of the standard. CVTs according to all classes can be used.

The protection IED has effective filters for these transients, which gives secure and correct operation with CVTs.

19.3 SNTP server requirements

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

19.4 PTP requirements

For PTP to perform properly, the Ethernet equipment that is used needs to be compliant with IEEE1588. The clocks used must follow the IEEE1588 standard BMC (Best Master Algorithm) and shall, for instance, not claim class 7 for a longer time than it can guarantee 1us absolute accuracy.

19.5 IEC/UCA 61850-9-2LE Merging unit requirements

The merging units that supply the IED with measured values via the process bus must fulfill the IEC/UCA 61850-9-2LE standard.

This part of the IEC 61850 is specifying “Communication Service Mapping (SCSM) – Sampled values over ISO/IEC 8802”, in other words – sampled data over Ethernet. The 9-2 part of the IEC 61850 protocol uses also definitions from 7-2, “Basic communication structure for substation and feeder equipment – Abstract communication service interface (ACSI)”. The set of functionality implemented in the IED (IEC/UCA 61850-9-2LE) is a subset of the IEC 61850-9-2. For example the IED covers the client part of the standard, not the server part.

The standard does not define the sample rate for data, but in the UCA users group recommendations there are indicated sample rates that are adopted, by consensus, in the industry.

There are two sample rates defined: 80 samples/cycle (4000 samples/sec. at 50Hz or 4800 samples/sec. at 60 Hz) for a merging unit “type1” and 256 samples/cycle for a merging unit “type2”. The IED can receive data rates of 80 samples/cycle.

Note that the IEC/UCA 61850-9-2LE standard does not specify the quality of the sampled values, only the transportation. Thus, the accuracy of the current and voltage inputs to the merging unit and the inaccuracy added by the merging unit must be coordinated with the requirement for actual type of protection function.

Factors influencing the accuracy of the sampled values from the merging unit are for example anti aliasing filters, frequency range, step response, truncating, A/D conversion inaccuracy, time tagging accuracy etc.

In principle the accuracy of the current and voltage transformers, together with the merging unit, shall have the same quality as direct input of currents and voltages.

Section 20 Glossary

AC	Alternating current
ACC	Actual channel
ACT	Application configuration tool within PCM600
A/D converter	Analog-to-digital converter
ADBS	Amplitude deadband supervision
ADM	Analog digital conversion module, with time synchronization
AI	Analog input
ANSI	American National Standards Institute
AR	Autoreclosing
ASCT	Auxiliary summation current transformer
ASD	Adaptive signal detection
ASDU	Application service data unit
AWG	American Wire Gauge standard
BBP	Busbar protection
BFOC/2,5	Bayonet fibre optic connector
BFP	Breaker failure protection
BI	Binary input
BIM	Binary input module
BOM	Binary output module
BOS	Binary outputs status
BR	External bistable relay
BS	British Standards
BSR	Binary signal transfer function, receiver blocks
BST	Binary signal transfer function, transmit blocks
C37.94	IEEE/ANSI protocol used when sending binary signals between IEDs
CAN	Controller Area Network. ISO standard (ISO 11898) for serial communication
CB	Circuit breaker
CBM	Combined backplane module

CCITT	Consultative Committee for International Telegraph and Telephony. A United Nations-sponsored standards body within the International Telecommunications Union.
CCM	CAN carrier module
CCVT	Capacitive Coupled Voltage Transformer
Class C	Protection Current Transformer class as per IEEE/ ANSI
CMPPS	Combined megapulses per second
CMT	Communication Management tool in PCM600
CO cycle	Close-open cycle
Codirectional	Way of transmitting G.703 over a balanced line. Involves two twisted pairs making it possible to transmit information in both directions
COM	Command
COMTRADE	Standard Common Format for Transient Data Exchange format for Disturbance recorder according to IEEE/ANSI C37.111, 1999 / IEC 60255-24
Contra-directional	Way of transmitting G.703 over a balanced line. Involves four twisted pairs, two of which are used for transmitting data in both directions and two for transmitting clock signals
COT	Cause of transmission
CPU	Central processing unit
CR	Carrier receive
CRC	Cyclic redundancy check
CROB	Control relay output block
CS	Carrier send
CT	Current transformer
CU	Communication unit
CVT or CCVT	Capacitive voltage transformer
DAR	Delayed autoreclosing
DARPA	Defense Advanced Research Projects Agency (The US developer of the TCP/IP protocol etc.)
DBDL	Dead bus dead line
DBLL	Dead bus live line
DC	Direct current
DFC	Data flow control
DFT	Discrete Fourier transform

DHCP	Dynamic Host Configuration Protocol
DIP-switch	Small switch mounted on a printed circuit board
DI	Digital input
DLLB	Dead line live bus
DNP	Distributed Network Protocol as per IEEE Std 1815-2012
DR	Disturbance recorder
DRAM	Dynamic random access memory
DRH	Disturbance report handler
DSP	Digital signal processor
DTT	Direct transfer trip scheme
ECT	Ethernet configuration tool
EHV network	Extra high voltage network
EIA	Electronic Industries Association
EMC	Electromagnetic compatibility
EMF	Electromotive force
EMI	Electromagnetic interference
EnFP	End fault protection
EPA	Enhanced performance architecture
ESD	Electrostatic discharge
F-SMA	Type of optical fibre connector
FAN	Fault number
FCB	Flow control bit; Frame count bit
FOX 20	Modular 20 channel telecommunication system for speech, data and protection signals
FOX 512/515	Access multiplexer
FOX 6Plus	Compact time-division multiplexer for the transmission of up to seven duplex channels of digital data over optical fibers
FPN	Flexible product naming
FTP	File Transfer Protocol
FUN	Function type
G.703	Electrical and functional description for digital lines used by local telephone companies. Can be transported over balanced and unbalanced lines
GCM	Communication interface module with carrier of GPS receiver module

GDE	Graphical display editor within PCM600
GI	General interrogation command
GIS	Gas-insulated switchgear
GOOSE	Generic object-oriented substation event
GPS	Global positioning system
GSAL	Generic security application
GSE	Generic substation event
HDLC protocol	High-level data link control, protocol based on the HDLC standard
HFBR connector type	Plastic fiber connector
HMI	Human-machine interface
HSAR	High speed autoreclosing
HSR	High-availability Seamless Redundancy
HV	High-voltage
HVDC	High-voltage direct current
IDBS	Integrating deadband supervision
IEC	International Electrical Committee
IEC 60044-6	IEC Standard, Instrument transformers – Part 6: Requirements for protective current transformers for transient performance
IEC 60870-5-103	Communication standard for protection equipment. A serial master/slave protocol for point-to-point communication
IEC 61850	Substation automation communication standard
IEC 61850-8-1	Communication protocol standard
IEEE	Institute of Electrical and Electronics Engineers
IEEE 802.12	A network technology standard that provides 100 Mbits/s on twisted-pair or optical fiber cable
IEEE P1386.1	PCI Mezzanine Card (PMC) standard for local bus modules. References the CMC (IEEE P1386, also known as Common Mezzanine Card) standard for the mechanics and the PCI specifications from the PCI SIG (Special Interest Group) for the electrical EMF (Electromotive force).
IEEE 1686	Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities
IED	Intelligent electronic device
IET600	Integrated engineering tool

I-GIS	Intelligent gas-insulated switchgear
IOM	Binary input/output module
Instance	When several occurrences of the same function are available in the IED, they are referred to as instances of that function. One instance of a function is identical to another of the same kind but has a different number in the IED user interfaces. The word "instance" is sometimes defined as an item of information that is representative of a type. In the same way an instance of a function in the IED is representative of a type of function.
IP	1. Internet protocol. The network layer for the TCP/IP protocol suite widely used on Ethernet networks. IP is a connectionless, best-effort packet-switching protocol. It provides packet routing, fragmentation and reassembly through the data link layer. 2. Ingression protection, according to IEC 60529
IP 20	Ingression protection, according to IEC 60529, level 20
IP 40	Ingression protection, according to IEC 60529, level 40
IP 54	Ingression protection, according to IEC 60529, level 54
IRF	Internal failure signal
IRIG-B:	InterRange Instrumentation Group Time code format B, standard 200
ITU	International Telecommunications Union
LAN	Local area network
LIB 520	High-voltage software module
LCD	Liquid crystal display
LDCM	Line data communication module
LDD	Local detection device
LED	Light-emitting diode
LNT	LON network tool
LON	Local operating network
MCB	Miniature circuit breaker
MCM	Mezzanine carrier module
MPM	Main processing module
MVAL	Value of measurement
MVB	Multifunction vehicle bus. Standardized serial bus originally developed for use in trains.
NCC	National Control Centre

NOF	Number of grid faults
NUM	Numerical module
OCO cycle	Open-close-open cycle
OCP	Overcurrent protection
OLTC	On-load tap changer
OTEV	Disturbance data recording initiated by other event than start/pick-up
OV	Overvoltage
Overreach	A term used to describe how the relay behaves during a fault condition. For example, a distance relay is overreaching when the impedance presented to it is smaller than the apparent impedance to the fault applied to the balance point, that is, the set reach. The relay “sees” the fault but perhaps it should not have seen it.
PCI	Peripheral component interconnect, a local data bus
PCM	Pulse code modulation
PCM600	Protection and control IED manager
PC-MIP	Mezzanine card standard
PMC	PCI Mezzanine card
POR	Permissive overreach
POTT	Permissive overreach transfer trip
Process bus	Bus or LAN used at the process level, that is, in near proximity to the measured and/or controlled components
PRP	Parallel redundancy protocol
PSM	Power supply module
PST	Parameter setting tool within PCM600
PTP	Precision time protocol
PT ratio	Potential transformer or voltage transformer ratio
PUTT	Permissive underreach transfer trip
RASC	Synchrocheck relay, COMBIFLEX
RCA	Relay characteristic angle
RISC	Reduced instruction set computer
RMS value	Root mean square value
RS422	A balanced serial interface for the transmission of digital data in point-to-point connections
RS485	Serial link according to EIA standard RS485
RTC	Real-time clock

RTU	Remote terminal unit
SA	Substation Automation
SBO	Select-before-operate
SC	Switch or push button to close
SCL	Short circuit location
SCS	Station control system
SCADA	Supervision, control and data acquisition
SCT	System configuration tool according to standard IEC 61850
SDU	Service data unit
SFP	Small form-factor pluggable (abbreviation) Optical Ethernet port (explanation)
SLM	Serial communication module.
SMA connector	Subminiature version A, A threaded connector with constant impedance.
SMT	Signal matrix tool within PCM600
SMS	Station monitoring system
SNTP	Simple network time protocol – is used to synchronize computer clocks on local area networks. This reduces the requirement to have accurate hardware clocks in every embedded system in a network. Each embedded node can instead synchronize with a remote clock, providing the required accuracy.
SOF	Status of fault
SPA	Strömberg Protection Acquisition (SPA), a serial master/slave protocol for point-to-point and ring communication.
SRY	Switch for CB ready condition
ST	Switch or push button to trip
Starpoint	Neutral point of transformer or generator
SVC	Static VAr compensation
TC	Trip coil
TCS	Trip circuit supervision
TCP	Transmission control protocol. The most common transport layer protocol used on Ethernet and the Internet.
TCP/IP	Transmission control protocol over Internet Protocol. The de facto standard Ethernet protocols incorporated into 4.2BSD Unix. TCP/IP was developed by DARPA for Internet working and encompasses both network layer and

	transport layer protocols. While TCP and IP specify two protocols at specific protocol layers, TCP/IP is often used to refer to the entire US Department of Defense protocol suite based upon these, including Telnet, FTP, UDP and RDP.
TEF	Time delayed earth-fault protection function
TLS	Transport Layer Security
TM	Transmit (disturbance data)
TNC connector	Threaded Neill-Concelman, a threaded constant impedance version of a BNC connector
TP	Trip (recorded fault)
TPZ, TPY, TPX, TPS	Current transformer class according to IEC
TRM	Transformer Module. This module transforms currents and voltages taken from the process into levels suitable for further signal processing.
TYP	Type identification
UMT	User management tool
Underreach	A term used to describe how the relay behaves during a fault condition. For example, a distance relay is underreaching when the impedance presented to it is greater than the apparent impedance to the fault applied to the balance point, that is, the set reach. The relay does not "see" the fault but perhaps it should have seen it. See also Overreach.
UTC	Coordinated Universal Time. A coordinated time scale, maintained by the Bureau International des Poids et Mesures (BIPM), which forms the basis of a coordinated dissemination of standard frequencies and time signals. UTC is derived from International Atomic Time (TAI) by the addition of a whole number of "leap seconds" to synchronize it with Universal Time 1 (UT1), thus allowing for the eccentricity of the Earth's orbit, the rotational axis tilt (23.5 degrees), but still showing the Earth's irregular rotation, on which UT1 is based. The Coordinated Universal Time is expressed using a 24-hour clock, and uses the Gregorian calendar. It is used for aeroplane and ship navigation, where it is also sometimes known by the military name, "Zulu time." "Zulu" in the phonetic alphabet stands for "Z", which stands for longitude zero.
UV	Undervoltage
WEI	Weak end infeed logic
VT	Voltage transformer

$3I_0$	Three times zero-sequence current. Often referred to as the residual or the earth-fault current
$3U_0$	Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage



—

ABB AB

Grid Automation Products

721 59 Västerås, Sweden

Phone: +46 (0) 21 32 50 00

abb.com/protection-control