RELION® 670 SERIES

Railway application RER670 Version 2.2 IEC

Commissioning manual

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Conformity

This product complies with the directive of the Council of the European Communities on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive 2004/108/EC) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2006/95/EC). This conformity is the result of tests conducted by ABB in accordance with the product 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.

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Section 1 Introduction

1.1 This manual

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 substation 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.

1.2 Intended audience

This manual addresses the personnel responsible for commissioning, maintenance and taking the IED in and out of normal service.

The commissioning personnel must have a basic knowledge of handling electronic equipment. The commissioning and maintenance personnel must be well experienced in using protection equipment, test equipment, protection functions and the configured functional logics in the IED.

1.3 Product documentation

1.3.1 Product documentation set

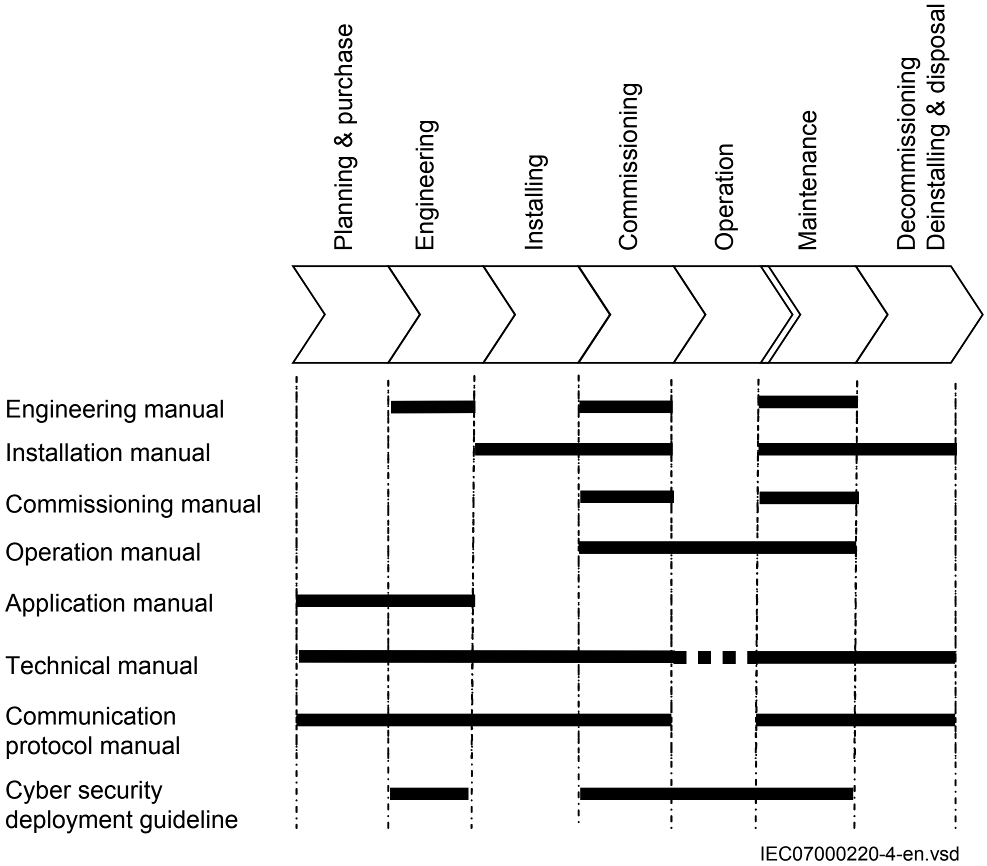


Figure 1: The intended use of manuals throughout the product lifecycle

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, as well as communication engineering for IEC 61850.

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 substation 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
A/October 2017	Information updated
B/November 2017	ZMFPDIS and ZMFCPDIS - Added missing setting tables
C/March 2018	2.2 Maintenance release 1
D/June 2018	Added new functions and resolved bugs

1.3.3 Related documents

Documents related to RER670	Document numbers
Application manual	1MRK 506 375-UEN
Commissioning manual	1MRK 506 377-UEN
Product guide	1MRK 506 378-BEN
Technical manual	1MRK 506 376-UEN
Type test certificate	1MRK 506 378-TEN

670 series manuals	Document numbers
Operation manual	1MRK 500 127-UEN
Engineering manual	1MRK 511 398-UEN
Installation manual	1MRK 514 026-UEN
Communication protocol manual, DNP3	1MRK 511 391-UUS
Communication protocol manual, IEC 60870-5-103	1MRK 511 394-UEN
Communication protocol manual, IEC 61850 Edition 2	1MRK 511 393-UEN
Communication protocol manual, LON	1MRK 511 395-UEN
Communication protocol manual, SPA	1MRK 511 396-UEN
Point list manual, DNP3	1MRK 511 397-UUS
Accessories guide	1MRK 514 012-BEN
Cyber security deployment guideline	1MRK 511 399-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.
- Dimensions are provided both in inches and millimeters. If it is not specifically mentioned then the dimension is in millimeters.

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
BRPTOC	BRPTOC	BRPTOC
BTIGAPC	B16IFCVI	BTIGAPC
CCRWRBRF	CCRWRBRF	CCRWRBRF
CCSSPVC	CCSRDIF	CCSSPVC
CMMXU	CMMXU	CMMXU
CMSQI	CMSQI	CMSQI
CVMMXN	CVMMXN	CVMMXN
D2PTOC	D2LLN0 D2PTOC PH1PTRC	D2PTOC PH1PTRC
DPGAPC	DPGGIO	DPGAPC
DRPRDRE	DRPRDRE	DRPRDRE
ECPSCH	ECPSCH	ECPSCH
ECRWPSCH	ECRWPSCH	ECRWPSCH
EF2PTOC	EF2LLN0 EF2PTRC EF2RDIR GEN2PHAR PH1PTOC	EF2PTRC EF2RDIR GEN2PHAR PH1PTOC
EFPIOC	EFPIOC	EFPIOC
ETPMMTR	ETPMMTR	ETPMMTR

Table continues on next page

Function block name	Edition 1 logical nodes	Edition 2 logical nodes
ITBGAPC	IB16FCVB	ITBGAPC
L4UFCNT	L4UFCNT	L4UFCNT
LPHD	LPHD	-
LPTTR	LPTTR	LPTTR
MVGAPC	MVGGIO	MVGAPC
O2RWPTOV	GEN2LLN0 O2RWPTOV PH1PTRC	O2RWPTOV PH1PTRC
PHPIOC	PHPIOC	PHPIOC
QCBAY	QCBAY	BAY/LLN0
QCRSV	QCRSV	QCRSV
RCHLCCH	RCHLCCH	RCHLCCH
REFPDIF	REFPDIF	REFPDIF
ROV2PTOV	GEN2LLN0 PH1PTRC ROV2PTOV	PH1PTRC ROV2PTOV
RWRFLO	-	RWRFLO
SAPTUF	SAPTUF	SAPTUF
SCHLCCH	SCHLCCH	SCHLCCH
SCILO	SCILO	SCILO
SCSWI	SCSWI	SCSWI
SDEPSDE	SDEPSDE	SDEPSDE SDEPTOC SDEPTOV SDEPTRC
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
T1PPDIF	-	T1PPDIF T1PPHAR T1PPTRC

Table continues on next page

Function block name	Edition 1 logical nodes	Edition 2 logical nodes
TEIGAPC	TEIGGIO	TEIGAPC TEIGGIO
TEILGAPC	TEILGGIO	TEILGAPC
TMAGAPC	TMAGGIO	TMAGAPC
TPPIOC	TPPIOC	TPPIOC
U2RWPTUV	GEN2LLN0 PH1PTRC U2RWPTUV	PH1PTRC U2RWPTUV
VMMXU	VMMXU	VMMXU
VMSQI	VMSQI	VMSQI
VNMMXU	VNMMXU	VNMMXU
VSGAPC	VSGGIO	VSGAPC
WRNCALH	WRNCALH	WRNCALH
XENCPOW	-	XENCPOW
ZCPSCH	ZCPSCH	ZCPSCH
ZCRWPSCH	ZCRWPSCH	ZCRWPSCH
ZCVPSOF	ZCVPSOF	ZCVPSOF
ZGTPDIS	ZGTLLN0 ZGPDIS ZGPTRC	ZGPDIS ZGPTRC
ZRWPDIS	-	PSRWPDIS ZRWPDIS ZRWPTRC

Section 2 Safety information

2.1 Symbols on the product

All warnings must be observed.

Read the entire manual before doing installation or any maintenance work on the product. All warnings must be observed.

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

Do not touch the unit in operation. The installation shall take into account the worst case temperature.

2.2 Warnings

Observe the warnings during all types of work related to the product.

Only electrically skilled persons with the proper authorization and knowledge of any safety hazards are allowed to carry out the electrical installation.

National and local electrical safety regulations must always be followed. Working in a high voltage environment requires serious approach to avoid human injuries and damage to equipment.

Do not touch circuitry during operation. Potentially lethal voltages and currents are present.

Always use suitable isolated test pins when measuring signals in open circuitry. Potentially lethal voltages and currents are present.

Never connect or disconnect a wire and/or a connector to or from a IED during normal operation. Hazardous voltages and currents are present that may be lethal. Operation may be disrupted and IED and measuring circuitry may be damaged.

Dangerous voltages can occur on the connectors, even though the auxiliary voltage has been disconnected.

Always connect the IED to protective earth, regardless of the operating conditions. This also applies to special occasions such as bench testing, demonstrations and off-site configuration. This is class 1 equipment that shall be earthed.

Never disconnect the secondary connection of current transformer circuit without short-circuiting the transformer’s secondary winding. Operating a current transformer with the secondary winding open will cause a massive potential build-up that may damage the transformer and may cause injuries to humans.

Never remove any screw from a powered IED or from a IED connected to powered circuitry. Potentially lethal voltages and currents are present.

Take adequate measures to protect the eyes. Never look into the laser beam.

The IED with accessories should be mounted in a cubicle in a restricted access area within a power station, substation or industrial or retail environment.

2.3 Caution signs

Whenever changes are made in the IED, measures should be taken to avoid inadvertent tripping.

The IED contains components which are sensitive to electrostatic discharge. ESD precautions shall always be observed prior to touching components.

Always transport PCBs (modules) using certified conductive bags.

Do not connect live wires to the IED. Internal circuitry may be damaged

Always use a conductive wrist strap connected to protective earth when replacing modules. Electrostatic discharge (ESD) may damage the module and IED circuitry.

Take care to avoid electrical shock during installation and commissioning.

Changing the active setting group will inevitably change the IEDs operation. Be careful and check regulations before making the change.

2.4 Note signs

Observe the maximum allowed continuous current for the different current transformer inputs of the IED. See technical data.

Section 3 Available functions

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.

3.1 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	Railway
			RER670
Differential protection			
REFPDIF	87N	Restricted earth fault protection, low impedance	2-A50 1-B60 1-B70
T1PPDIF	87T	Transformer differential protection, two windings	2-A50
Impedance protection			
ZCVPSOF		Automatic switch onto fault logic, voltage and current based	1-B60 1-B70
ZGTPDIS	21T	Underimpedance protection for generators and transformers	2-A50 1-B60 1-B70
ZRWPDIS	21	Distance protection, quadrilateral characteristic	1-B60
ZRCPDIS	21	Catenary distance protection, quadrilateral characteristic	2-B70

3.2 Back-up protection functions

IEC 61850 or function name	ANSI	Function description	Railway
			RER670
Current protection			
PHPIOC	50	Instantaneous phase overcurrent protection	2-C61
D2PTOC	51_67	Directional phase overcurrent protection, two steps	8-C61
EFRWPIOC	50N	Instantaneous residual overcurrent protection	1-C61
EF2PTOC	51N 67N[1)]	Directional residual overcurrent protection, two steps	3-C61
SDEPSDE	67N	Sensitive directional residual overcurrent and power protection	1-C61
LPTTR	26	Thermal overload protection, one time constant	2-C61
CCRWRBRF	50BF	Breaker failure protection	2-C61
BRPTOC	50	Overcurrent protection with binary release	8-C61
TPPIOC	64	Transformer tank overcurrent protection	1-A50 1-B60 1-B70
Voltage protection			
U2RWPTUV	27	Undervoltage protection, two steps	2-C61
O2RWPTOV	59	Overvoltage protection, two steps	2-C61
ROV2PTOV	59N	Two step residual overvoltage protection	2-C61
Frequency protection			
SAPTUF	81L	Underfrequency protection	2-C61

1) 67N requires voltage

3.3 Control and monitoring functions

IEC 61850 or function name	ANSI	Function description	Railway
			RER670
Control			
SESRSYN	25	Synchrocheck, energizing check and synchronizing	1-H51
SMBRREC	79	Autorecloser	1-H52
APC10	3	Control functionality for a single bay, max 10 objects (1CB), including interlocking (see Table 4)	1-H37
APC15	3	Control functionality for a single bay, max 15 objects (2CB), including interlocking (see Table 5)	1-H38
QCBAY		Bay control	1
LOCREM		Handling of LR-switch positions	1
LOCREMCTRL		LHMI control of PSTO	1
SXCBR		Circuit breaker	6
TCMYLTC	84	Tap changer control and supervision, 6 binary inputs	1-H53
TCLYLTC	84	Tap changer control and supervision, 32 binary inputs	1-H54
SLGAPC		Logic rotating switch for function selection and LHMI presentation	15
VSGAPC		Selector mini switch	30
DPGAPC		Generic communication function for Double Point indication	32
SPC8GAPC		Single point generic control function 8 signals	5
AUTOBITS		Automation bits, command function for DNP3.0	2
SINGLECMD		Single command, 16 signals	4

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Railway
			RER670
I103CMD		Function commands for IEC 60870-5-103	1
I103GENCMD		Function commands generic for IEC 60870-5-103	35
I103POSCMD		IED commands with position and select for IEC 60870-5-103	50
I103POSCMDV		IED direct commands with position for IEC 60870-5-103	50
I103IEDCMD		IED commands for IEC 60870-5-103	1
I103USRCMD		Function commands user defined for IEC 60870-5-103	3
XENCPOW	25T	Transformer energization control	1-A50/1-H55
Secondary system supervision			
CCSSPVC	87	Current circuit supervision	3-G04
FRWSPVC		Fuse failure supervision	3-C61
FRWSPVC		Fuse failure supervision	3-C61
DELVSPVC	78V	Voltage delta supervision, 2 phase	4
DELISPVC	71	Current delta supervision, 2 phase	4
DELSPVC	78	Real delta supervision, real	4
Logic			
SMPPTRC	94	Tripping logic	12-C61
SMAGAPC		General start matrix block	12-C61
STARTCOMB		Start combinator	32
TMAGAPC		Trip matrix logic	12
ALMCALH		Logic for group alarm	5
WRNCALH		Logic for group warning	5
INDCALH		Logic for group indication	5

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Railway		
			RER670		
AND, GATE, INV, LLD, OR, PULSETIMER, RSMEMORY, SRMEMORY, TIMERSET, XOR		Basic configurable logic blocks (see Table 3)	40-420		
FXDSIGN		Fixed signal function block	1		
B16I		Boolean to integer conversion, 16 bit	18		
BTIGAPC		Boolean to integer conversion with logical node representation, 16 bit	16		
IB16		Integer to Boolean 16 conversion	14		
ITBGAPC		Integer to Boolean 16 conversion with Logic Node representation	16		
TEIGAPC		Elapsed time integrator with limit transgression and overflow supervision	12		
INTCOMP		Comparator for integer inputs	30		
REALCOMP		Comparator for real inputs	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

Table 4: Number of function instances in APC10

Function name	Function description	Total number of instances
SCILO	Interlocking	10
BB_ES		3
A1A2_BS		2
A1A2_DC		3
ABC_BC		1
BH_CONN		1
BH_LINE_A		1
BH_LINE_B		1
DB_BUS_A		1
DB_BUS_B		1
DB_LINE		1
ABC_LINE		1
AB_TRAFO		1
SCSWI	Switch controller	10
SXSWI	Circuit switch	9
QCRSV	Apparatus control	2
RESIN1		1
RESIN2		59
POS_EVAL	Evaluation of position indication	10
XLNPROXY	Proxy for signals from switching device via GOOSE	12
GOOSEXLNRCV	GOOSE function block to receive a switching device	12

Table 5: Number of function instances in APC15

Function name	Function description	Total number of instances
SCILO	Interlocking	15
BB_ES		3
A1A2_BS		2
A1A2_DC		3
ABC_BC		1
BH_CONN		1
BH_LINE_A		1
BH_LINE_B		1
DB_BUS_A		1
DB_BUS_B		1
DB_LINE		1
ABC_LINE		1
AB_TRAFO		1
SCSWI	Switch controller	15
SXSWI	Circuit switch	14
QCRSV	Apparatus control	2
RESIN1		1
RESIN2		59
POS_EVAL	Evaluation of position indication	15
XLNPROXY	Proxy for signals from switching device via GOOSE	20
GOOSEXLNRCV	GOOSE function block to receive a switching device	20

Table 6: Total number of instances for configurable logic blocks Q/T

Configurable logic blocks Q/T	Total number of instances
ANDQT	120
INDCOMBSPQT	20
INDEXTSPQT	20
INVALIDQT	22
INVERTERQT	120
ORQT	120
PULSETIMERQT	40
RSMEMORYQT	40
SRMEMORYQT	40
TIMERSETQT	40
XORQT	40

Table 7: Total number of instances for extended logic package

Extended configurable logic block	Total number of instances
AND	220
GATE	49
INV	220
LLD	49
OR	220
PULSETIMER	89
RSMEMORY	40
SLGAPC	74
SRMEMORY	130
TIMERSET	113
VSGAPC	120
XOR	89

IEC 61850 or function name	ANSI	Function description	Railway
			RER670
Monitoring			
AISVBAS		General service value presentation of analog inputs	1
EVENT		Event function	14
DRPRDRE, A4RADR,		Disturbance report	1
SPGAPC		Generic communication function for Single Point indication	96
SP16GAPC		Generic communication function for Single Point indication 16 inputs	16
MVGAPC		Generic communication function for measured values	24
BINSTATREP		Logical signal status report	3
RANGE_XP		Measured value expander block	66
SSIMG	63	Insulation supervision for gas medium	21
SSIML	71	Insulation supervision for liquid medium	3
SSCBR		Circuit breaker condition monitoring	6-M15

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Railway
			RER670
RWRFLO		Fault locator, multi section	1-B60 1-B70
I103MEAS		Measurands for IEC 60870-5-103	1
I103MEASUSR		Measurands user defined signals for IEC 60870-5-103	3
I103AR		Function status auto-recloser for IEC 60870-5-103	1
I103EF		Function status earth-fault for IEC 60870-5-103	1
I103FLTPROT		Function status fault protection for IEC 60870-5-103	1
I103IED		IED status for IEC 60870-5-103	1
I103SUPERV		Supervison status for IEC 60870-5-103	1
I103USRDEF		Status for user defined signals for IEC 60870-5-103	14
L4UFCNT		Event counter with limit supervision	30
CHMMHAN	ITHD	Current harmonic monitoring, 2 phase	3-M25
VHMMHAN	VTHD	Voltage harmonic monitoring, 2 phase	3-M26
Metering			
PCFCNT		Pulse-counter logic	16
ETPMMTR		Function for energy calculation and demand handling	6

3.4 Communication

IEC 61850 or function name	ANSI	Function description	Railway
			RER670
Station communication			
LONSPA, SPA		SPA communication protocol	1
HORZCOMM		Network variables via LON	1
IEC 61850-8-1		IEC 61850	1

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Railway
			RER670
GOOSEINTLKRCV		Horizontal communication via GOOSE for interlocking	59
GOOSEBINRCV		GOOSE binary receive	11
GOOSEDPRCV		GOOSE function block to receive a double point value	40
GOOSEINTRCV		GOOSE function block to receive an integer value	24
GOOSEMVRCV		GOOSE function block to receive a measurand value	56
GOOSESPRCV		GOOSE function block to receive a single point value	40
MULTICMDRCV, MULTICMDSND		Multiple command and transmit	60/10
AGSAL		Generic security application component	1
LD0LLN0		IEC 61850 LD0 LLN0	1
SYSLLN0		IEC 61850 SYS LLN0	1
LPHD		Physical device information	1
PCMACCS		IED configuration protocol	1
FSTACCS		Field service tool access	1
		IEC 61850-9-2 Process bus communication, 8 merging units	1-P30
ACTIVLOG		Activity logging	1
ALTRK		Service tracking	1
PRP		IEC 62439-3 Parallel redundancy protocol	1-P23
HSR		IEC 62439-3 High-availability seamless redundancy	1-P24
PTP		Precision time protocol	1
SCHLCCH		Access point diagnostic for non-redundant Ethernet port	6
RCHLCCH		Access point diagnostic for redundant Ethernet ports	3
Remote communication			
BinSignRec1_1 BinSignRec1_2 BinSignReceive2		Binary signal transfer receive	3/3/6
BinSignTrans1_1 BinSignTrans1_2 BinSignTransm2		Binary signal transfer transmit	3/3/6
Scheme communication			
ZCPSCH	85	Scheme communication logic for distance or overcurrent protection	1-B60 1-B70
ZCRWPSCH	85	Current reversal and weak-end infeed logic for distance protection	1-B60 1-B70
ECPSCH	85	Scheme communication logic for residual overcurrent protection	1-B60 1-B70
ECRWPSCH	85	Current reversal and weak-end infeed logic for residual overcurrent protection	1-B60 1-B70

3.5 Basic IED functions

Table 8: 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
TIMEZONE	Time synchronization
IRIG-B	Time synchronization
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
SMMI	Signal matrix for mA inputs
SMAI1 - SMAI12	Signal matrix for analog inputs
ATHSTAT	Authority status
ATHCHCK	Authority check
AUTHMAN	Authority management
FTPACCS	FTP access with password
ALTMS	Time master supervision
ALTIM	Time management
COMSTATUS	Protocol diagnostic

Table 9: 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
Table continues on next page		

IEC 61850 or function name	ANSI	Description
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 4 Starting up

4.1 Factory and site acceptance testing

Testing the proper IED operation is carried out at different occasions, for example:

- Acceptance testing
- Commissioning testing
- Maintenance testing

This manual describes the workflow and the steps to carry out the commissioning testing.

Factory acceptance testing (FAT) is typically done to verify that the IED and its corresponding configuration meet the requirements of the utility or industry. This test is the most complex and in depth, as it is done to familiarize the user with a new product or to verify a new configuration. The complexity of this testing depends on several factors, such as:

- New IED type
- New configuration
- Modified configuration

Site acceptance testing (SAT or commissioning testing) is typically done to verify that the installed IED is correctly set and connected to the power system. SAT requires that the acceptance testing has been performed and that the application configuration is verified.

Maintenance testing is a periodic verification that the IED is healthy and has correct settings, depending on changes in the power system. There are also other types of maintenance testing.

4.2 Commissioning checklist

Before starting up commissioning at site, check that the following items are available.

- Single line diagram
- Protection block diagram
- Circuit diagram
- Setting list and configuration
- RJ-45 Ethernet cable (CAT 5)

- Three-phase test kit or other test equipment depending on the complexity of the configuration and functions to be tested.
- PC with PCM600 installed along with the connectivity packages corresponding to the IEDs to be tested.
- Administration rights on the PC, to set up IP addresses
- Product documentation (engineering manual, installation manual, commissioning manual, operation manual, technical manual and communication protocol manual)

4.3 Checking the power supply

Do not insert anything else to the female connector but the corresponding male connector. Inserting anything else (such as a measurement probe) may damage the female connector and prevent a proper electrical contact between the printed circuit board and the external wiring connected to the screw terminal block.

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

4.4 Energizing the IED

4.4.1 Checking the IED operation

Check all connections to external circuitry to ensure correct installation, before energizing the IED and carrying out the commissioning procedures.

Energize the power supply of the IED to start it up. Keep the DC power supply on until the Root menu or the selected default screen is shown on the HMI before interrupting the DC power supply again. The energization could be done in a number of ways, from energizing a whole cubicle with many IEDs to energizing each single IED one by one.

If HW (i.e. I/O and/or communication boards etc.) have been changed (i.e. removed, replaced, or added), the user should re-configure the IED by navigating in the local HMI menu to: **Main menu/Configuration/Reconfigure HW modules** to activate the changed hardware modules in order to enable the self-supervision function to detect possible hardware errors.

Check also the self-supervision function in **Main menu/Diagnostics/IED status/General** menu in local HMI to verify that the IED operates properly.

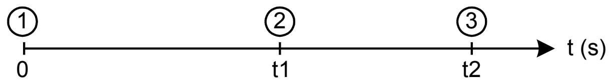
Set the IED time if no time synchronization source is configured.

To ensure that the IED is according to the delivery and ordering specifications documents delivered together with each IED, the user should also after start-up use the built in HMI to check the IED's:

- Software version, **Main menu/Diagnostics/IED status/Product identifiers**.
- Serial number, **Main menu/Diagnostics/IED status/Product identifiers**.
- Installed modules and their ordering number, **Main menu/Diagnostics/IED status/Installed HW**.

4.4.2 IED start-up sequence

When the IED is energized, the green LED starts flashing instantly. After approximately 55 seconds the window lights up and the window displays 'IED Startup'. The main menu is displayed and the upper row should indicate 'Ready' after about 90 seconds. A steady green light indicates a successful startup.



xx04000310-1-en.vsd

Figure 2: Typical IED start-up sequence

1 IED energized. Green LED instantly starts flashing

2 LCD lights up and "IED startup" is displayed

3 The main menu is displayed. A steady green light indicates a successful startup.

If the upper row in the window indicates 'Fail' instead of 'Ready' and the green LED flashes, an internal failure in the IED has been detected.

4.5 Setting up communication between PCM600 and the IED

The communication between the IED and PCM600 is independent of the communication protocol used within the substation or to the NCC.

The communication media is always Ethernet and the used transport layer is TCP/IP.

Each IED has an RJ-45 Ethernet interface connector on the front. The front Ethernet connector is recommended to be used for communication with PCM600.

When an Ethernet-based station protocol is used, PCM600 communication can use the same Ethernet port and IP address.

To connect PCM600 to the IED, two basic variants must be considered.

- Direct point-to-point link between PCM600 and the IED front port. The front port can be seen as a service port.
- A link via a station LAN or from remote via a network.

The physical connection and the IP address must be configured in both cases to enable communication.

The communication procedures are the same in both cases.

1. If needed, set the IP address for the IEDs.
2. Set up the PC or workstation for a direct link (point-to-point), or
3. Connect the PC or workstation to the LAN/WAN network.
4. Configure the IED IP addresses in the PCM600 project for each IED to match the IP addresses of the physical IEDs.

Setting up IP addresses

Communication between the IED and PCM600 is enabled from the LHMI. The IP address and the corresponding communication subnetwork mask must be set via the Ethernet configuration tool (ECT) for each available Ethernet interface in the IED. Each Ethernet interface has a default factory IP address when the IED is delivered. The IP adress and the subnetwork mask might have to be reset when an additional Ethernet interface is installed or an interface is replaced.

DHCP is available for the front port, and a device connected to it can thereby obtain an automatically assigned IP address via the local HMI path **Main menu/ Configuration/Communication/Ethernet configuration/Front port/DHCP**.

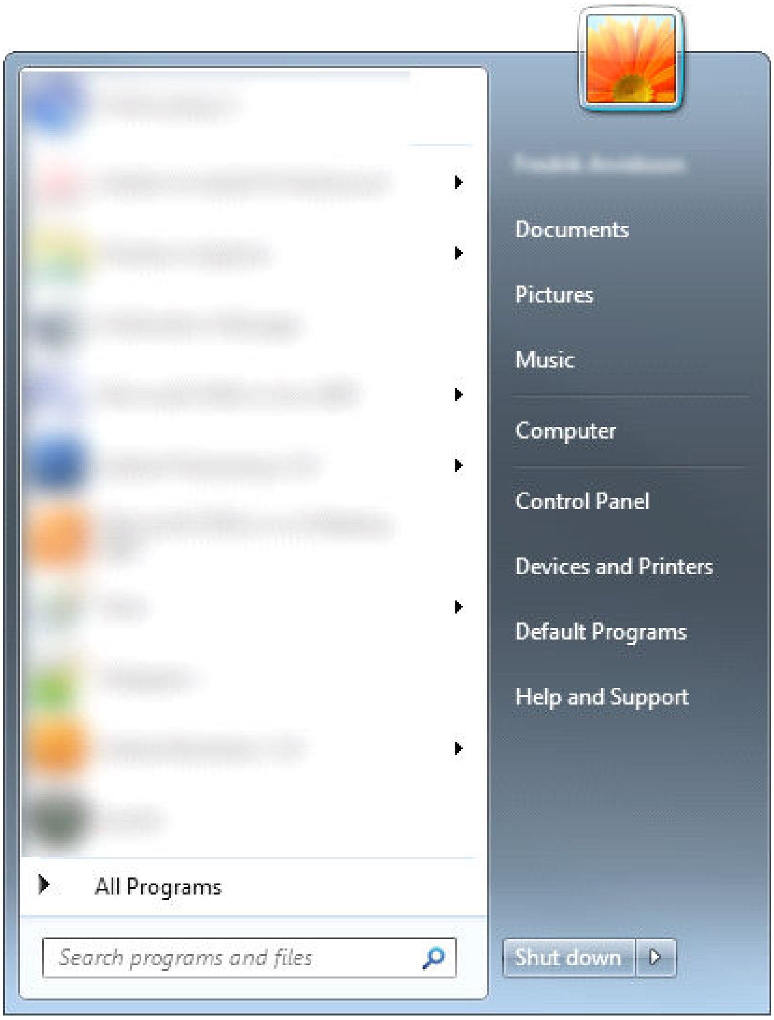
Alternatively the default IP address for the IED front port is 10.1.150.3 and the corresponding subnetwork mask is 255.255.255.0, which can be set via the local HMI path **Main menu/Configuration/Communication/TCP-IP configuration/ ETHFRNT:1Main menu/Configuration/Communication/Ethernet configuration/AP_FRONT**.

Setting up the PC or workstation for point-to-point access to IEDs front port

An ethernet cable (max 2 m length) with RJ-45 connectors is needed to connect two physical Ethernet interfaces together without a hub, router, bridge or switch in between.

If an IED is equipped with optical LC interface, a converter between RJ-45 and LC is needed.

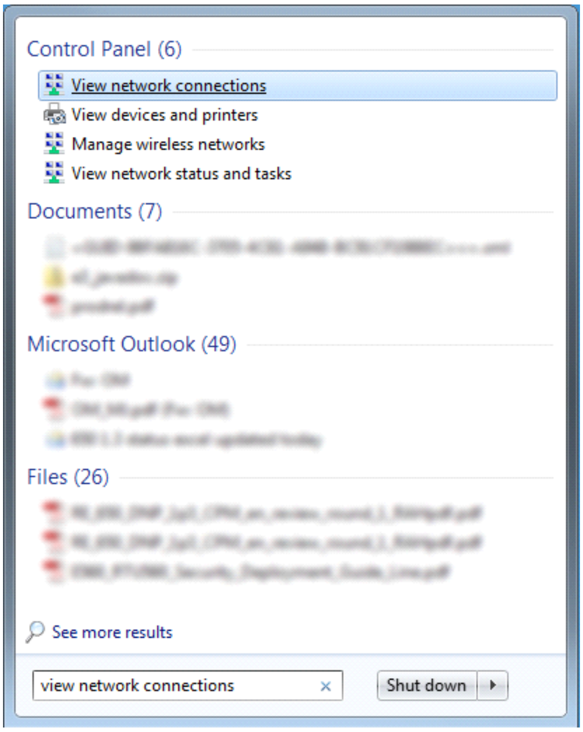
1. Select **Search programs and files** in the **Start menu** in Windows.



IEC13000057-1-en.vsd

Figure 3: Select: Search programs and files

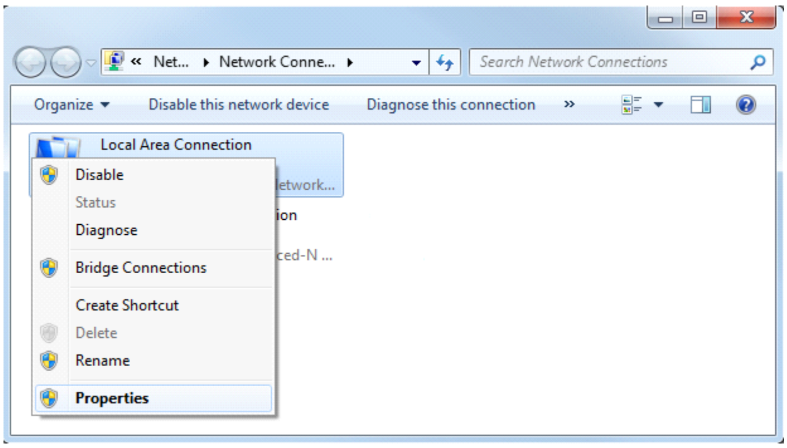
2. Type **View network connections** and click on the **View network connections** icon.



IEC13000058-1-en.vsd

Figure 4: Click View network connections

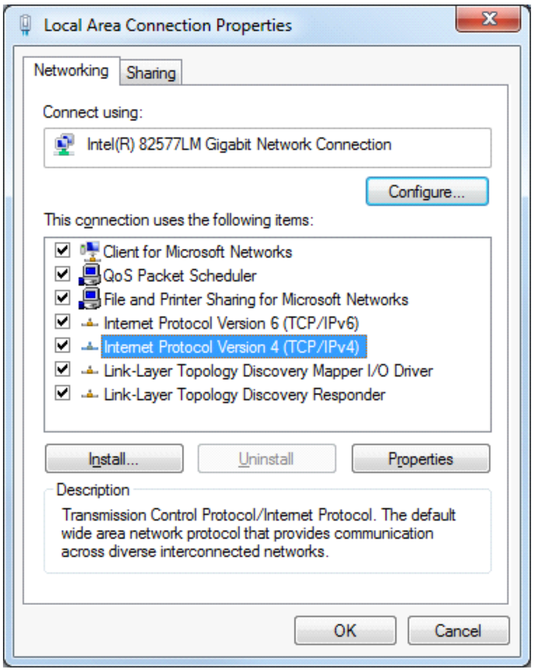
3. Right-click and select **Properties**.



IEC13000059-1-en.vsd

Figure 5: Right-click Local Area Connection and select Properties

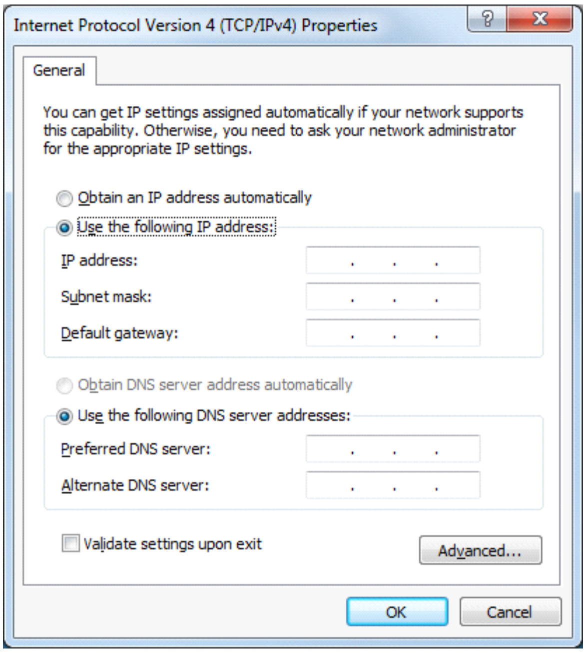
4. Select the TCP/IPv4 protocol from the list of configured components using this connection and click **Properties**.



IEC13000060-1-en.vsd

Figure 6: Select the TCP/IPv4 protocol and open Properties

5. Select **Use the following IP address** and define *IP address* and *Subnet mask* if the front port is used and if the *IP address* is not set to be obtained automatically by the IED,see Figure 7. The IP address must be different from the IP address chosen for the IED.



IEC13000062-1-en.vsd

Figure 7: Select: Use the following IP address

6. Use the *ping* command to verify connectivity with the IED.
7. Close all open windows and start PCM600.

The PC and IED must belong to the same subnetwork for this set-up to work.

Setting up the PC to access the IED via a network

The same method is used as for connecting to the front port.

The PC and IED must belong to the same subnetwork for this set-up to work.

4.6 Writing an application configuration to the IED

When writing a configuration to the IED with PCM600, the IED is automatically set in configuration mode. When the IED is set in configuration mode, all functions are blocked. The red LED on the IED flashes, and the green LED is lit while the IED is in the configuration mode.

When the configuration is written and completed, the IED is automatically set into normal mode. For further instructions please refer to the users manuals for PCM600.

4.7 Checking CT circuits

Check that the wiring is in strict accordance with the supplied connection diagram.

The CTs must be connected in accordance with the circuit diagram provided with the IED, both with regards to phases and polarity. The following tests shall be performed on every primary CT connected to the IED:

- Primary injection test to verify the current ratio of the CT, the correct wiring up to the protection IED and correct phase sequence connection (that is L1, L2, L3.)
- Polarity check to prove that the predicted direction of secondary current flow is correct for a given direction of primary current flow. This is an essential test for the proper operation of the differential function and directional protection functions.
- CT secondary loop resistance measurement to confirm that the current transformer secondary loop DC resistance is within the specification for the connected protection functions. When the measured loop resistance is near the calculated value for maximum DC resistance, perform a complete burden test.
- CT excitation test in order to confirm that the current transformer is of the correct accuracy rating and that there are no shorted turns in the current transformer windings. Manufacturer's design curves must be available for the current transformer to compare the actual results.
- Earthing check of the individual CT secondary circuits to verify that each three-phase set of main CTs is properly connected to the station earth and only at one electrical point.
- Insulation resistance check.

While the CT primary is energized, the secondary circuit shall never be open circuited because extremely dangerous high voltages may arise.

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

If the CT secondary circuit earth connection is removed without the current transformer primary being de-energized, dangerous voltages may result in the secondary CT circuits.

4.8 Checking VT circuits

Check that the wiring is in strict accordance with the supplied connection diagram.

Correct possible errors before continuing to test the circuitry.

Test the circuitry.

- Polarity check when applicable; this test is often omitted for CVTs
- VT circuit voltage measurement (primary injection test)
- Earthing check
- Phase relationship
- Insulation resistance check

The primary injection test verifies the VT ratio and the wiring all the way from the primary system to the IED. Injection must be performed for each phase-to-neutral circuit.

While testing VT secondary circuit and associated secondary equipment, care shall be exercised to isolate the VT from the circuit being tested to avoid backcharging the VT from the secondary side.

4.9 Using the RTXP test switch

The RTXP test switch is designed to provide the means of safe testing of the IED. This is achieved by the electromechanical design of the test switch and test plug handle. When the test plug handle is inserted, it first blocks the trip and alarm circuits then it short circuits the CT secondary circuit and opens the VT secondary circuits making the IED available for secondary injection.

When pulled out, the test handle is mechanically stopped in half withdrawn position. In this position, the current and voltage enter the protection, but the alarm and trip circuits are still isolated and the IED is in test mode. Before removing the test handle, check the measured values in the IED.

Not until the test handle is completely removed, the trip and alarm circuits are restored for operation.

Verify that the contact sockets have been crimped correctly and that they are fully inserted by tugging on the wires. Never do this with current circuits in service.

Current circuit

1. Verify that the contacts are of current circuit type.
2. Verify that the short circuit jumpers are located in the correct slots.

Voltage circuit

1. Verify that the contacts are of voltage circuit type.
2. Check that no short circuit jumpers are located in the slots dedicated for voltage.

Trip and alarm circuits

1. Check that the correct types of contacts are used.

4.10 Checking the binary input/output circuits

Do not insert anything else to the female connector but the corresponding male connector. Inserting anything else (such as a measurement probe) may damage the female connector and prevent a proper electrical contact between the printed circuit board and the external wiring connected to the screw terminal block.

4.10.1 Binary input circuits

Preferably, disconnect the binary input connector from the binary input cards. Check all connected signals so that both input level and polarity are in accordance with the IED specifications.

4.11 Checking optical connections

Check that the Tx and Rx optical connections are correct.

An IED equipped with optical connections has an minimum space requirement of 180 mm for plastic fiber cables and 275 mm for glass fiber cables. Check the allowed minimum bending radius from the optical cable manufacturer.

Section 5 Configuring the IED and changing settings

5.1 Overview

The customer specific values for each setting parameter and a configuration file have to be available before the IED can be set and configured, if the IED is not delivered with a configuration.

Use the configuration tools in PCM600 to verify that the IED has the expected configuration.

Each function included in the IED has several setting parameters, which have to be set in order to make the IED behave as intended. A factory default value is provided for each parameter.The Parameter Setting Tool in PCM600 is used when changing setting parameters.

All settings can be

- Entered manually through the local HMI.
- Written from a PC, either locally or remotely using PCM600. Front or rear port communication has to be established before the settings can be written to the IED.

Make sure that the DC supply is not turned off when the IED saves the written configuration.

The IED uses a FLASH disk for storing configuration data and process data like counters, object states, Local/Remote switch position etc. Since FLASH memory is used, measures have been taken in software to make sure that the FLASH disk is not worn out by too intensive storing of data.

This means, that to be absolutely sure that all data have been saved to FLASH, it is necessary to leave the IED with auxiliary power connected after all the commissioning is done(including setting the Local/Remote switch to the desired position) for at least one hour after the last commissioning action performed on the IED.

After that time has elapsed, it will be safe to turn the IED off, no data will be lost.

5.2 Configuring analog CT inputs

The analog input channels must be configured to get correct measurement results as well as correct protection functionality. Because all protection algorithms in the IED utilize the primary system quantities, it is extremely important to make sure that connected current transformer settings are done properly. These data are calculated by the system engineer and normally set by the commissioner from the local HMI or from PCM600.

The analog inputs on the transformer input module are dimensioned for either 1A or 5A. Each transformer input module has a unique combination of current and voltage inputs. Make sure the input current rating is correct and that it matches the order documentation.

The primary CT data are entered via the HMI menu under **Main menu/ Configurations/Analog modules**

The following parameter shall be set for every current transformer connected to the IED:

Table 10: CT configuration

Parameter description	Parameter name	Range	Default
Rated CT primary current in A	CTPRIMn n = channel number	from 0 to 99999	3000

This parameter defines the primary rated current of the CT. For two set of CTs with ratio 1000/1 and 1000/5 this parameter is set to the same value of 1000 for both CT inputs. The parameter *CTStarPoint* can be used in order to reverse the direction of the CT. This might be necessary if two sets of CTs have different star point locations in relation to the protected busbar.

For main CTs with 2A rated secondary current, it is recommended to connect the secondary wiring to the 1A input.

Take the rated permissive overload values for the current inputs into consideration.

5.3 Supervision of input/output modules

I/O modules configured with PCM600 (BIM, BOM or IOM) are supervised.

I/O modules that are not configured are not supervised.

Each logical I/O module has an error flag that indicates signal or module failure. The error flag is also set when the physical I/O module of the correct type is not detected in the connected slot.

Section 6 Establishing connection and verifying the SPA/IEC communication

6.1 Entering settings

If the IED is connected to a monitoring or control system via the rear SPA/IEC103 port, the SPA/IEC103 port has to be set either for SPA or IEC103 use.

6.1.1 Entering SPA settings

The SPA/IEC port is located on the rear side of the IED. Two types of interfaces can be used:

- plastic fibers with connector type HFBR
- glass fibers with connector type ST

When using the SPA protocol, the rear SPA/IEC port must be set for SPA use.

Procedure:

1. Set the port 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.
2. Set the *SlaveAddress* and *BaudRate* for the rear SPA port on the local HMI under **Main menu/Configuration/Communication/Station communication/SPA/SPA:1**. Use the same settings for these as is set in the SMS system for the IED.

6.1.2 Entering IEC settings

The SPA/IEC port is located on the rear side of the IED. Two types of interfaces can be used:

- plastic fibers with connector type HFBR
- glass fibers with connector type ST

When using the IEC protocol, the rear SPA/IEC port must be set for IEC use.

Procedure:

1. Set the port for IEC 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 an IEC port.
2. Set the *SlaveAddress* and *BaudRate* for the rear IEC port on the local HMI under **Main menu/Configuration/Communication/Station communication/IEC60870-5-103/OPTICAL103:1**. Use the same settings for these as is set in the SMS system for the IED.

6.2 Verifying the communication

To verify that the rear communication with the SMS/SCS system is working, there are some different methods. Choose one of the following.

6.2.1 Verifying SPA communication

Procedure

1. Use a SPA-emulator and send “RF” to the IED. The answer from the IED should be the type and version of it, for example, “REL670 2.1...”.
2. Generate one binary event by activating a function, which is configured to an EVENT block where the used input is set to generate events on SPA. The configuration must be made with the PCM600 software. Verify that the event is presented in the SMS/SCS system.

During the following tests of the different functions in the IED, verify that the events and indications in the SMS/SCS system are as expected.

6.2.2 Verifying IEC communication

To verify that the IEC communication with the IEC master system is working, there are some different methods. Choose one of the following.

Procedure

1. Check that the master system time-out for response from the IED, for example after a setting change, is > 40 seconds.
2. Use a protocol analyzer and record the communication between the IED and the IEC master. Check in the protocol analyzer’s log that the IED answers the master messages.
3. Generate one binary event by activating a function that is configured to an event block where the used input is set to generate events on IEC. The configuration must be made with the PCM600 software. Verify that the event is presented in the IEC master system.

During the following tests of the different functions in the IED, verify that the events and indications in the IEC master system are as expected.

6.3 Fiber optic loop

The SPA communication is mainly used for SMS. It can include different numerical IEDs with remote communication possibilities. The fiber optic loop can contain < 20-30 IEDs depending on requirements on response time. Connection to a personal computer (PC) can be made directly (if the PC is located in the substation) or by telephone modem through a telephone network with ITU (CCITT) characteristics.

Table 11: Max distances between IEDs/nodes

glass	< 1000 m according to optical budget
plastic	< 25 m (inside cubicle) according to optical budget

6.4 Optical budget calculation for serial communication with SPA/IEC

Table 12: Example

	Distance 1 km Glass	Distance 25 m Plastic
Maximum attenuation	- 11 dB	- 7 dB
4 dB/km multi mode: 820 nm - 62.5/125 um	4 dB	-
0.16 dB/m plastic: 620 nm - 1mm	-	4 dB
Margins for installation, aging, and so on	5 dB	1 dB
Losses in connection box, two contacts (0.5 dB/contact)	1 dB	-
Losses in connection box, two contacts (1 dB/contact)	-	2 dB
Margin for 2 repair splices (0.5 dB/splice)	1 dB	-
Maximum total attenuation	11 dB	7 dB

Section 7 Establishing connection and verifying the LON communication

7.1 Communication via the rear ports

7.1.1 LON communication

LON communication is normally used in substation automation systems. Optical fiber is used within the substation as the physical communication link.

The test can only be carried out when the whole communication system is installed. Thus, the test is a system test and is not dealt with here.

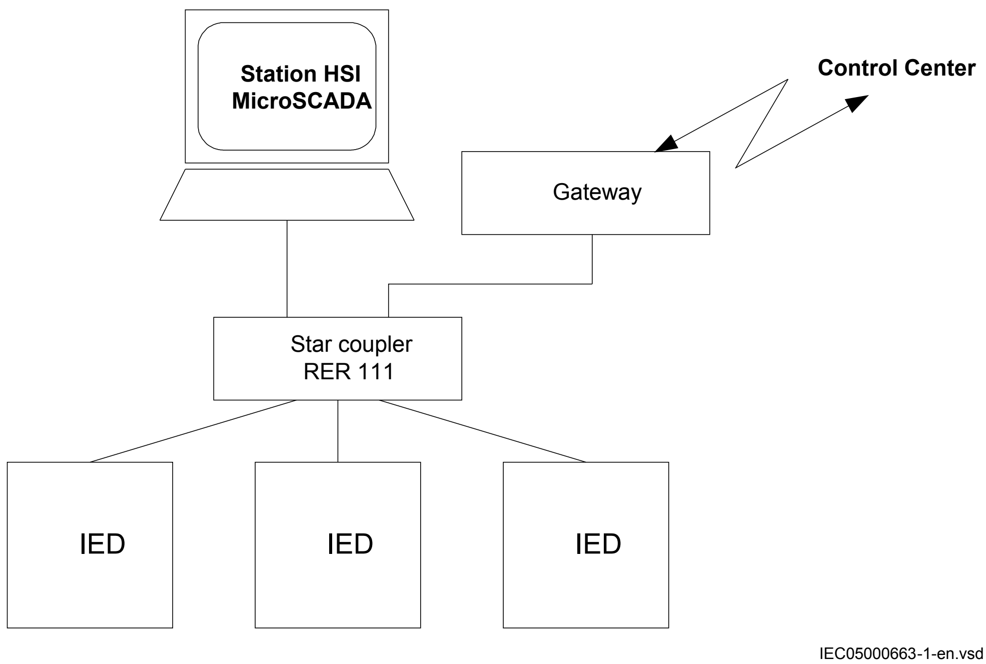


Figure 8: Example of LON communication structure for a substation automation system

An optical network can be used within the substation 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 fiber optic LON bus is implemented using either glass core or plastic core fiber optic cables.

Table 13: Specification of the fiber optic connectors

	Glass fiber	Plastic fiber
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)

7.1.2 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.

7.1.3 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 fibers 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.

7.2 Optical budget calculation for serial communication with LON

Table 14: Example

	Distance 1 km Glass	Distance10 m Plastic
Maximum attenuation	-11 dB	- 7 dB
4 dB/km multi mode: 820 nm - 62.5/125 um	4 dB	-
0.3 dB/m plastic: 620 nm - 1mm	-	3 dB
Margins for installation, aging, and so on	5 dB	2 dB
Losses in connection box, two contacts (0.75 dB/contact)	1.5 dB	-
Losses in connection box, two contacts (1dB/contact)	-	2 dB
Margin for repair splices (0.5 dB/splice)	0.5 dB	-
Maximum total attenuation	11 dB	7 dB

Section 8 Establishing connection and verifying the IEC 61850 communication

8.1 Overview

The rear optical Ethernet ports are used for:

- process bus (IEC/UCA 61850-9-2LE) communication
- substation bus (IEC 61850-8-1) communication

8.2 Setting the station communication

To enable IEC 61850 communication, the corresponding ports must be activated. The rear access points can be used for IEC 61850-8-1 and IEC/UCA 61850-9-2LE communication. IEC 61850-8-1 redundant communication requires the use of two Ethernet ports, when it is activated for Ethernet port the next immediate port is selected as the second Ethernet port and will become hidden.

When configuring RER670 for 9-2LE streams in a 16,7Hz system, the IED shall be set to 16,7Hz and the MU to 50Hz (4kHz sampling).

To enable IEC 61850 station communication:

In this example access points 1, 2 and 3 are used.

1. Activate IEC 61850-8-1 (substation bus) communication.
   Navigate to: **Main menu/Configuration/Communication/Station communication/IEC61850–8–1/IEC61850–8–1:1**
2. Enable operation for Access Point 1 and 3 in the Ethernet configuration tool (ECT) in PCM600.
3. Enable redundant communication for Acess point 1 using ECT.
4. Enable IEC/UCA 61850-9-2LE (process bus) communication for Access point 3 by connecting it to a Merging unit in the Merging units tab in ECT.

There are no settings needed for the IEC/UCA 61850-9-2LE communication in the local HMI branch **Station communication**. Make sure that the optical fibers are connected correctly. Communication is enabled whenever the merging unit starts sending data.

8.3 Verifying the communication

To verify that the communication is working a test/analyzing tool, for example ITT600, can be used.

Verifying redundant IEC 61850-8-1 communication

Ensure that the IED receives IEC 61850-8-1 data on the selected Ethernet ports. Browse in the local HMI to **Main menu/Diagnostics/Communication/Ethernet status/Access point/APStatusRedundant/RCHLCCH:1** and check that ChARedStatus and ChBRedStatus are shown as *Ok*. Remove the optical connection to one of the Ethernet ports. Verify that either signal status (depending on which connection that was removed) is shown as *Error* and the that other signal is shown as *Ok*. Be sure to re-connect the removed connection after completed verification.

Section 9 Testing IED operation

9.1 Preparing for test

9.1.1 Requirements

IED test requirements:

- Calculated settings
- Application configuration diagram
- Signal matrix (SMT) configuration
- Terminal connection diagram
- Technical manual
- Three-phase test equipment
- Process bus, IEC/UCA 61850-9-2LE, MU test simulator, if IEC/UCA 61850-9-2LE process bus communication is used.
- PCM600

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

The terminal diagram, available in the technical reference manual, is a general diagram of the IED.

Note that the same diagram is not always applicable to each specific delivery (especially for the configuration of all the binary inputs and outputs).

Therefore, before testing, check that the available terminal diagram corresponds to the IED.

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

The test equipment should be able to provide a three-phase supply of voltages and currents. The magnitude of voltage and current as well as the phase angle between voltage and current must be variable. The voltages and currents from the test equipment must be obtained from the same source and they must have minimal harmonic content. If the test equipment cannot indicate the phase angle, a separate phase-angle measuring instrument is necessary.

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

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

- Binary outputs signals
- Service values on the local HMI (logical signals or phasors)
- A PC with PCM600 application configuration software in work online mode

All setting groups that are used should be tested.

This IED is designed for a maximum continuous current of four times the rated current.

All references to CT and VT must be interpreted as analog values received from merging units (MU) via IEC/UCA 61850-9-2LE communication protocol, analog values received from the transformer input module, or analog values received from the LDCM.

When using a MU test simulator, make sure it is set to the correct SVID and that the system frequency is set to the same as in the IED.

Please observe the measuring accuracy of the IED, the test equipment and the angular accuracy for both of them.

Consider the configured logic from the function block to the output contacts when measuring the operate time.

After intense testing, it is important that the IED is not immediately restarted, which might cause a faulty trip due to flash memory restrictions. Some time must pass before the IED is restarted. For more information about the flash memory, refer to section “Configuring the IED and changing settings”.

9.1.2 Preparing the IED to verify settings

If a test switch is included, start preparation by making the necessary connections to the test switch. This means connecting the test equipment according to a specific and designated IED terminal diagram.

Put the IED into the test mode to facilitate the test of individual functions and prevent unwanted operation caused by other functions. The busbar differential protection is not included in the test mode and is not prevented to operate during the test operations. The test switch should then be connected to the IED.

Verify that analog input signals from the analog input module are measured and recorded correctly by injecting currents and voltages required by the specific IED.

To make testing even more effective, use PCM600. PCM600 includes the Signal monitoring tool, which is useful in reading the individual currents and voltages, their amplitudes and phase angles. In addition, PCM600 contains the Disturbance handling tool. The content of reports generated by the Disturbance handling tool can be configured which makes the work more efficient. For example, the tool may be configured to only show time tagged events and to exclude analog information and so on.

Check the disturbance report settings to ensure that the indications are correct.

For information about the functions to test, for example signal or parameter names, see the technical manual. The correct initiation of the disturbance recorder is made on start and/or release or trip from a function. Also check that the wanted recordings of analog (real and calculated) and binary signals are achieved.

Parameters can be entered into different setting groups. Make sure to test functions for the same parameter setting group. If needed, repeat the tests for all different setting groups used. The difference between testing the first parameter setting group and the remaining is that there is no need for testing the connections.

During testing, observe that the right testing method, that corresponds to the actual parameters set in the activated parameter setting group, is used.

Set and configure the function(s) before testing. Most functions are highly flexible and permit a choice of functional and tripping modes. The various modes are checked at the factory as part of the design verification. In certain cases, only modes with a high probability of coming into operation need to be checked when commissioned to verify the configuration and settings.

9.2 Activating the test mode

Put the IED into the test mode before testing. The test mode blocks all protection functions and some of the control functions in the IED, and the individual functions to be tested can be unblocked to prevent unwanted operation caused by other functions. In this way, it is possible to test slower back-up measuring functions without the interference from faster measuring functions. The test switch should then be connected to the IED.Test mode is indicated when the yellow StartLED flashes.

It is important that the IED function to be tested is put into test mode, even if the MU is sending data marked as "test". The IED will interpret these data as valid if it is not in test mode.

1. Browse to the **TESTMODE** menu and press *E*.
   The **TESTMODE** menu is found on the local HMI under **Main menu/ Test/IED test mode/TESTMODE**
2. Use the up and down arrows to choose *On* and press *E*.
3. Press the left arrow to exit the menu.
   The dialog box *Save changes* appears.
4. Choose *Yes*, press *E* and exit the menu.
   The yellow startLED above the LCD will start flashing when the IED is in test mode.

9.3 Preparing the connection to the test equipment

The IED can be equipped with a test switch of type RTXP8, RTXP18 or RTXP24. The test switch and its associated test plug handle (RTXH8, RTXH18 or RTXH24) are a part of the COMBITEST system, which provides secure and convenient testing of the IED.

When using the COMBITEST, preparations for testing are automatically carried out in the proper sequence, that is, for example, blocking of tripping circuits, short circuiting of CTs, opening of voltage circuits, making IED terminals available for secondary injection. Terminals 1 and 8, 1 and 18 as well as 1 and 12 of the test switches RTXP8, RTXP18 and RTXP24 respectively are not disconnected as they supply DC power to the protection IED.

The RTXH test-plug handle leads may be connected to any type of test equipment or instrument. When a number of protection IEDs of the same type are tested, the test-plug handle only needs to be moved from the test switch of one protection IED to the test switch of the other, without altering the previous connections.

Use COMBITEST test system to prevent unwanted tripping when the handle is withdrawn, since latches on the handle secure it in the half withdrawn position. In this position, all voltages and currents are restored and any re-energizing transients are given a chance to decay before the trip circuits are restored. When the latches are released, the handle can be completely withdrawn from the test switch, restoring the trip circuits to the protection IED.

If a test switch is not used, perform measurement according to the provided circuit diagrams.

Never disconnect the secondary connection of a current transformer circuit without first short-circuiting the transformer's secondary winding. Operating a current transformer with the secondary winding open will cause a massive potential build up that may damage the transformer and cause personal injury.

9.4 Connecting the test equipment to the IED

Connect the test equipment according to the IED specific connection diagram and the needed input and output signals for the function under test. An example of a connection is shown in figure 9.

Connect the current and voltage terminals. Pay attention to the current polarity. Make sure that the connection of input and output current terminals and the connection of the residual current conductor is correct. Check that the input and output logical signals in the logic diagram for the function under test are connected to the corresponding binary inputs and outputs of the IED under test.

To ensure correct results, make sure that the IED as well as the test equipment are properly earthed before testing.

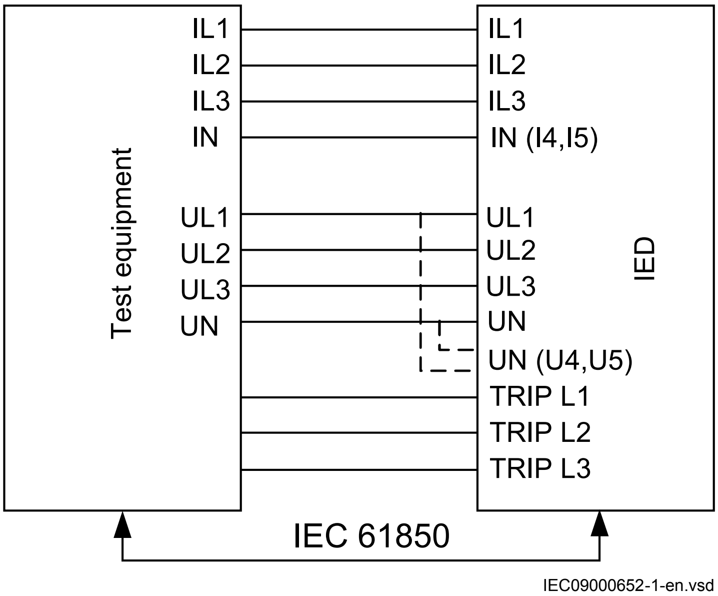


Figure 9: Connection example of the test equipment to the IED when test equipment is connected to the transformer input module

9.5 Releasing the function to be tested

Release or unblock the function to be tested. This is done to ensure that only the function or the chain of functions to be tested are in operation and that other functions are prevented from operating. Release the tested function(s) by setting the corresponding *Blocked* parameter under Function test modes to *No* in the local HMI .

When testing a function in this blocking feature, remember that not only the actual function must be activated, but the whole sequence of interconnected functions (from measuring inputs to binary output contacts), including logic must be activated. Before starting a new test mode session, scroll through every function to ensure that only the function to be tested (and the interconnected ones) have the parameters *Blocked* and eventually *EvDisable* set to *No* and *Yes* respectively. Remember that a function is also blocked if the BLOCK input signal on the corresponding function block is active, which depends on the configuration. Ensure that the logical status of the BLOCK input signal is equal to 0 for the function to be tested. Event function blocks can also be individually blocked to ensure that no events are reported to a remote station during the test. This is done by setting the parameter *EvDisable* to *Yes*.

Any function is blocked if the corresponding setting in the local HMI under **Main menu/Test/Function test modes** menu remains *On*, that is, the parameter *Blocked* is set to *Yes* and the parameter *TESTMODE* under **Main menu/Test/IED test mode** remains active. All functions that were blocked or released in a previous test mode session, that is, the parameter *Test mode* is set to *On*, are reset when a new test mode session is started.

Procedure

1. Click the **Function test modes** menu.
   The Function test modes menu is located in the local HMI under **Main menu/Test/Function test modes**.
2. Browse to the function instance that needs to be released.
3. Set parameter *Blocked* for the selected function to *No*.

9.6 Verifying analog primary and secondary measurement

Verify that the connections are correct and that measuring and scaling is done correctly. This is done by injecting current and voltage to the IED.

Besides verifying analog input values from the merging unit via the IEC/UCA 61850-9-2LE process bus, analog values from the transformer input module can be verified as follows.

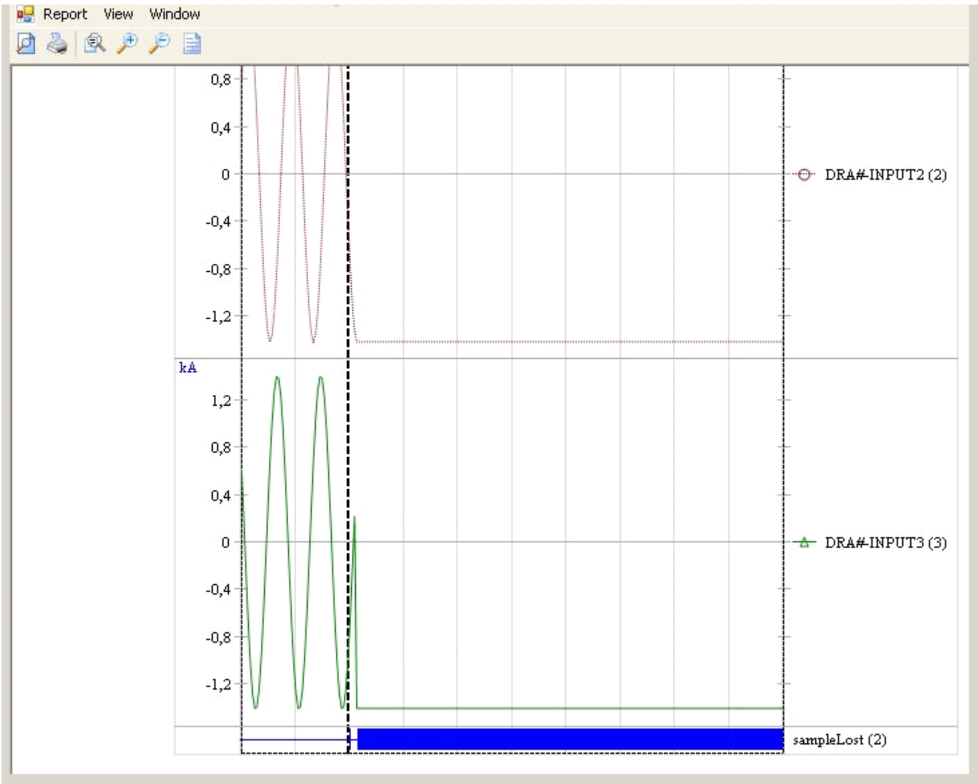
Apply input signals as needed according to the actual hardware and the application configuration.

1. Inject a symmetrical three-phase voltage and current at rated value.
2. Compare the injected value with the measured values.
   The voltage and current phasor menu in the local HMI is located under **Main menu/Measurements/Analog primary values** and **Main menu/Measurements/Analog secondary values**.
3. Compare the frequency reading with the set frequency and the direction of the power.
   The frequency and active power are located under **Main menu/Measurements/Monitoring/ServiceValues(MMXN)/CVMMXN:x**. Then navigate to the bottom of the list to find the frequency.
4. Inject an unsymmetrical three-phase voltage and current, to verify that phases are correctly connected.

If some setting deviates, check the analog input settings under

Main menu/Configuration/Analog modules

If the IEC/UCA 61850-9-2LE communication is interrupted during current injection, the report tool in PCM600 will display the current that was injected before the interruption.



IEC10000032-1-en.vsd

Figure 10: PCM600 report tool display after communication interruption

9.7 Testing the protection functionality

Each protection function must be tested individually by secondary injection.

- Verify operating levels (trip) and timers.
- Verify alarm and blocking signals.
- Use the disturbance handling tool in PCM600 to evaluate that the protection function has received the correct data and responded correctly (signaling and timing).
- Use the event viewer tool in PCM600 to check that only expected events have occurred.

9.8 Forcing of binary input/output signals for testing

9.8.1 Forcing concept

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, IOM & SOM) can be set to a value (i.e active or not-active), selected by the user, while the IED is in test mode. For inputs, this is true regardless of the actual signal voltage present on the input. For outputs, any output relay can be forced to be active or not, regardless of the current requested state of the output in the IED logic configuration.

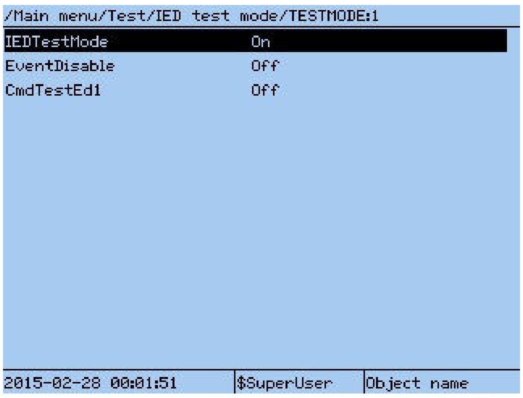
Be observant that forcing of binary inputs and outputs on an IED, with inappropriate setup, can result in potential danger.

9.8.2 How to enable forcing

To enable forcing, the IED must first be put into IED test mode. While the IED is not in test mode, the LHMI/PCM600 menus that relate to forcing will not have any effect on the input/output status due to safety reasons.

9.8.2.1 Enable forcing by using LHMI

1. Enable IED TESTMODE by setting *IEDTestMode* to *On* under **Main menu/ Test/IED test mode/TESTMODE:1**.



IEC15000029-1-en

2. Exit back to the root menu.
3. Select *Yes* in the save dialogue box.
   Once the IED is in test mode the yellow Start LED starts to blink.

9.8.2.2 Enable forcing using TESTMODE function block

- Use the TESTMODE function block, appropriately configured in PCM600/ ACT.

It may be convenient to control the input on mentioned component from, for example, an LHMI function key or similar during commissioning to quickly and easily enter IED test mode.

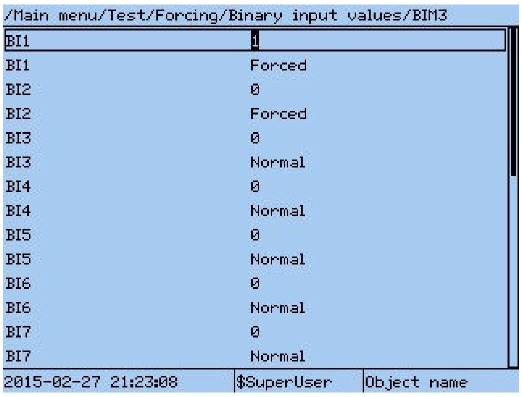
9.8.3 How to change binary input/output signals using forcing

Once the IED is in IED test mode, the LHMI/PCM600 menus can be used to control input/output signals freely.

9.8.3.1 Forcing by using LHMI

Editing a signal value directly

- Edit the input/output value directly to select the desired logical level, by doing following:
  1. Select the value line of the desired signal, see figure 11.
  2. Press the Enter key to edit the value.



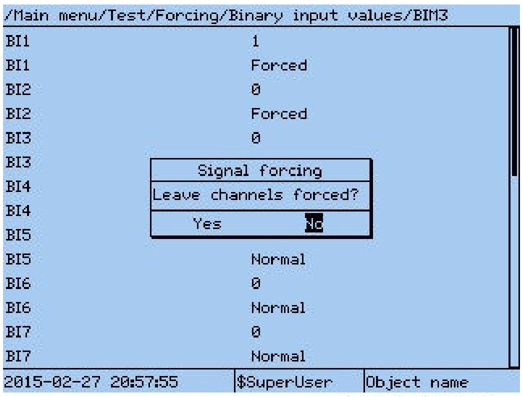
IEC15000021-1-en

Figure 11: Value line of the desired signal

  3. Use the up/down arrows on the LHMI to change the signal value or the appropriate menu in PCM600.
     The status of the signal changes automatically to Forced (i.e. there is no need to set the status to Forced manually).

On the LHMI, these edit changes have immediate effect. This means that the value changes directly when the up/down arrow is pressed (i.e. there is no need to press the Enter key to effectuate the change).

When navigating away from a LHMI forcing menu for an I/O board, the user is prompted to either leave the signals forced, or to revert all of them back to the unforced state.

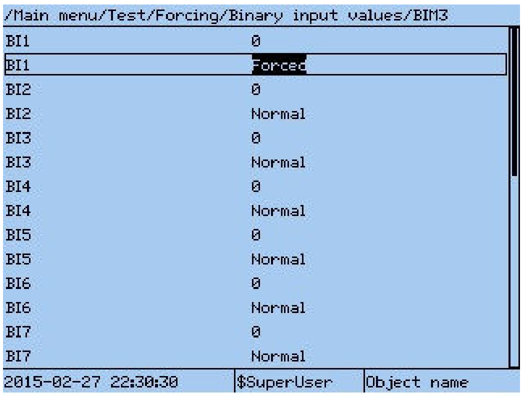


IEC15000022-1-en

It is possible to power-cycle the IED in this state without losing the forcing states and values. This means that once a signal is forced, and the IED remains in IED test mode, the input or output will appear “frozen” at the value selected by the user, even if the IED is switched off and back on again.

Freezing a signal value without changing it

- Set the status of a signal to Forced, in the forcing menu that corresponds to the I/O card in question. See example of LHMI menu in figure 12



IEC15000020-1-en

Figure 12: Example of LHMI menu using BIM3

The signal “freezes” and will not change value even if, for example, a binary input signal voltage changes level, or if a binary output is activated as the result of a protection function block activating.

9.8.3.2 Forcing by using PCM600

In PCM600 the concept is a bit different compared to LHMI.The forcing is accomplished by entering a forcing session. Within such a session, multiple signals on multiple I/O boards may be edited and changed at the same time and has no effect on the IED. Once the user is satisfied with the forcing setup, then all the changes can be effectuated simultaneously towards the IED, potentially changing inputs and outputs on multiple I/O boards at the same time. It is also possible to abort this operation (described in step 6 below) and to undo all forcing.

1. Right click on the IED in the plant structure and select *Signal Monitoring.*
2. Click on the *List View* tab.
3. Click *Forcing Session* in the menu *IED/Start Forcing*.

IEC15000023-1-en

4. Click *Start editing signal value for forcing* on the tool bar.

IEC15000024-1-en

The Signal Monitoring menu changes and indicates the forcing values that can be edited.

Index	Module Name	Module Type	Channel Name	Channel Type	Signal Name	Signal Value	Signal Unit
91	IOM_5	Hardware Module (Hardware I/O)	BI4	Binary Input	BI4	false	
92	IOM_5	Hardware Module (Hardware I/O)	BI4STATUS	Binary Output	BI4STATUS	Normal	
93	IOM_5	Hardware Module (Hardware I/O)	BI5	Binary Input	BI5	false	
94	IOM_5	Hardware Module (Hardware I/O)	BI5STATUS	Binary Output	BI5STATUS	Normal	
95	IOM_5	Hardware Module (Hardware I/O)	BI6	Binary Input	BI6	false	
96	IOM_5	Hardware Module (Hardware I/O)	BI6STATUS	Binary Output	BI6STATUS	Normal	
97	IOM_5	Hardware Module (Hardware I/O)	BI7	Binary Input	BI7	false	
98	IOM_5	Hardware Module (Hardware I/O)	BI7STATUS	Binary Output	BI7STATUS	Normal	
99	IOM_5	Hardware Module (Hardware I/O)	BI8	Binary Input	BI8	false	
100	IOM_5	Hardware Module (Hardware I/O)	BI8STATUS	Binary Output	BI8STATUS	Normal	
101	IOM_5	Hardware Module (Hardware I/O)	OSCWRN	Binary Input	OSCWRN	Normal operation	
102	IOM_5	Hardware Module (Hardware I/O)	BO1VALUE	Binary Output	BO1VALUE	false	
103	IOM_5	Hardware Module (Hardware I/O)	BO1	Binary Output	BO1	Normal	
104	IOM_5	Hardware Module (Hardware I/O)	BO2VALUE	Binary Output	BO2VALUE	false	
105	IOM_5	Hardware Module (Hardware I/O)	BO2	Binary Output	BO2	Normal	
106	IOM_5	Hardware Module (Hardware I/O)	BO3VALUE	Binary Output	BO3VALUE	false	
107	IOM_5	Hardware Module (Hardware I/O)	BO3	Binary Output	BO3	Normal	
108	IOM_5	Hardware Module (Hardware I/O)	BO4VALUE	Binary Output	BO4VALUE	false	
109	IOM_5	Hardware Module (Hardware I/O)	BO4	Binary Output	BO4	Normal	
110	IOM_5	Hardware Module (Hardware I/O)	BO5VALUE	Binary Output	BO5VALUE	false	
111	IOM_5	Hardware Module (Hardware I/O)	BO5	Binary Output	BO5	Normal	
112	IOM_5	Hardware Module (Hardware I/O)	BO6VALUE	Binary Output	BO6VALUE	false	
113	IOM_5	Hardware Module (Hardware I/O)	BO6	Binary Output	BO6	Normal	
114	IOM_5	Hardware Module (Hardware I/O)	BO7VALUE	Binary Output	BO7VALUE	true	
115	IOM_5	Hardware Module (Hardware I/O)	BO7	Binary Output	BO7	Normal	
116	IOM_5	Hardware Module (Hardware I/O)	BO8VALUE	Binary Output	BO8VALUE	false	
117	IOM_5	Hardware Module (Hardware I/O)	BO8	Binary Output	BO8	Normal	
118	IOM_5	Hardware Module (Hardware I/O)	BO9VALUE	Binary Output	BO9VALUE	false	
119	IOM_5	Hardware Module (Hardware I/O)	BO9	Binary Output	BO9	Normal	
120	IOM_5	Hardware Module (Hardware I/O)	BO10VALUE	Binary Output	BO10VALUE	false	
121	IOM_5	Hardware Module (Hardware I/O)	BO10	Binary Output	BO10	Normal	
122	IOM_5	Hardware Module (Hardware I/O)	BO11VALUE	Binary Output	BO11VALUE	false	

IEC15000025-1-en

5. Select and edit the values.
6. Click *Acknowledge and send*.

IEC15000026-1-en

This commits the values to the IED and exits the editing session.

7. Click *Cancel* to abort the changes and revert back to actual IED values.

IEC15000032-1-en

Regardless if the forcing changes are commited or canceled, the forcing is still active.

To force more signals, click the button *Start editing signal value for forcing* again.

9.8.4 How to undo forcing changes and return the IED to normal operation

Regardless of which input/output signals have been forced, all forced signals will return to their normal states immediately when the IED is taken out of test mode.

When the forcing is removed by exiting from IED test mode, both input and output signals may change values. This means that logic input signals may activate functions in the IED and that output relays may change state, which can be potentially dangerous.

9.8.4.1 Undo forcing by using TESTMODE component

- If the IED test mode was entered through the test mode function block:
  1. Deactivate the control input on that block.

  This immediately undoes all forcing, regardless of how it was accomplished and disabled all the way to force signals.

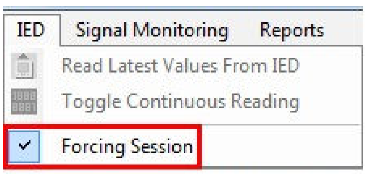
9.8.4.2 Undo forcing by using LHMI

- If the IED test mode was enabled to using the LHMI:
  1. Set *IEDTestMode* to *Off* in the *LHMI* menu.
  2. Exit from the menu and click *Yes* in the Save dialogue box.

  This immediately undoes all forcing, regardless of how it was accomplished and disabled.

9.8.4.3 Undo forcing by using PCM600

1. Uncheck *Forcing Session* under the menu *IED*.



IEC15000031-1-en

2. Click *Yes* in the confirmation dialogue box.
   PCM600 will revert all forced signals back to unforced and the real signal values will immediately take effect again.

This may change both binary input values and output relay states and will undo any forcing done by using the LHMI.

If the IED is left in test mode, then it is still possible to perform new forcing operations, both from LHMI and from PCM600

Section 10 Testing functionality by secondary injection

10.1 Testing disturbance report

10.1.1 Introduction

The following sub-functions are included in the disturbance report function:

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

If the disturbance report is set on, then its sub-functions are also set up and so it is not possible to only switch these sub-functions off. The disturbance report function is switched off (parameter *Operation* = *Off*) in PCM600 or the local HMI under **Main menu/Settings/IED Settings/Monitoring/Disturbance report/DRPRDRE: 1**.

10.1.2 Disturbance report settings

When the IED is in test mode, the disturbance report can be made active or inactive. If the disturbance recorder is turned on during test mode, recordings will be made. When test mode is switched off all recordings made during the test session are cleared.

Setting *OpModeTest* for the control of the disturbance recorder during test mode are located on the local HMI under **Main menu/Settings/IED Settings/ Monitoring/Disturbance report/DRPRDRE:1**.

10.1.3 Disturbance recorder (DR)

A *Manual Trig* can be started at any time. This results in a recording of the actual values from all recorded channels.

The *Manual Trig* can be started in two ways:

1. From the local HMI under **Main menu/Disturbance records**.
    1.1. Enter on the row at the bottom of the HMI called **Manual trig**.

A new recording begins. The view is updated if you leave the menu and return.

1.2. Navigate to **General information** or to **Trip values** to obtain more detailed information.

2. Open the Disturbance handling tool for the IED in the plant structure in PCM600.
   2.1. Right-click and select *Execute manual Trig* in the window *Available recordings in IED*.
   2.2. Read the required recordings from the IED.
   2.3. Refresh the window *Recordings* and select a recording.
   2.4. Right-click and select *Create Report* or *Open With* to export the recordings to any disturbance analyzing tool that can handle Comtrade formatted files.

Evaluation of the results from the disturbance recording function requires access to a PC either permanently connected to the IED or temporarily connected to the Ethernet port (RJ-45) on the front. The PCM600 software package must be installed in the PC.

Disturbance upload can be performed by the use of PCM600 or by any third party tool with IEC 61850 protocol. Reports can automatically be generated from PCM600. Disturbance files can be analyzed by any tool reading Comtrade formatted disturbance files.

It could be useful to have a printer for hard copies. The correct start criteria and behavior of the disturbance recording function can be checked when IED protective functions are tested.

When the IED is brought into normal service it is recommended to delete all recordings, made during commissioning to avoid confusion in future fault analysis.

All recordings in the IED can be deleted in two ways:

1. in the local HMI under **Main menu/Clear/Reset disturbances**, or
2. in the Disturbance handling tool in PCM600 by selecting *Delete all recordings in the IED...* in the window *Available Recordings in IED*.

10.1.4 Event recorder (ER) and Event list (EL)

The result from the event recorder and event list can be viewed on the local HMI or, after upload, in PCM600 as follows:

1. on the local HMI under **Main menu/Events**, or in more details via
2. the *Event Viewer* in PCM600.
   The internal FIFO register of all events will appear when the event viewer is launched.

When the IED is brought into normal service it is recommended to delete all events resulting from commissioning tests to avoid confusion in future fault analysis. All events in the IED can be cleared in the local HMI under **Main Menu//Clear/Clear internal event list** or **Main menu/Clear/Clear process event list**. It is not possible to clear the event lists from PCM600.

When testing binary inputs, the event list (EL) might be used instead. No uploading or analyzing of registrations is then needed since the event list keeps running, independent of start of disturbance registration.

10.2 Identifying the function to test in the technical reference manual

Use the technical manual to identify function blocks, logic diagrams, input and output signals, setting parameters and technical data.

10.3 Differential protection

10.3.1 Restricted earth fault protection, low impedance REFPDIF

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Logical signals for REFPDIF protection are available on the local HMI under **Main menu/Settings/IED Settings/Differential protection/LowImpREF(87N, IdN/I)/REFPDIF (87N; IdN/I):x**, , where x = 1 and 2.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

10.3.1.1 Verifying the settings

1. Connect the test set for single-phase current injection to the protection terminals connected to the CT in the power transformer neutral-to-earth circuit.
2. Increase the injection current more than the *IdMin* setting and note the operating value of the protection function.
3. Check that all trip and start signals appear according to the configuration logic.
4. Decrease the current slowly from operate value and note the reset value.
5. Connect the timer and set the current to ten times the value of the *IdMin* setting.
6. Switch on the current and note the operate time.

7. Connect the test set to terminal L1 and neutral of the two-phase current input configured to REFPDIF. Also inject a current higher than half the *IdMin* setting in the neutral-to-earth circuit with the same phase angle and with polarity corresponding to an internal fault.
8. Increase the current injected in L1, and note the operate value. Decrease the current slowly and note the reset value.
9. Inject current into terminal L2 in the same way as in step 7 above and note the operate and reset values.
10. Inject a current equal to half the *IdMin* setting into terminal L1.
11. Inject a current in the neutral-to-earth circuit with the same phase angle, amplitude and polarity corresponding to an external fault.
12. Increase the current to five times the operating value and check that the protection does not operate.
13. Finally check that trip information is stored in the event and disturbance recorder.

10.3.1.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.3.2 Single-phase railway power transformer differential protection T1PPDIF

Set the IED in *Test Mode*, and release the function to be tested. All other settings should be the same as when the IED is in operation.

Logical signal values for the single-phase railway power transformer differential protection (T1PPDIF) are available on the local HMI under **Main menu/Test/Function status/Differential Protection/T1PPDIF**

To verify the signals and settings, the following fault types should be tested:

- Restrained protection
- Unrestrained protection
- Directional unrestrained protection
- Directional sensitive protection
- Differential Alarm
- Blocking functionality

10.3.2.1 Verifying the restrained protection

1. Use settings for the installation.
2. Inject currents corresponding to the transformer rated current on both sides so that the differential current is 0% and the bias current is 100%.
3. Decrease the injected current on one side until TRRES is set, and note the value.
4. Increase the injected current until TRRES is reset, and note the value.

10.3.2.2 Verifying the unrestrained protection

1. Use the settings for the installation.
2. Feed one side of the IED with injected current only, increase the current until TRUNRES is set, and note the value.
3. Decrease the injected current until TRUNRES is reset, and note the value.

10.3.2.3 Verifying the directional unrestrained protection

1. Use settings for the installation.
2. Inject currents corresponding to the transformer rated current on both sides so that the differential current is 0% and the bias current is 100%.
3. Decrease the phase angle between the sides slowly from 180 degrees until TRDRUNR is set, and note the value of the angle between the two sides at the moment of the TRDRUNR operation.
4. Increase the phase angle back slowly until TRDRUNR resets, and note the value.

10.3.2.4 Verifying the directional sensitive protection

1. Use settings for the installation.
2. Inject currents corresponding to the transformer rated current on both sides so that the differential current is 0% and the bias current is 100%.
3. Make sure that both currents are above 10 percent of the rated current values.
4. Slowly decrease the phase angle between the sides from 180 degrees apart until TRDRSEN is set, and note the value.
5. Ensure that START is not set, otherwise it will block TRDRSEN.
6. Increase the phase angle back slowly until TRDRSEN resets, and note the value.

10.3.2.5 Verifying the differential alarm

1. Use settings for the installation.
2. Inject currents corresponding to the transformer rated current on both sides so that the differential current is 0% and the bias current is 100%.
3. Decrease the injected current on one side until IDALARM is set, and note the value and alarm delay.
4. Increase the injected current until IDALARM resets, and note the value.

10.3.2.6 Verifying the blocking functionality

1. Use the settings for the installation.
2. Inject currents corresponding to the transformer rated current on both sides so that the differential current is 0% and the bias current is 100%.
3. Decrease the injected current on one side until TRRES is set.
4. Increase the 2nd harmonic on one side above *I2/I1Ratio* and verify that TRRES is reset (blocked).
5. If required, use the same procedure to test the 5^{th} harmonic blocking feature.

10.3.2.7 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values if they were changed for testing purposes.

10.4 Impedance protection

10.4.1 Automatic switch onto fault logic ZCVPSOF

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

The automatic switch onto fault logic function ZCVPSOF is checked using secondary injection tests. ZCVPSOF is activated either by the external input BC or by the internal DLD. FUFSPVC is done with a pre-fault condition where the phase voltages and currents are at zero. A reverse two-phase fault with zero impedance and a two-phase fault with an impedance corresponding to the whole line is applied. This fault shall cause an instantaneous trip and result in a TRIP indication.

10.4.1.1 Activating ZCVPSOF externally

1. Set *AutoInitMode* to *DLD disabled* and *Mode* to *Impedance*.
2. Activate the switch onto fault BC input.

During normal operating conditions, the BC input is de-energized.

3. Apply a two-phase fault condition corresponding to a fault at approximately 45% of the line or with impedance at 50% of the used zone setting and current greater than 30% of *IBase*.
   The ZACC input is activated.
4. Check that the TRIP output, external signals and indication are obtained. The TRIP output will be obtained *tSOTF* after the BC input is activated.

10.4.1.2 Initiating ZCVPSOF automatically and setting mode to impedance

1. Set *AutoInitMode* to *Voltage* and *Mode* to *Impedance*.
2. Deactivate the switch onto fault BC input.
3. Set the current and voltage inputs to lower than *IPh<* and *UPh<* for at least *tDuration*.
4. Apply a two-phase fault condition corresponding to a fault at approximately 45% of the line or with impedance at 50% of the used zone setting and current greater than 30% of *IBase*.
   The ZACC input is activated.
5. Check that the correct TRIP output, external signals and indication are obtained after 15 ms from the ZACC input activation.

10.4.1.3 Initiating ZCVPSOF automatically and setting mode to UILevel

1. Set *AutoInitMode* to *Voltage* and *Mode* to *UILevel*.
2. Deactivate the switch onto fault BC input.
3. Set the current and voltage inputs to lower than *IPh<* and *UPh<* for at least *tDuration*.
4. Apply the two-phase currents in such a way that the magnitudes are greater than *IPh<* and the two-phase voltages in such a way that the magnitudes are lower than *UPh<* at least for the duration of the *tDuration* setting.
5. Check that the correct TRIP output, external signals and indication are obtained.
   The timing of the TRIP output depends on the *tDuration* setting and the distance protection release of the ZACC input signal.
   - If ZACC comes before the elapse of *tDuration*, TRIP will be activated *tDuration*+15 ms after *UPh* and *IPh* changes are done.
   - If *tDuration* elapses before the ZACC input signal activates, TRIP will be activated 15 ms after the ZACC activation.

10.4.1.4 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.4.2 Distance protection zone, quadrilateral characteristic ZRWPDIS

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for ZRWPDIS are available on the local HMI under **Main menu/Test/Function status/Impedance protection//DistanceProt2Ph(21,Z<)/ZRWPDIS(21;Z<):1**.

The Signal Monitoring tool in PCM600 shows same signals that are available on the Local HMI.

10.4.2.1 Verifying the signals and settings

Testing the underimpedance starting element

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to its rated value or lower. But make sure it is higher than the set minimum operating current.

Ensure that the maximum continuous current to the IED does not exceed four times its rated value, if the measurement of the operating characteristics runs under constant voltage conditions.

The test procedure has to take into consideration that the shaped load encroachment characteristic is active. It is therefore necessary to check the setting. To verify the settings with the shaped load encroachment characteristic, the test should be carried out according to figures mentioned below. In cases where the load encroachment characteristic is not activated, tests according to the adjusted figures should be carried out.

To verify the settings, the operating points according to the following fault types should be tested:

- One phase-to-earth fault
- One phase-to-phase fault

Set *Operation* to On always to check for performance of distance protection during testing.

Solidly earthed system

1. Select type of earthing system by setting parameter *SystemEarthing* and set to Solidly.
2. Select *CharStartZ<* to Circular and set *OpLoadEnch* to On.
3. Set *Z1CircleStart*, *REOverRLStart*, *XEOverXLStart*, *LineAng* and *ArgLd* to default values. Also, set *RLd* such that its value is lower than *Z1CircleStart*.

Phase-to-earth fault - circular characteristic

Test points that are to be considered for measurement accuracy of set impedance reach are shown in Figure 13 and Table 15.

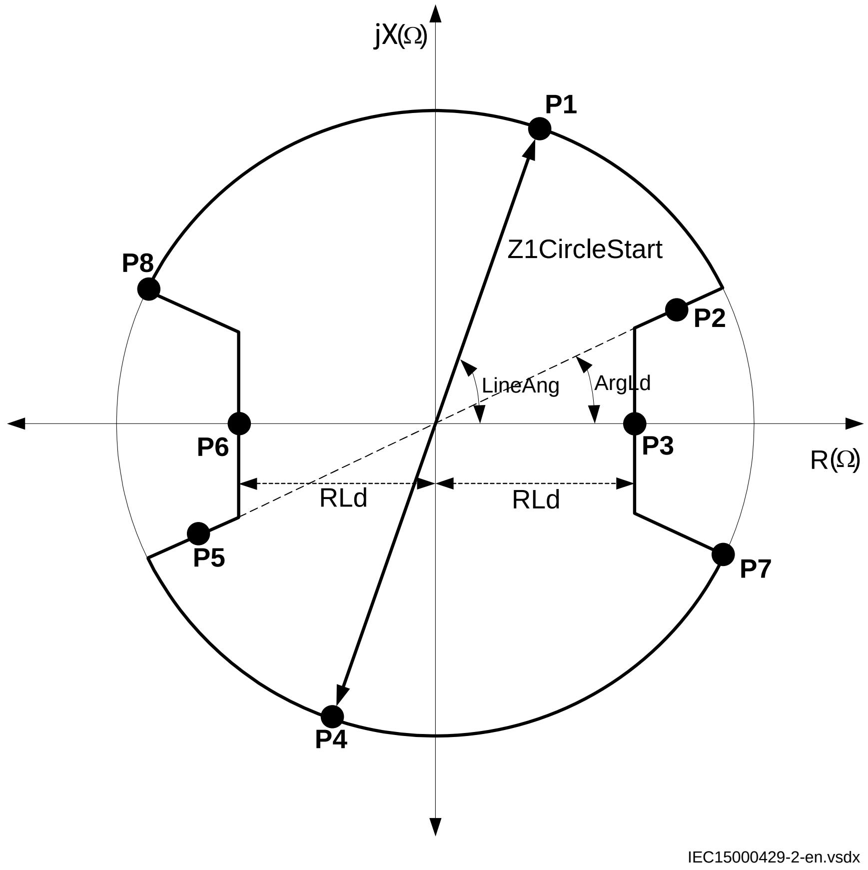


Figure 13: Proposed test points for phase-to-earth loop of circular characteristic in solidly earthed system

Table 15: Test points for phase-to-earth loop of circular characteristic

Test point	R	X	Comment
P1	*Z1CircleStart* * cos(*LineAng*) * (1+*REOverRLStart*)	*Z1CircleStart* * sin(*LineAng*) * (1+*XEOverXLStart*)	
P2	0.8 * *Z1CircleStart* * cos(*ArgLd*) * (1+*REOverRLStart*)	0.8 * *Z1CircleStart* * sin(*ArgLd*) * (1+*XEOverXLStart*)	If 2I0 < *I0MinOp*
P3	*RLd*	0	If 2I0 < *I0MinOp*
P4	-*Z1CircleStart* * cos(*LineAng*) * (1+*REOverRLStart*)	-*Z1CircleStart* * sin(*LineAng*) * (1+*XEOverXLStart*)	
P5	-0.8 * *Z1CircleStart* * cos(*ArgLd*) * (1+*REOverRLStart*)	-0.8 * *Z1CircleStart* * sin(*ArgLd*) * (1+*XEOverXLStart*)	If 2I0 < *I0MinOp*
Table continues on next page			

Test point	R	X	Comment
P6	-*RLd*	0	If 2I0 < *I0MinOp*
P7	*Z1CircleStart* * cos(*ArgLd*) * (1+*REOverRLStart*)	-*Z1CircleStart* * sin(*ArgLd*) * (1+*XEOverXLStart*)	
P8	-*Z1CircleStart* * cos(*ArgLd*) * (1+*REOverRLStart*)	*Z1CircleStart* * sin(*ArgLd*) * (1+*XEOverXLStart*)	

1. Change the magnitude and angle of phase-to-earth voltage in phase L1 to achieve impedances at test points P1, P2, …, P8.
2. For each test point, observe that the output signals STELEMST and STNDZL1 are activated.
3. Repeat the above test by injecting phase-to-earth voltage in phase L2 in accordance with test points and observe that the output signals STELEMST and STNDZL2 are activated.

Phase-to-phase fault - circular characteristic

Test points that are to be considered for measurement accuracy of set impedance reach are shown in Figure 14 and Table 16.

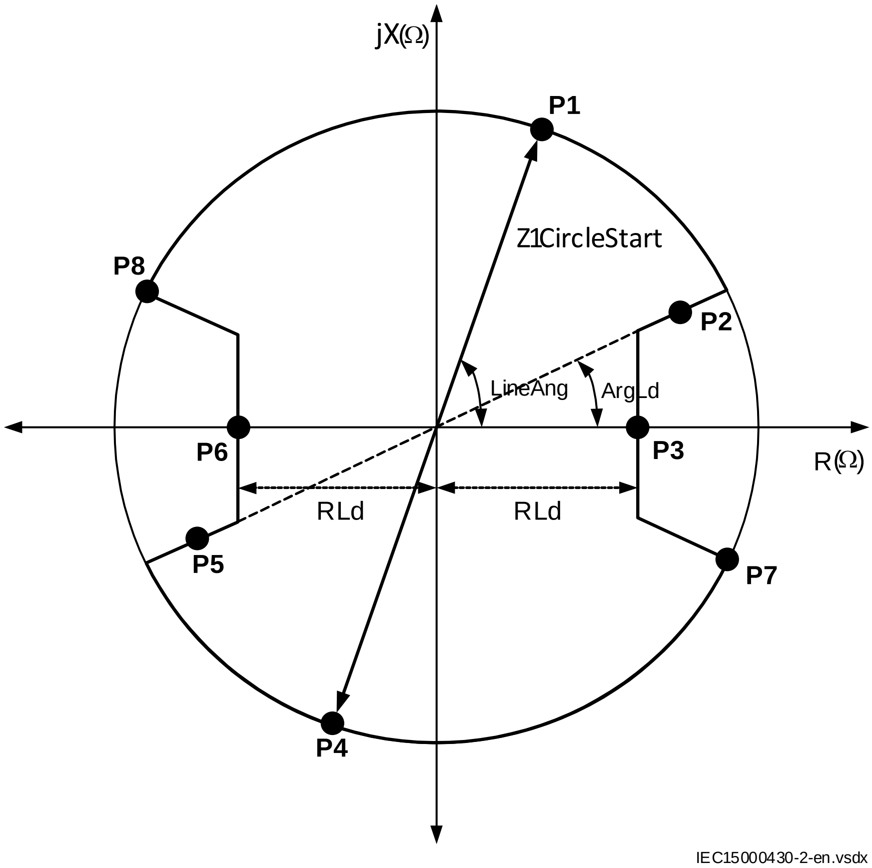


Figure 14: Proposed test points for phase-to-phase loop of circular characteristic in solidly earthed system

Table 16: Test points for phase-to-phase loop of circular characteristic

Test point	R	X	Comment
P1	*Z1CircleStart* * cos(*LineAng*)	*Z1CircleStart* * sin(*LineAng*)	
P2	0.8 * *Z1CircleStart* * cos(*ArgLd*)	0.8 * *Z1CircleStart* * sin(*ArgLd*)	
P3	RLd	0	
P4	-*Z1CircleStart* * cos(*LineAng*)	-*Z1CircleStart* * sin(*LineAng*)	
P5	-0.8 * *Z1CircleStart* * cos(*ArgLd*)	-0.8 * *Z1CircleStart* * sin(*ArgLd*)	
P6	-RLd	0	
P7	*Z1CircleStart* * cos(*ArgLd*)	-*Z1CircleStart* * sin(*ArgLd*)	
P8	-*Z1CircleStart* * cos(*ArgLd*)	*Z1CircleStart* * sin(*ArgLd*)	

1. Change the magnitude and angle of phase-to-phase voltage to achieve impedances at test points P1, P2, …, P8.
2. For each test point, observe that the output signals STELEMST, STNDZL1 and STNDZL2 are activated.

Change setting parameter *CharStartZ<* to Quadrilateral and set *OpLoadEnch* to On. Also, Set *X1Start*, *REOverRLStart*, *XEOverXLStart*, *LineAng*, *AngLd*, *RFPEStart* and *RFPPStart* to default values. Set *RLd* such that it is lower than *RFPEStart/RFPPStart*.

Phase-to-earth fault - quadrilateral characteristic

Test points that are to be considered for measurement accuracy of set reactive reach are shown in Figure 15 and Table 17.

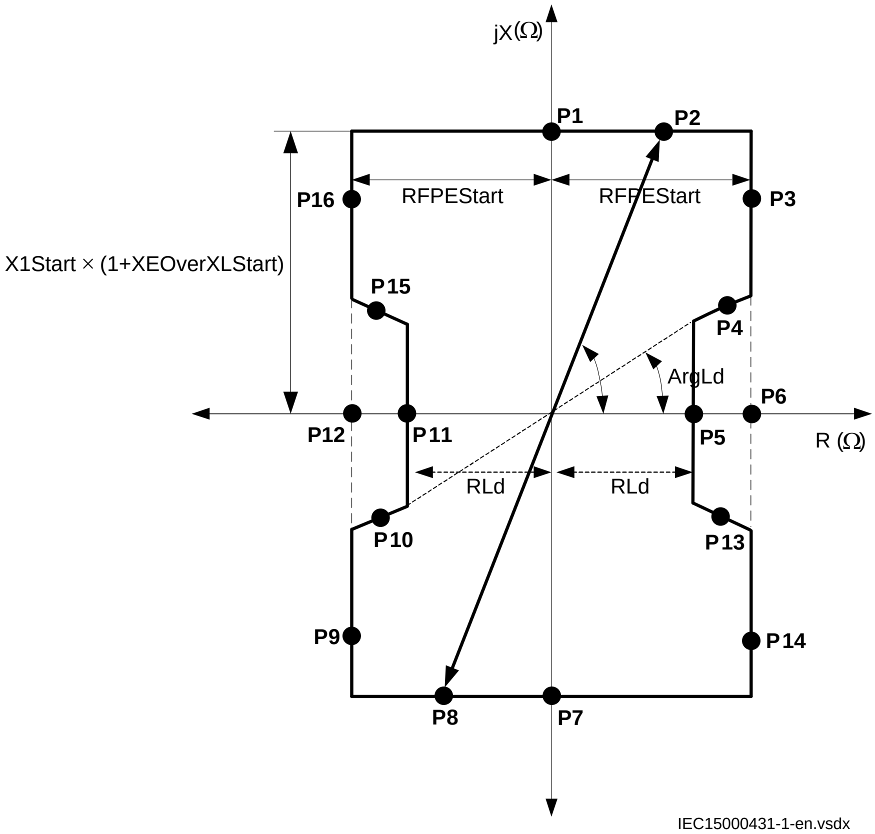


Figure 15: Proposed test points for phase-to-earth loop of quadrilateral characteristic in solidly earthed system

Table 17: Test points for phase-to-earth loop of quadrilateral characteristic

Test point	R	X	Comment
P1	0	*X1Start* * (1+*XEOverXLStart*)	
P2	((*X1Start* * (1+*XEOverXLStart*))/ tan(*LineAng*))	*X1Start* * (1+*XEOverXLStart*)	
P3	*RFPEStart*	0.8 * *X1Start* * (1+*XEOverXLStart*)	
P4	0.8 * *RFPEStart*	0.8 * *RFPEStart* * tan(*ArgLd*)	If 2I0 < *I0MinOp*
P5	*RLd*	0	If 2I0 < *I0MinOp*
P6	*RFPEStart*	0	If *OpLoadEnch* = Off or 2I0 > *I0MinOp*
P7	0	-*X1Start* * (1+*XEOverXLStart*)	
P8	-((*X1Start* * (1+*XEOverXLStart*))/ tan(*LineAng*))	-*X1Start* * (1+*XEOverXLStart*)	
P9	-*RFPEStart*	-0.8 * *X1Start* * (1+*XEOverXLStart*)	
P10	-0.8 * *RFPEStart*	-0.8 * *RFPEStart* * tan(*ArgLd*)	If 2I0 < *I0MinOp*
P11	-*RLd*	0	If 2I0 < *I0MinOp*
P12	-*RFPEStart*	0	If *OpLoadEnch* = Off or 2I0 > *I0MinOp*
P13	0.8 * *RFPEStart*	-0.8 * *RFPEStart* * tan(*ArgLd*)	If 2I0 < *I0MinOp*
P14	*RFPEStart*	-0.8 * *X1Start* * (1+*XEOverXLStart*)	
P15	-0.8 * *RFPEStart*	0.8 * *RFPEStart* * tan(*ArgLd*)	If 2I0 < *I0MinOp*
P16	-*RFPEStart*	0.8 * *X1Start* * (1+*XEOverXLStart*)	

1. Change the magnitude and angle of phase-to-earth voltage in phase L1 to achieve impedances at test points P1, P2, …, P16.
2. For each test point, observe that the output signals STELEMST and STNDZL1 are activated.
3. Repeat the above test by injecting phase-to-earth voltage in phase L2 in accordance with test points and observe that the output signals STELEMST and STNDZL2 are activated.

For phase-to-earth loop of quadrilateral characteristic in solidly earthed system used for starting element, the fault resistive reach can be expanded by considering *REOverRLStart* into their fault resistance settings and the resultant resistive reach becomes *RFPEStart* * (1 + *REOverRLStart*).

Phase-to-phase fault - quadrilateral characteristic

Test points that are to be considered for measurement accuracy of set reactive reach are shown in Figure 16 and Table 18.

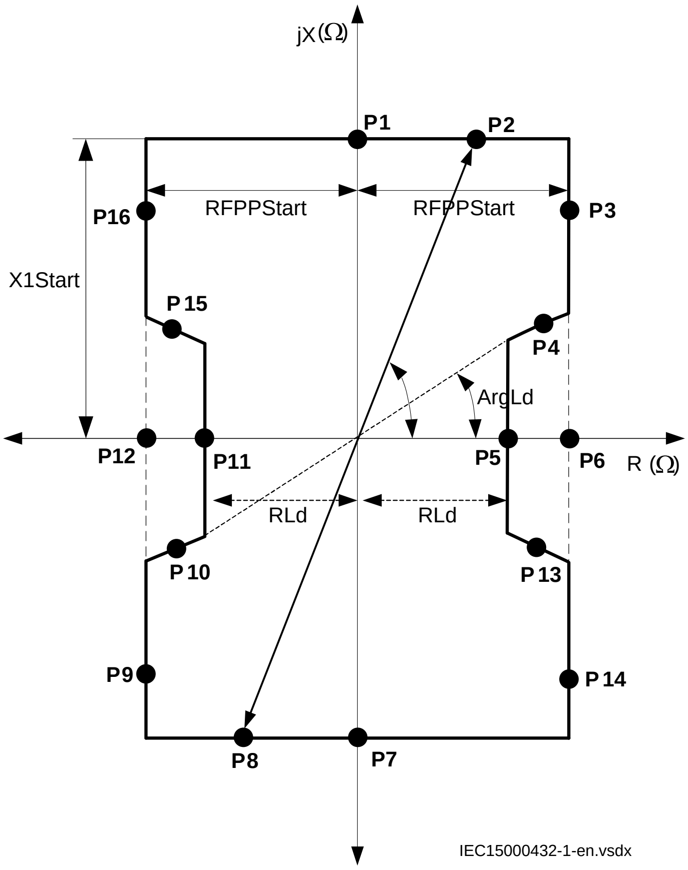


Figure 16: Proposed test points for phase-to-phase loop of quadrilateral characteristic in solidly earthed system

Table 18: Test points for phase-to-phase loop of quadrilateral characteristic

Test point	R	X	Comment
P1	0	*X1Start*	
P2	(*X1Start* / tan(*LineAng*))	*X1Start*	
P3	*RFPPStart*	0.8 * *X1Start*	
P4	0.8 * *RFPPStart*	0.8 * *RFPPStart* * tan(*ArgLd*)	
P5	*RLd*	0	
P6	*RFPPStart*	0	If *OpLoadEnch* = *Off*
Table continues on next page			

Test point	R	X	Comment
P7	0	-*X1Start*	
P8	-(*X1Start* / tan(*LineAng*))	-*X1Start*	
P9	-*RFPPStart*	-0.8 * *X1Start*	
P10	-0.8 * *RFPPStart*	-0.8 * *RFPPStart* * tan(*ArgLd*)	
P11	-*RLd*	0	
P12	-*RFPPStart*	0	If *OpLoadEnch* = *Off*
P13	0.8 * *RFPPStart*	-0.8 * *RFPPStart* * tan(*ArgLd*)	
P14	*RFPPStart*	-0.8 * *X1Start*	
P15	-0.8 * *RFPPStart*	0.8 * *RFPPStart* * tan(*ArgLd*)	
P16	-*RFPPStart*	0.8 * *X1Start*	

1. Change the magnitude and angle of phase-to-phase voltage to achieve impedances at test points P1, P2, …, P16.
2. For each test point, observe that the output signals STELEMST, STNDZL1 and STNDZL2 are activated.

Compensated/high impedance earthed systems

1. Select type of earthing system by setting parameter *SystemEarthing* and set to either Compensated or High impedance.
2. Select *CharStartZ<* to Circular and set *OpLoadEnch* to On.
3. Set *Z1CircleStart*, *REOverRLStart*, *XEOverXLStart*, *LineAng* and *ArgLd* to default values. Also, set *RLd* such that its value is lower than *Z1CircleStart*.

Phase-to-earth fault – circular characteristic

Test points that are to be considered for measurement accuracy of set impedance reach are shown in Figure 17 and Table 19.

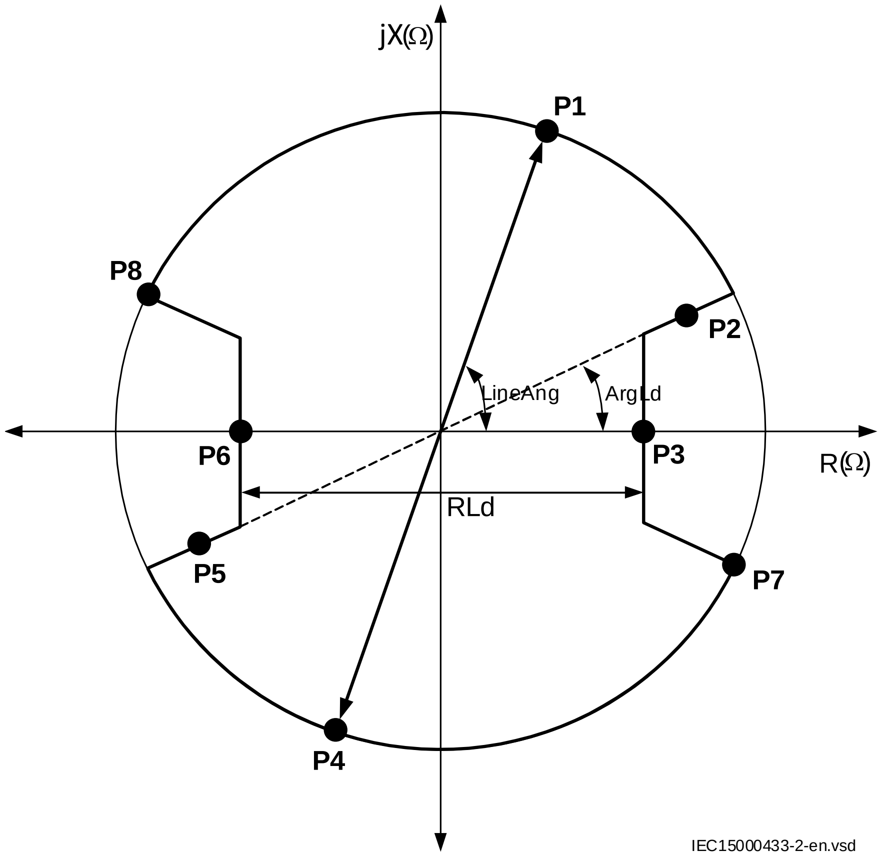


Figure 17: Proposed test points for phase-to-earth loop of circular characteristic in compensated/high impedance earthed systems

Table 19: Test points for phase-to-earth loop of circular characteristic for compensated/high impedance earthed systems

Test point	R	X	Comment
P1	*Z1CircleStart* /2 * cos(*LineAng*)	*Z1CircleStart* /2 * sin(*LineAng*)	
P2	0.8 * *Z1CircleStart* /2 * cos(*ArgLd*)	0.8 * *Z1CircleStart* /2 * sin(*ArgLd*)	If 2I0 < *I0MinOp*
P3	*RLd* /2	0	If 2I0 < *I0MinOp*
P4	-*Z1CircleStart* /2 * cos(*LineAng*)	-*Z1CircleStart* /2 * sin(*LineAng*)	
P5	-0.8 * *Z1CircleStart* /2 * cos(*ArgLd*)	-0.8 * *Z1CircleStart* /2 * sin(*ArgLd*)	If 2I0 < *I0MinOp*
P6	-*RLd* /2	0	If 2I0 < *I0MinOp*
P7	*Z1CircleStart* /2 * cos(*ArgLd*)	-*Z1CircleStart* /2 * sin(*ArgLd*)	
P8	-*Z1CircleStart* /2 * cos(*ArgLd*)	*Z1CircleStart* /2 * sin(*ArgLd*)	

1. Change the magnitude and angle of phase-to-earth voltage in phase L1 to achieve impedances at test points P1, P2, …, P8. At the same time, inject voltage magnitude of 0.0 V and current of 0.0 A in phase L2.
2. For each test point, observe that the output signals STELEMST and STNDZL1 are activated.
3. Repeat the above test by injecting phase-to-earth voltage in phase L2 in accordance with test points and steps described above and observe that the output signals STELEMST and STNDZL2 are activated.

Change setting parameter *CharStartZ<* to Quadrilateral and set *OpLoadEnch* to On. Also, Set *X1Start*, *REOverRLStart*, *XEOverXLStart*, *LineAng*, *AngLd*, and *RFPEStart* to default values. Ensure *RLd* value is lower than *RFPEStart*.

Phase-to-earth fault – quadrilateral characteristic

Test points that are to be considered for measurement accuracy of set reactive reach are shown in Figure 18 and Table 20.

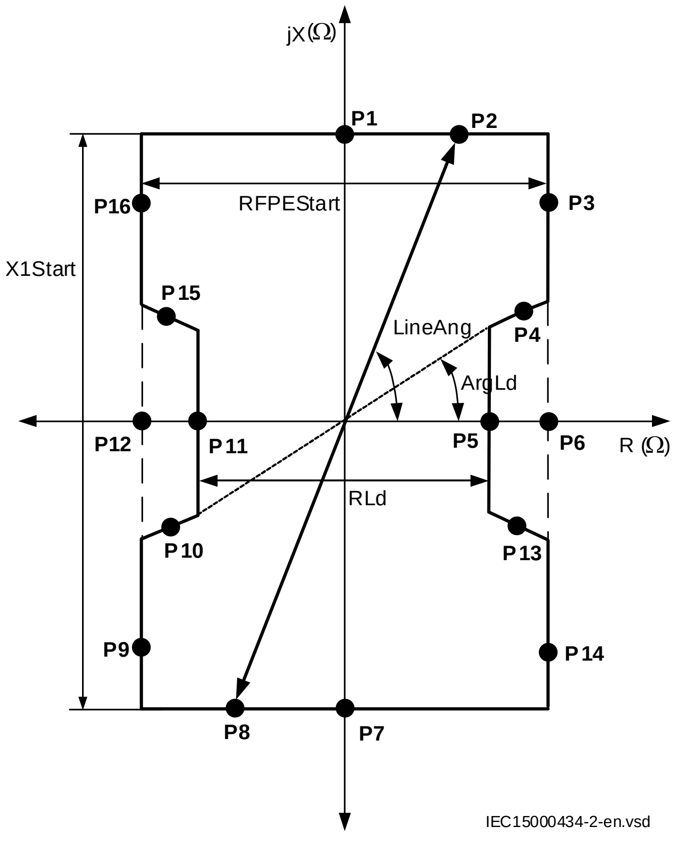


Figure 18: Proposed test points for phase-to-earth loop of quadrilateral characteristic in compensated/high impedance earthed systems

Table 20: Test points for phase-to-earth loop of quadrilateral characteristic for compensated/ high impedance earthed systems

Test point	R	X	Comment
P1	0	*X1Start* /2	
P2	(*X1Start* /2 / tan(*LineAng*))	*X1Start* /2	
P3	*RFPEStart* /2	0.8 * *X1Start* /2	
P4	0.8 * *RFPEStart* /2	0.8 * *RFPEStart* /2 * tan(*ArgLd*)	If 2I0 < *I0MinOp*
P5	*RLd* /2	0	If 2I0 < *I0MinOp*
P6	*RFPEStart* /2	0	If *OpLoadEnch* = Off or 2I0 > *I0MinOp*
P7	0	-*X1Start* /2	
P8	-(*X1Start* /2 / tan(*LineAng*))	-*X1Start* /2	
P9	-*RFPEStart* /2	-0.8 * *X1Start* /2	
P10	-0.8 * *RFPEStart* /2	-0.8 * *RFPEStart*/2 * tan(*ArgLd*)	If 2I0 < *I0MinOp*
P11	-*RLd* /2	0	If 2I0 < *I0MinOp*
P12	-*RFPEStart* /2	0	If *OpLoadEnch* = Off or 2I0 > *I0MinOp*
P13	0.8 * *RFPEStart* /2	-0.8 * *RFPEStart* /2 * tan(*ArgLd*)	If 2I0 < *I0MinOp*
P14	*RFPEStart* /2	-0.8 * *X1Start* /2	
P15	-0.8 * *RFPEStart* /2	0.8 * *RFPEStart* /2 * tan(*ArgLd*)	If 2I0 < *I0MinOp*
P16	-*RFPEStart* /2	0.8 * *X1Start* /2	

1. Change the magnitude and angle of phase-to-earth voltage in phase L1 to achieve impedances at test points P1, P2, …, P16. At the same time, inject voltage magnitude of 0.0 V and current of 0.0 A in phase L2.
2. For each test point, observe that the output signals STELEMST and STNDZL1 are activated.
3. Repeat the above test by injecting phase-to-earth voltage in phase L2 in accordance with test points and steps described above and observe that the output signals STELEMST and STNDZL2 are activated.

Testing the residual overcurrent start

Inject currents in both the phases so that the residual current (2I0) is measured and if it exceeds *KI0Stab* times maximum current measured in both the phases and also make sure that the residual current exceeds *I0MinOp* value, the outputs STELEMST and STIE are get activated.

Testing the phase selection element

Compensated earthed system

1. Create phase-to-earth fault as described in phase-to-earth fault in compensated/high impedance earthed system. Distance measuring loops L1E and L2E based on underimpedance starting will be blocked for measurement for a duration of *tI01*.
2. If a current magnitude is injected in a phase greater than *I01* set value, respective distance measuring loops L1E and L2E will be released for measurement. The output STCND would become 1 or 2.
3. Phase-to-phase loop L1L2 will be released for measurement if there is any start signal from underimpedance starting and no start signal from residual overcurrent start. The output STCND would become 4.
4. Create a fault so that there is no pick-up from underimpedance starting element and pick-up from residual overcurrent start. Set *ModeStubLine* to Off.
5. Measuring loop L1E will be released for distance measurement after set delay of *tI0* sec if magnitude of phase L1 is above *KI* times magnitude of phase L2 and *ModePhSelKI* set to Off. Repeat the same by injecting the current in phase L2. The output STCND would become 1 or 2.
6. Create a fault so that there is no pick-up from underimpedance starting element and pick-up from residual overcurrent start after a delay time of *tI0*. Set *ModePhSelKI* to On.
7. Difference between the two phase currents must be less than *I0MinPhSel* value in order to release either PE loops or PP loop for distance measurement based on mode of setting *ModeI0StRel*. The output STCND would become 3 or 4.

Solidly earthed system

1. Create a phase-to-earth fault as described in phase-to-earth fault in solidly earthed system.
2. Distance measuring loops L1E and L2E will be released if there were respective start signals from L1E and L2E loops of underimpedance starting element and residual overcurrent start. The output STCND would become 1 or 2.
3. Create a phase-to-phase fault as described in phase-to-phase fault in solidly earthed system.
4. Distance measuring loop L1L2 will be released if there is start output from phase-to-phase loop of underimpedance start and no start output from residual overcurrent start. The output STCND would become 4.
5. Three measuring loops will be released for distance measurement after delayed start output from residual overcurrent start by *tI0* sec if there were no start output from underimpedance starting and *ModeStubLine* set to Off. The output STCND would become 7.

High impedance earthed system

1. Create a phase-to-earth fault as described in phase-to-earth fault in compensated/high impedance earthed system. Distance measuring loops L1E and L2E will be released for measurement based on respective start outputs from underimpedance starting and also presence of residual overcurrent start. The output STCND would be 1 or 2.
2. Phase-to-phase loop L1L2 will be released for measurement if there is any start signal from underimpedance starting and no start signal from residual overcurrent start. The output STCND would become 4.
3. Three measuring loops will be released for distance measurement after delayed start output from residual overcurrent start by *tI0* sec if there were no start output from underimpedance starting and *ModeStubLine* set to Off. The output STCND would be 7.
4. Create a fault so that neutral voltage (UL1+UL2) is measured and if it exceeds set *U0DetMin* value, loops L1E and L2E will be released for measurement. The output STCND would be 3.

Testing the end zone timer function

End zone timer logic acts as remote back-up to the distance protection and utilizes the output signals from starting and phase selection elements.

1. To test end zone 1, set *OpModetEnd1* to On.
2. Set *OpDirEnd1* to Forward, *OpModeI0* to Off and *tEnd1* to default value.
3. Inject phase voltage and phase current in accordance with Chapter 'Phase-to-earth fault - circular characteristic' for test points P1, P2 and P3 or Chapter 'Phase-to-earth fault - quadrilateral characteristic' for test points P1, P2, P3, P4 and P5 if *SystemEarthing* is chosen as Solidly.
4. If *SysemEarthing* is selected as Compensated / High impedance, phase voltage and phase current will be injected in accordance with Chapter 'Phase-to-earth fault – circular characteristic' for test points P1, P2 and P3 or Chapter 'Phase-to-earth fault – quadrilateral characteristic' for test points P1, P2, P3, P4 and P5.
5. If *OpDirEnd1* is set to Non-directional, the injected phase voltage and phase current will be in accordance with Chapters 'Phase-to-earth fault - circular characteristic' and 'Phase-to-earth fault - quadrilateral characteristic' when *SystemEarthing* is chosen as Solidly and Chapters 'Phase-to-earth fault – circular characteristic' and 'Phase-to-earth fault - quadrilateral characteristic' when *SysemEarthing* is selected as Compensated / High impedance.
6. If *OpModeI0* is set to On, residual overcurrent based tripping will take place if there were no pick-up from underimpedance starting.
7. Trip outputs TRIP, TRL1 and TRL2 are get activated after set delay of *tEnd1*.
8. Repeat the above steps to test end zone 2 logic.

Testing the measuring element

1. Set *OpZx* to On, *DirModeZx* to Forward, *LEModeZx* to On, *LCModeZx* to Off and *PhSelModeZx* to Phsel logic. Assume that the output LDCND is available before performing testing of measuring zone for accuracy. Where x = 1, 2, …, 6.
2. Set *ZoneCharSym* to NonSymmetry.
3. Set *ModePhPref* to Equal priority.
4. Set *ArgNegRes* and *ArgDir* to their default values.
5. Set *X1FWZx*, *LineAng*, *ArgLd*, *REOverRLZx*, *XEOverXLZx*, *RFPEFwZx*, *RFPERvZx*, *RFPPFwZx* and *RFPPRvZx* accordingly. Also, ensure that the *RLd* value is lower than set *RFPEFWZx/RFPPFwZx* values.
6. Reach settings of starting element must be larger than zone reach settings to have proper selectivity.

Phase-to-earth fault – measuring element

Test points that are to be considered for measurement accuracy of set reactance reach are shown in Figure 19 and Table 21.

Where:

X1Fw = *X1FwZx* * (1 + *XEOverXLZx*)

R1Fw = (*X1FwZx* / tan (*LineAng*)) * (1 + *REOverRLZx*)

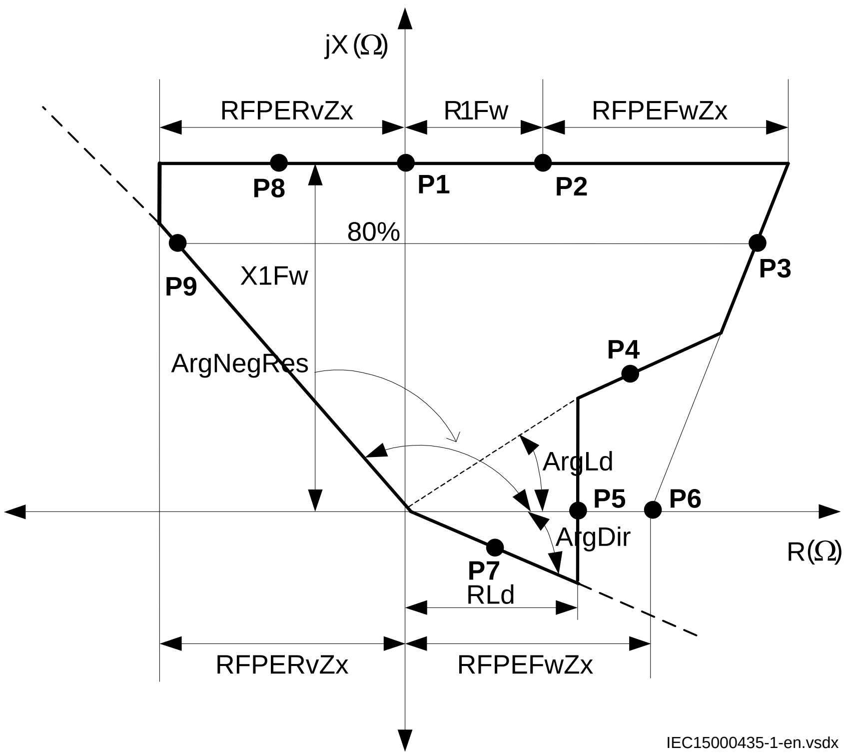


Figure 19: Proposed test points for phase-to-earth loop of measuring element

Table 21: Test points for phase-to-earth loop measuring element

Test point	R	X	Comment
P1	0	*X1Fw*	
P2	*R1Fw*	*X1Fw*	
P3	(0.8 * *R1Fw*) + *RFPEFwZx*	0.8 * *X1Fw*	
P4	0.8 * *RFPEFwZx*	0.8 * *RFPEFwZx* * tan (*ArgLd*)	
P5	*RLd*	0	
P6	*RFPEFwZx*	0	If *LEModeZx* = Off and *OpLoadEnch* = Off
P7	0.5 * *RLd*	0.5 * *RLd* * tan (*ArgDir*)	
P8	0.5 * *RFPERvZx*	*X1Fw*	
P9	0.8 * *X1Fw* * tan (*ArgNegRes*)	0.8 * *X1Fw*	

1. Change the magnitude and angle of phase-to-earth voltage in phase L1 to achieve impedances at test points P1, P2, …, P9.
2. Test points P7 and P9 are intended to test the directional lines of impedance protection and used to find directional accuracy for phase-to-earth faults.
3. For each test point, observe that the start output signals START, STZx, STNDZx, STL1 and STPE are activated.
4. Trip signals TRIP, TRZx, TRL1 will appear after set delay time of *tPEZx* if *OpModetPEZx* is set to On and *TimerSelZx* is set to Timers separated.
5. Repeat the above test by injecting phase-to-earth voltage in phase L2 in accordance with test points and steps described above and observe that the start output signals START, STZx, STNDZx, STL1 and STPE are activated.
6. Trip signals TRIP, TRZx, TRL2 will appear after set delay time of *tPEZx* if *OpModetPEZx* is set to On and *TimerSelZx* is set to Timers separated.

phase-to-phase fault – measuring element

Test points that are to be considered for measurement accuracy of set reactance reach are shown in Figure 20 and Table 22.

Where:

X1Fw = *X1FwZx*

R1Fw = *X1FwZx* / tan (*LineAng*)

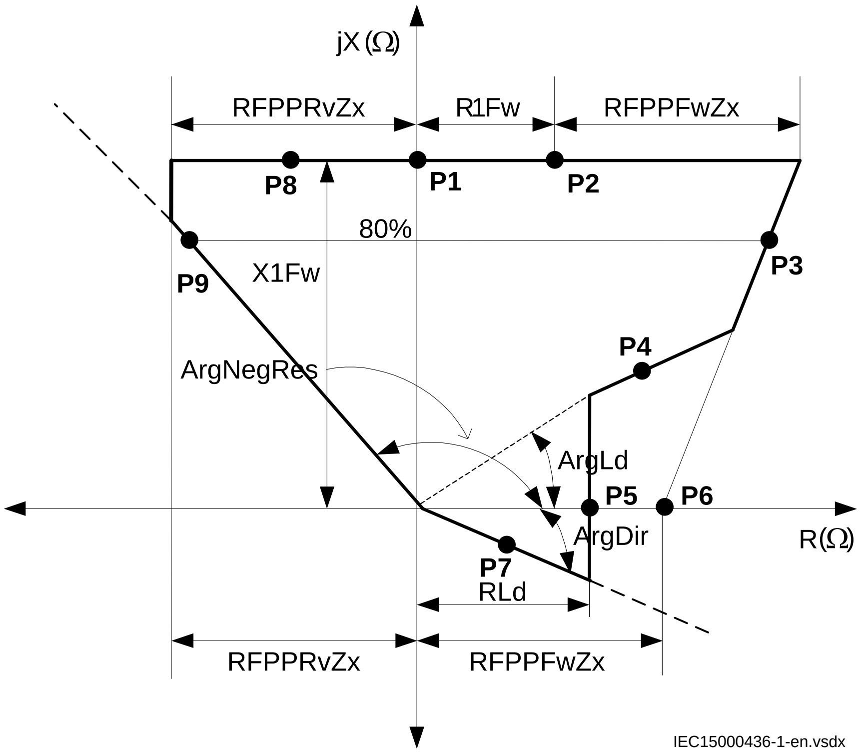


Figure 20: Proposed test points for phase-to-phase loop of measuring element

Table 22: Test points for phase-to-phase loop measuring element

Test point	R	X	Comment
P1	0	*X1Fw*	
P2	*R1Fw*	*X1Fw*	
P3	(0.8 * *R1Fw*) + *RFPPFwZx*	0.8 * *X1Fw*	
P4	0.8 * *RFPPFwZx*	0.8 * *RFPPFwZx* * tan (*ArgLd*)	
P5	*RLd*	0	
P6	*RFPPFwZx*	0	If *LEModeZx* = Off and *OpLoadEnch* = Off
P7	0.5 * *RLd*	0.5 * *RLd* * tan (*ArgDir*)	
P8	0.5 * *RFPPRvZx*	*X1Fw*	
P9	0.8 * *X1Fw* * tan (*ArgNegRes*)	0.8 * *X1Fw*	

1. Inject the magnitude and angle of phase-to-phase voltage to achieve impedances at test points P1, P2, …, P9.
2. Test points P7 and P9 are intended to test the directional lines of impedance protection and used to find directional accuracy for phase-to-phase faults.
3. For each test point, observe that the start output signals START, STZx, STNDZx, STL1, STL2 and STPP are activated.
4. Trip signals TRIP, TRZx, TRL1 and TRL2 will appear after set delay time of *tPPZx* if *OpModetPPZx* is set to On and *TimerSelZx* is set to Timers separated.

Testing the neutral voltage shift protection

1. Set *SystemEarthing* to High impedance and *UMinDisp* to default value.
2. Inject phase voltage and phase currents such that there is no start output STELEMST observed from starting element. Also, make sure that residual voltage is measured with this condition.
3. If this measured neutral voltage/residual voltage exceeds set *UMinDisp* value, the outputs TRIP, TRL1 and TRL2 get activated after a set delay of *tU0*.

Testing the stub line with line end in-feed protection in compensated earthed systems

1. Set *ModeStubLine* to On and set *UPPMin* and *KU* to default values.
2. Also, set *ModePhPref* to Equal Priority.
3. Inject phase voltage and phase currents so that there is STIE detected for a test condition created and no pick-up from underimpedance starting i.e. STNDZL1 and STNDZL2 are low.
4. If the injected phase L2 voltage is higher than *KU* times phase L1 voltage and injected phase-to-phase voltage is above set *UPPMin* value, the trip outputs TRIP and TRL1 will be activated after a set delay of *tI0Stub*.
5. Similarly, if the injected phase L1 voltage is higher than *KU* times phase L2 voltage and injected phase-to-phase voltage is above set *UPPMin* value, the trip outputs TRIP and TRL2 will be activated after a set delay of *tI0Stub*.
6. If *ModePhPref* to L1 before L2, fault on phase L2 will be cleared after additional delay time of *tGL2* (i.e. *tI0Stub* + *tGL2*) when *OpModetGL2* is set to On.

Testing the phase preference mode in compensated earthed systems

1. Inject phase voltage and phase current for phase L2 in accordance with test points described in Chapter 'Phase-to-earth fault – measuring element'.
2. If *ModePhPref* is set to Equal priority, trip signal TRL2 will be appeared immediately after a set delay of *tPEZx*.
3. If *ModePhPref* is set to L1 before L2, *STPHPRERL2* will appear which indicates fault has been occurred in phase L2.

4. If the fault persists for a duration of *tPEZx* + *tGL2*, TRL2 will appear or fault persists for a duration of additional timer *txL2* plus extension time *tVL2* (i.e. *txL2* + *tVL2*), TRL2 will appear.
5. If during time *tVL2*, make a test point such that start signal STELEMST resets and also magnitude of phase L1 is below *U0Min* value, the output signals STPHPRERL2 and TRL2 will reset indicating that fault on phase L2 is cleared.
6. If during time *tVL2*, inject voltages in phases such that change in phase L1 voltage is lower than set *duOverdt* value and change in phase L2 voltage is higher than set *dUOverdt* value, the output signals STPHPRERL2 and TRL2 will reset indicating that fault on phase L2 is cleared.

10.4.2.2 Completing the test

Continue to test another function or end the test by changing the Test mode setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.4.3 Commissioning manual

10.4.3.1 Catenary distance protection ZRCPDIS

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for ZRCPDIS are available on the local HMI under **Main menu/Test/Function status/Impedance protection/ DistanceProt1Ph(21,Z<)/ZRCPDIS(21;Z<):*x***, where x = 1 or 2.

The Signal Monitoring tool in PCM600 shows the same signals that are available on the local HMI.

Verifying the signals and settings

Measure the operating characteristics during constant current conditions. Keep the measured current as close as possible to the rated value of the IED or lower. Ensure that it is higher than the set minimum operating current.

Ensure that the maximum continuous current to the IED does not exceed four times of its rated value, if the measurement of the operating characteristics runs under constant voltage conditions.

To verify the settings, test the operating points given in the following figure by injecting appropriate voltage and current(s) to the IED through a secondary injection kit.

Always set *Operation* to *On* to check the performance of distance protection during testing.

Ensure that the setting parameter *TESTMODE* is set to *ON*.

Testing the measuring zone

1. Set *OpZx* to *On*, *DirModeZx* to *Forward*, *LEModeZx* to *On* and *LCModeZx* to *Off*.
   Assume that output LDCND is available before performing testing of measuring zone for accuracy. Where, x indicates the measuring zone under testing.
2. Set *ArgNegRes* and *ArgDir* settings.
3. Set *XFWZx*, *LineAng*, *ArgLd*, *RFFwZx* and *RFRvZx* settings accordingly. Also, ensure that *RLd* value is lower than the *RFFwZx* set value.
   The test points that are to be considered for measurement accuracy of set reactance reach are shown in Figure 21 and Table 23.

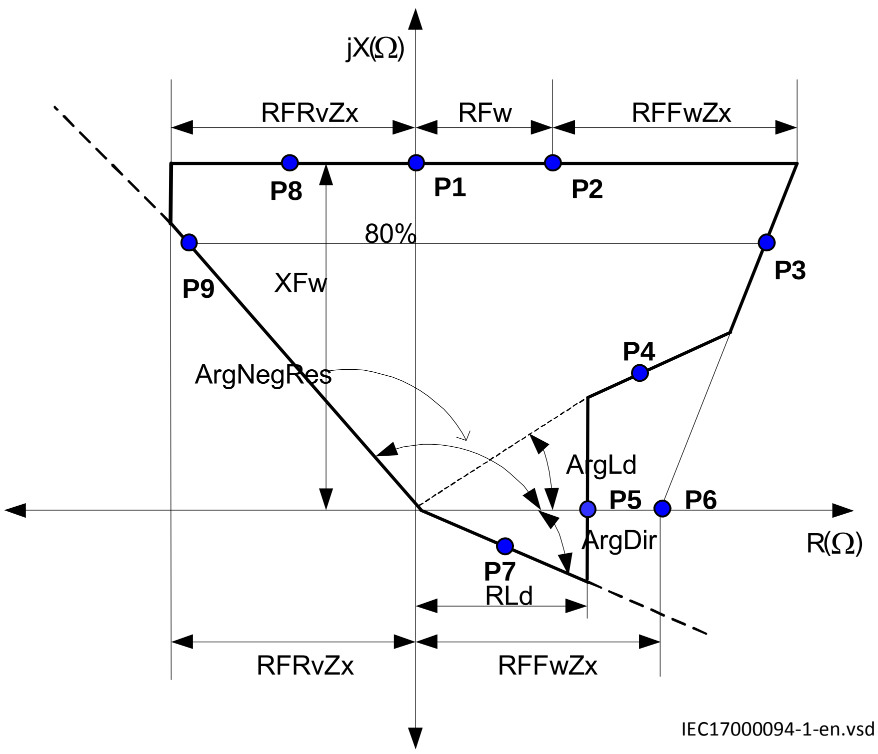


Figure 21: Proposed test points to measure the boundary of a measuring zone

Where:

XFw = XFwZx

RFw = XFwZx / tan(*LineAng*)

Table 23: *Test points to measure the boundary of a measuring zone in primary ohms*

Test point	R	X	Comment
P1	0	*XFw*	
P2	*RFw*	*XFw*	
P3	(0.8 * *RFw*) + *RFFwZx*	0.8 * *XFw*	
P4	0.8 * *RFFwZx*	0.8 * *RFFwZx* * tan(*ArgLd*)	
P5	*RLd*	0	
P6	*RFFwZx*	0	If LEModeZx = Off
P7	0.5 * *RLd*	0.5 * *RLd* * tan(*ArgDir*)	
P8	0.5 * *RFRvZx*	*XFw*	
P9	0.8 * *XFw* * tan(*ArgNegRes*)	0.8 * *XFw*	

4. Change the magnitude and angle of voltage to achieve impedances at test points P1, P2,...,.P9.
5. The test points P7 and P9 are intended to test the directional lines of impedance protection and are used to find the directional accuracy.
6. For each test points, observe that the start output signals, START, STZx and STNDZx are activated.
7. Trip signals TRIP and TRZx appears after a set delay time of *tZx*.

Completing the test

Continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.4.4 Underimpedance protection for railway transformers ZGTPDIS

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for ZGTPDIS are available on the local HMI under **Main menu/Tests/Function status/Impedance/ZGTPDIS (21T, Z<)/ ZGTPDIS:x**, where x = 1, 2. The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

10.4.4.1 Verifying the signals and settings

Keep the current constant while measuring operating characteristics. Keep the current as close as possible to its rated value or lower. However, make sure it is higher than set minimum operating current.

If the measurement of the operating characteristics runs under constant voltage conditions, ensure that the maximum continuous current in an IED does not exceed four times its rated value.

Verifying mho offset characteristic

To verify zone 1 mho offset characteristic, at least two points must be tested.

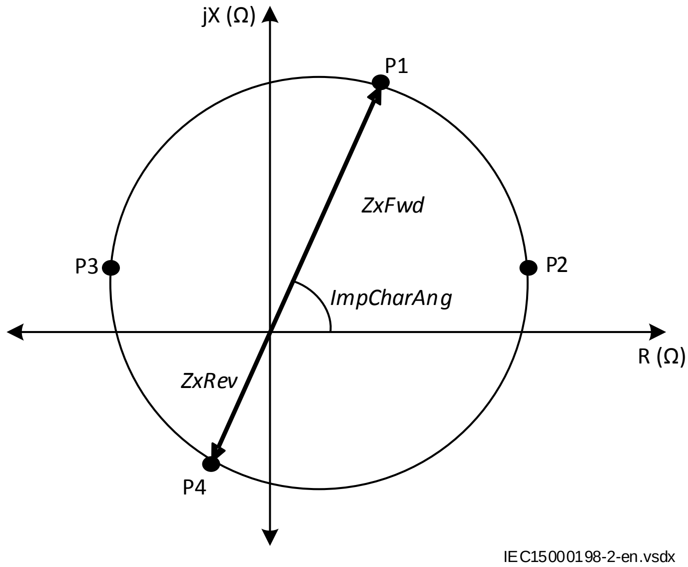


Figure 22: Commissioning test points for mho offset characteristic

Where,

ZxFwd	is the forward positive sequence impedance setting for zone x (where, x is 1- 3 depending on the zone selected)
ZxRev	is the reverse positive sequence impedance setting for zone x (where, x is 1- 3 depending on the zone selected)
ImpCharAng	is the impedance angle in deg

Test points	X	R
P1	*ZxFwd* · sin(*ImpCharAng*)	*ZxFwd* · cos(*ImpCharAng*)
P2	((*ZxFwd* -*ZxRev*) / 2) · sin(*ImpCharAng*)	*ZxFwd* / 2 · (1 + cos(*ImpCharAng*)) + *ZxRev* / 2 · (1 – cos(*ImpCharAng*))
P3	((*ZxFwd* -*ZxRev*) / 2) · sin(*ImpCharAng*)	-*ZxFwd* / 2 · (1 – cos(*ImpCharAng*)) - *ZxRev* / 2 · (1 + cos(*ImpCharAng*))
P4	-*ZxRev* · sin(*ImpCharAng*)	-*ZxRev* · cos(*ImpCharAng*)

1. Change the magnitude and angle of the voltage to achieve impedances at test points P1, P2, P3 and P4.
2. For each test point, check that the output signals START and STZx (where, x is 1- 3 depending on the zone selected) are activated.
3. Signals TRIP and TRZx will be activated after operate time delay *tZx* for the respective zone has elapsed.

Verifying quadrilateral characteristic

To verify zone quadrilateral characteristic, at least 10 points must be tested.

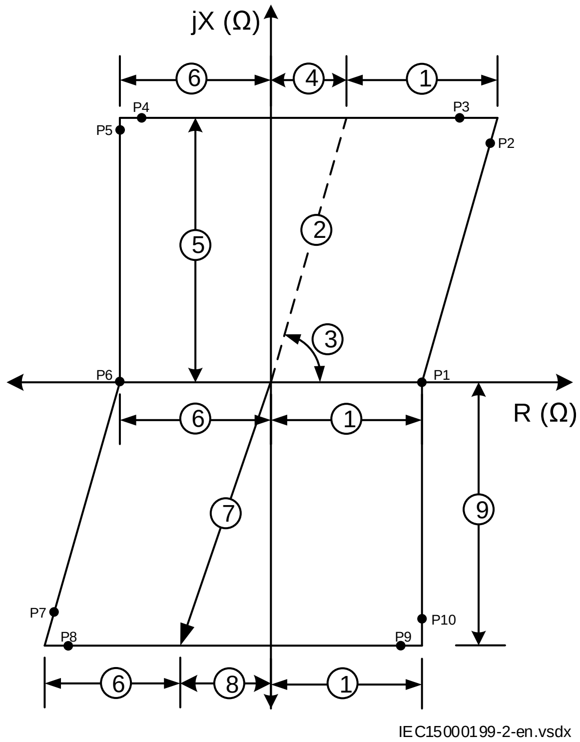


Figure 23: Commissioning test points for Quad non-dir characteristic

1. *RFFwZx*
2. *ZxFwd*
3. *ImpCharAng*
4. *ZxFwd * cos(ImpCharAng)*
5. *ZxFwd * sin(ImpCharAng)*
6. *RFRevZx*
7. *ZxRev*
8. *ZxRev * cos(ImpCharAng)*
9. *ZxRev * sin(ImpCharAng)*

Where x = 1, 2 and 3.

Table 24: Verifying quadrilateral characteristic

Test points	X	R
P1	0	*RFFwZx*
P2	0.8 · *ZxFwd* · sin*(ImpCharAng)*	0.8 · *ZxFwd* · cos*(ImpCharAng)* + *RFFwZx*
P3	*ZxFwd* · sin*(ImpCharAng)*	*ZxFwd* · cos*(ImpCharAng)* + 0.8 · *RFFwZx*
P4	*ZxFwd* · sin*(ImpCharAng)*	–0.8 · *RFRevZx*
P5	0.8 · *ZxFwd* · sin*(ImpCharAng)*	–*RFRevZx*
P6	0	–*RFRevZx*
P7	–0.8 · *ZxRev* · sin*(ImpCharAng)*	–0.8 · *ZxRev* · cos*(ImpCharAng)* – *RFRevZx*
P8	–*ZxRev* · sin*(ImpCharAng)*	–*ZxRev* · cos*(ImpCharAng)* – 0.8 · *RFRevZx*
P9	–*ZxRev* · sin*(ImpCharAng)*	0.8 · *RFFwZx*
P10	–0.8 · *ZxRev* · sin*(ImpCharAng)*	*RFFwZx*

Find the following from Table 24:

$$Z = \sqrt{\left(R^2 + X^2\right)}$$

(Equation 1)

$$\phi = \tan^{-1}\left(X / R\right)$$

(Equation 2)

Then inject relevant voltage and current in such a way that above impedance value is measured by the ZGTPDIS function.

1. Change the magnitude and angle of the phase-to-phase voltage to achieve impedances at test points P1, P2.....,P10.
2. For each test points, check that the output signals START and STZx (where, x is 1- 3 depending on the zone selected) are activated.
3. Signals TRIP and TRZx will be activated after operate time delay *tZx* for the respective zone has elapsed.

10.4.4.2 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5 Current protection

10.5.1 Instantaneous phase overcurrent protection 2-phase output PHPIOC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.5.1.1 Measuring the operate limit of set values

1. Inject a phase current into the IED with an initial value below that of the setting.
2. Increase the injected current in the Ln phase until the TRLn (n=1,2) signal appears.
3. Switch the fault current off.

    Observe: Do not exceed the maximum permitted overloading of the current circuits in the IED.

4. Compare the measured operating current with the set value *IP>>*.

10.5.1.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.2 Two-step directional phase overcurrent protection D2PTOC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for D2PTOC are available on the local HMI under **Main menu/Tests/Function status/Current protection/ DirOverCurr2Step(51_67, 2(2I>))/D2PTOC(51_67;2(2I>)):x**, where x = 1, 2,...8.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

10.5.2.1 Verifying the settings

The verification of the non-directional phase overcurrent function is done as instructed below, but without applying any polarizing voltage.

1. Connect the test set for current injection to the appropriate IED phases.
   If there is any configuration logic that is used to enable or block any of the two available overcurrent steps, make sure that the step under test is enabled.
2. Connect the test set for the appropriate two-phase voltage injection to the IED phases L1 and L2. The protection shall be fed with a symmetrical two-phase voltage.
3. Block step two when testing step 1. To test step 1, follow the procedure described below:
   3.1. Set the injected polarizing voltage larger than the set minimum polarizing voltage (default is 3.0% of *UBase*) and set the injection current to lag the appropriate voltage by an angle of about 45° if forward directional function is selected.
   If reverse directional function is selected, set the injection current to lag the polarizing voltage by an angle equal to 225° (equal to 45° + 180°).
   Monitor on the HMI service values for measured current, voltage and phase angle between the voltage and current in order to verify that D2PTOC function do measure the quantities as expected.
   3.2. Increase the injected current, note the operate value of the tested step of the function and compare it to the set value.
   3.3. Decrease the current slowly, note the reset value and compare it to the reset ratio 95%.
4. Set the injected current to 200% of the operate level of the tested stage, switch on the current and check the time delay.
   For inverse time curves, check the operate time at a current equal to 110% of the operate current for *txMin*.
5. Check that all operate and start contacts operate according to the configuration (signal matrixes).
6. Reverse the direction of the injected current and check that the protection does not operate.
7. Repeat the above described tests for the second step.
8. Check that start and trip information is stored in the event menu and in the built-in disturbance recorder.

10.5.2.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.3 Instantaneous residual overcurrent protection EFRWPIOC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

To verify the settings the following fault type should be tested:

- Phase-to-earth fault

Ensure that the maximum continuous current, supplied from the current source used for the test of the IED, does not exceed four times the rated current value of the IED.

10.5.3.1 Measuring the operate limit of set values

1. Inject a phase current into the IED with an initial value below the set value of *IN>>* and also make sure that the set value *IN>>* is in between *IN>>Min* and *IN>>Max*.
2. Increase the injected current in the phase until the TRIP signal appears.
3. Switch the fault current off.

Do not exceed the maximum permitted overloading of the current circuits in the IED.

4. Compare the measured operating current with the set value IN>>

10.5.3.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.4 Two step residual overcurrent protection EF2PTOC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.5.4.1 Directional Stage

1. Connect the test set for single current injection to the appropriate IED terminals.
   Connect the injection current to terminals L1 and neutral.
2. Set the injected polarizing voltage slightly larger than the set minimum polarizing voltage (default 2% of Ur) and set the injection current to lag the

voltage by an angle equal to the set reference characteristic angle (*AngleRCA*), for the forward direction.
For reverse direction, set the injection current to lag the polarizing voltage by an angle equal to RCA+ 180°.
3. Increase the injected current and note the value at which the directional stage operates.
4. Decrease the current slowly and note the reset value.
5. If the test has been performed by injection of current in phase L1, repeat the test, injecting current into terminal L2 with a polarizing voltage connected to terminal L2.
6. Set the injected current to 200% of the operate level, switch on the current and check the time delay.
7. Check that all trip and start contacts operate according to the configuration (signal matrixes)
8. Reverse the direction of the injected current and check that the stage operates accordingly.
9. Check that the protection does not operate when the polarizing voltage is zero.
10. Finally, check that start and trip information is stored in the event menu.

10.5.4.2 Two step non-directional earth fault protection

1. Do as described in Directional Stage, but without applying any polarizing voltage.

10.5.4.3 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.5 Sensitive directional residual overcurrent and power protection SDEPSDE

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals belonging to the sensitive directional residual overcurrent and power protection are available on the local HMI under **Main menu/Test/Function status/Current protection/SensDirResOvCurr(67N,IN>)/ SDEPSDE(67N,IN>):x**

10.5.5.1 Measuring the operate and time limit for set values

Operation mode $2I_0 \cdot \cos\varphi$

Procedure

1. Set the polarizing voltage to 1.2 · *UNRel>* and set the phase angle between voltage and current to the set characteristic angle (*RCADir*). Note that the current shall lag the voltage.
   Take setting *RCAComp* into consideration if not equal to *0*.
2. Inject current until the function picks up, and make sure that the operate current of the set directional element is equal to the *INcosPhi>* setting.
   The I Dir ($2I_0 \cdot \cos\varphi$) function activates the START and STDIRIN output.
3. Assume that φ is the phase angle between injected voltage ($-2U_0$) and current ($2I_0$) i.e. φ = *RCADir*-φ. Change φ to for example 45 degrees. Increase the injected current until the function operates.
4. Compare the result with the set value and make sure that the new injected $2I_0 \cdot \cos\varphi$ is equal to the setting *INcosPhi>*.
   Take the set characteristic into consideration, see Figure 24 and Figure 25.
5. Measure the operate time of the timer by injecting a current two times the set *INcosPhi>* value and the polarizing voltage 1.2 · *UNRel>*.

$$T_{inv} = \frac{kSN \cdot S_{ref}}{2I_{0test} \cdot 2U_{0test} \cdot \cos(\varphi)}$$

(Equation 3)

6. Compare the result with the expected value.
   The expected value depends on whether definite or inverse time was selected.
7. Set the polarizing voltage to zero and increase until the boolean output signal UNREL is activated, which is visible in the application configuration in PCM600 when the IED is in online mode and also on the IED HMI under test. Compare the voltage with the set value *UNRel>* .
8. Continue to test another function or complete the test by setting the test mode to *Off*.

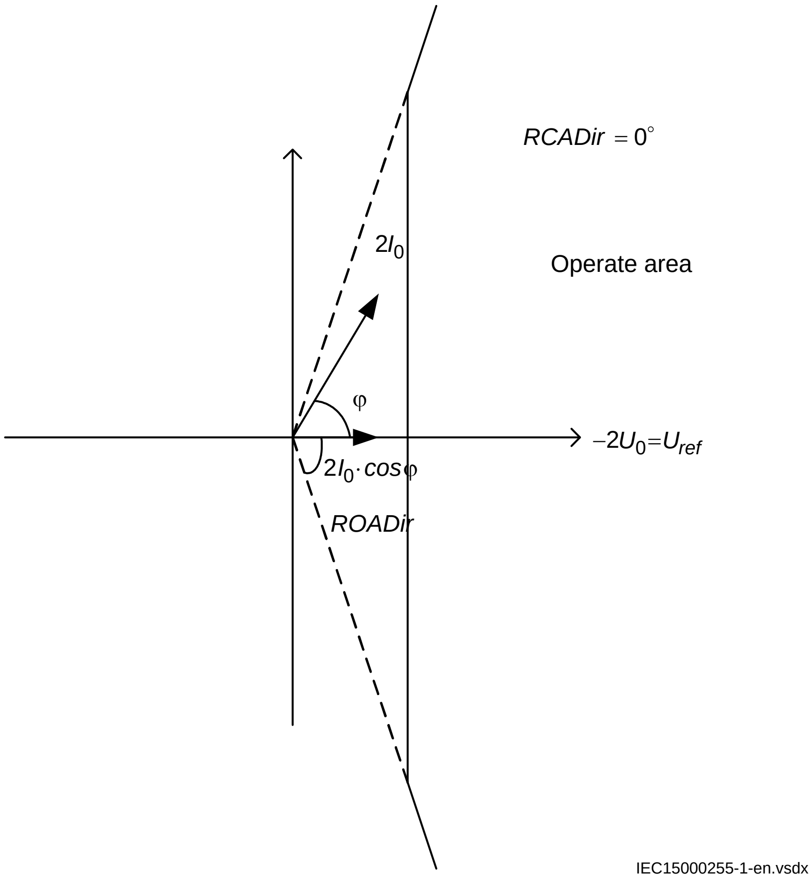


Figure 24: Characteristic with ROADir restriction

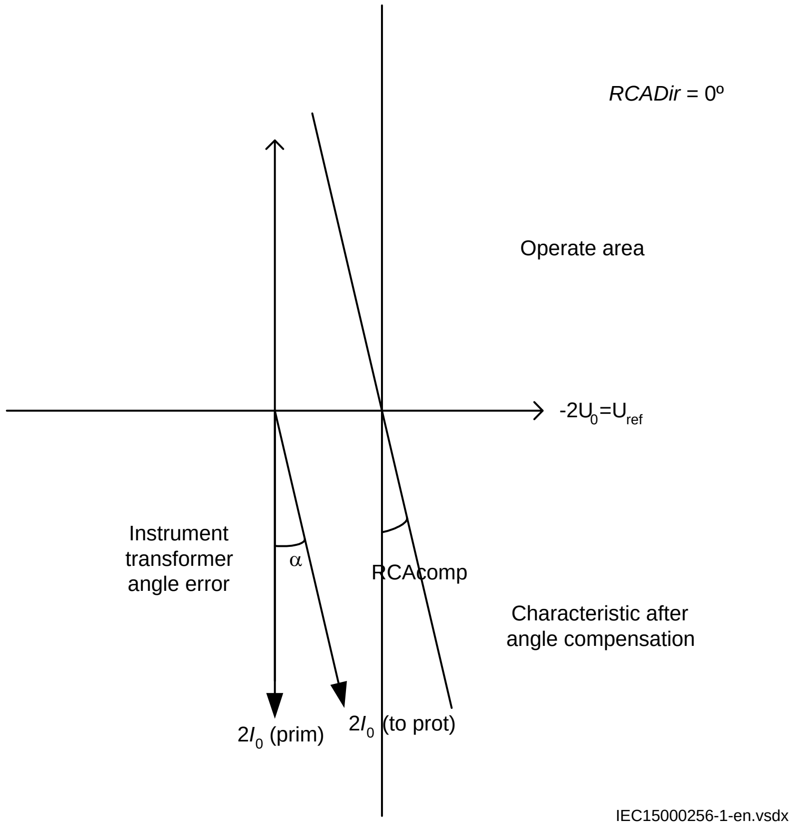


Figure 25: Explanation of RCAcomp

Operation mode $2I_0 \cdot 2U_0 \cdot \cos\varphi$

1. Set the polarizing voltage to 1.2 · *UNRel>* and set the phase angle between voltage and current to the set characteristic angle (*RCADir*). Note that the current shall lag the voltage.
2. Inject current until the function picks up, and make sure that the operate power is equal to the *SN>* setting for the set directional element.
   The function activates the START and STDIRIN outputs.

   Note that for operation, both the injected current and voltage must be greater than the set values *INRel>* and *UNRel>* respectively.

3. Assume that φ is the phase angle between injected voltage ($2U_0$) and current ($2I_0$) i.e. φ = *RCADir*-φ. Change φ to for example 45 degrees. Increase the injected current until the function operates.
4. Compare the result with the set value and make sure that the new injected $2I_0 \cdot 2U_0 \cdot \cos\varphi$ is equal to the setting *SN>*. Take the set characteristic into consideration, see Figure 24 and Figure 25.

5. Measure the operate time of the timer by injecting 1.2 · *UNRel>* and a current to get two times the set *SN>* operate value.

$$T_{inv} = kSN \cdot S_{ref} / 2I_{0test} \cdot 2U_{0test} \cdot \cos\varphi$$

(Equation 4)

6. Compare the result with the expected value.
   The expected value depends on whether definite or inverse time was selected.
7. Continue to test another function or complete the test by setting the test mode to *Off*.

Operation mode $2I_0$ and φ

1. Set the polarizing voltage to 1.2 · *UNRel>* and set the phase angle between voltage and current to the set characteristic angle (*RCADir*). Note that the current shall lag the voltage.
2. Inject current until the function picks up, and make sure that the operate current is equal to the *INDir>* setting for the set directional element.

   Note that for operation, both the injected current and voltage must be greater than the set values *INRel>* and *UNRel>* respectively.

   The function activates the START and STDIRIN output.
3. Measure with angles φ around *RCADir +/- ROADir.*
4. Compare the result with the set values, refer to Figure 26 for example characteristic.
5. Measure the operate time of the timer by injecting a current to get two times the set *SN_>* operate value.

$$T_{inv} = kSN \cdot S_{ref} / 2I_{0test} \cdot 2U_{0test} \cdot \cos\varphi$$

(Equation 5)

6. Compare the result with the expected value.
   The expected value depends on whether definite or inverse time was selected.
7. Continue to test another function or complete the test by setting the test mode to *Off*.

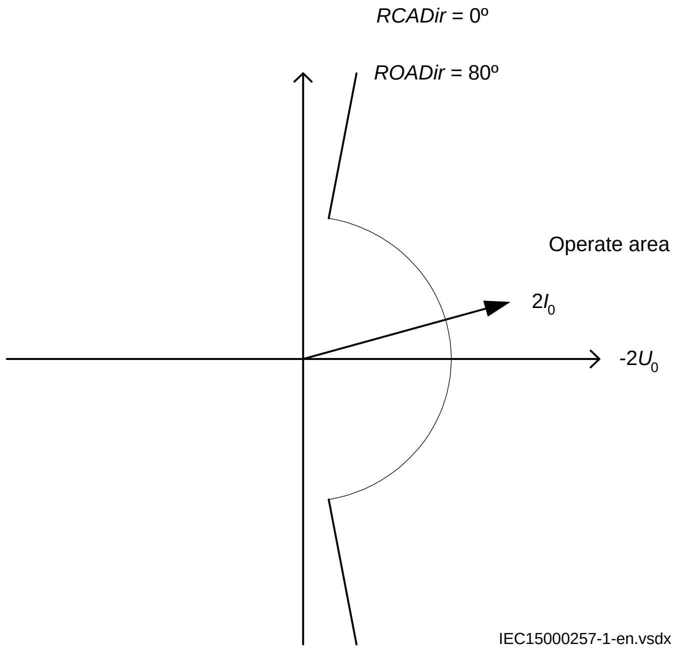


Figure 26: Example characteristic

Non-directional earth fault current protection

Procedure

1. Measure that the operate current is equal to the *INNonDir>* setting.
   The function activates the START and STDIRIN output.
2. Measure the operate time of the timer by injecting a current of 200% of the operate value.
3. Compare the result with the expected value.
   The expected value depends on whether definite or inverse time was selected.
4. Continue to test another function or complete the test by setting the test mode to *Off*.

Residual overvoltage release and protection

Procedure

1. Measure that the operate voltage is equal to the *UN>* setting.
   The function activates the START and STUN signals.
2. Measure the operate time by injecting a voltage 1.2 times set *UN>* operate value.
3. Compare the result with the set *tUN* operate value.
4. Inject a voltage 0.8 · *UNRel>* and a current high enough to operate the directional function at the chosen angle.
5. Increase the voltage until the directional function is released.
6. Compare the measured value with the set *UNRel>* operate value.

10.5.5.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.6 Thermal overload protection, one time constant, Celsius LPTTR

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Check that the input logical signal BLOCK is logical zero and that on the local HMI, the logical signal TRIP, START and ALARM are equal to logical zero.

10.5.6.1 Measuring the operate and time limit of set values

Testing the protection without external temperature compensation (NonComp)

1. Reset the thermal memory on the local HMI under **Main menu/Reset/Reset temperature/ThermalOverload1TimeConst(PTTR,26)/LPTTR:x**,
2. Switch the fault current on and take note of the temperature, available on the local HMI under **Main menu/Test/Function status/Current protection/ ThermOverLoad1TimeConst(PTTR,26)/LPTTR:x/TEMP**
3. Check the time until the actual temperature TEMP has reached the *AlarmTemp* level during injection.
   Monitor the signal ALARM until it appears on the corresponding binary output or on the local HMI.
4. Measure the LPTTR protection trip time.
   Use the TRIP signal from the configured binary output to stop the timer.
5. Take the TEMP readings.
   Compare with the setting of *TripTemp*.
6. Activate the BLOCK binary input.
   The signals ALARM, START and TRIP should disappear.
7. Reset the BLOCK binary input.
8. Check the reset limit (TdReset).
   Monitor the signal START until it disappears on the corresponding binary output or on the local HMI, take the TEMP readings and compare with the setting of *ReclTemp*.
9. Compare the measured trip time with the setting according to the formula.
10. Reset the thermal memory.
11. Continue to test another function or end the test by changing the test mode setting to *Off*.

10.5.6.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.7 Breaker failure protection CCRWRBRF

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for CCRWRBRF are available on the local HMI under **Main menu/Tests/Function status/Current protection/BreakerFailure(50BF, 2I>BF)/CCRWRBRF(50BF;2I>BF):x**, where x = 1, 2.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

The breaker failure protection function CCRWRBRF should normally be tested in conjunction with some other function that provides a start signal. An external START signal can also be used.

10.5.7.1 Checking the phase current operate value, *IP>*

The check of the *IP>* current level is made in *FunctionMode* = *Current*.

1. Apply the fault condition, including START of CCRWRBRF, with a current below the set *IP>*.
2. Repeat the fault condition and increase the current in steps until a trip occurs.
3. Compare the result with the set *IP>*.

If *No CBPos Check* or *Retrip off* is set, only back-up trip can be used to check set *IP>*.

10.5.7.2 Checking the re-trip and back-up times

The check of the set times can be made in connection with the check of operate values above.

Choose the applicable function and trip mode, such as *FunctionMode* = *Current* and *RetripMode* = *CB Pos Check* .

1. Apply the fault condition, including the START of CCRWRBRF, well above the set current value. Measure the time from START of CCRWRBRF.
2. Check the re-trip *t1* and back-up trip time *t2*.

10.5.7.3 Verifying the re-trip mode

Choose the mode below, which corresponds to the actual case.

In the cases below it is assumed that *FunctionMode* = *Current* is selected.

Checking the case without re-trip

1. Set *RetripMode* = *Retrip Off*.
2. Apply the fault condition, including the START of CCRWRBRF, well above the set current value.
3. Verify that no re-trip, but back-up trip is achieved after set time delay of *t2*.

Checking the re-trip with current check

1. Set *RetripMode* = *CB Pos Check*.
2. Apply the fault condition, including the START of CCRWRBRF, well above the set current value.
3. Verify that re-trip is achieved after set time *t1* and back-up trip after time *t2*.
4. Apply the fault condition, including the START of CCRWRBRF, with the current below the set current value *IP>*.
5. Verify that no re-trip and no back-up trip are obtained.

Checking re-trip without current check

1. Set *RetripMode* = *No CBPos Check*.
2. Apply the fault condition, including the START of CCRWRBRF, well above the set current value.
3. Verify that re-trip is achieved after the set time *t1*, and the back-up trip after time *t2*.
4. Apply the fault condition, including the START of CCRWRBRF, with the current below the set current value *IP>*.
5. Verify that re-trip is achieved after set time *t1*, but no back-up trip is obtained.

10.5.7.4 Verifying the back-up trip

In the case below, it is assumed that *FunctionMode* = *Current* is selected.

Checking that back-up tripping is not achieved at normal CB tripping

Use the actual tripping modes. The case below applies to re-trip with current check.

1. Apply the fault condition, including the START of CCRWRBRF, with the phase current well above the set value *IP>*.
2. Interrupt the current, with a margin before back-up trip time, *t2*. It may be made at issue of re-trip command.
3. Check that re-trip is achieved, if selected, but no back-up trip is obtained.

10.5.7.5 Verifying instantaneous back-up trip at CB faulty condition

Applies in a case where a signal from CB supervision function regarding CB being faulty and unable to trip is connected to input CBFLT.

1. Repeat the check of back-up trip time. Disconnect current and START input signals.
2. Activate the input CBFLT. The output CBALARM (CB faulty alarm) should appear after set time *tCBAlarm*. Keep the input activated.
3. Apply the fault condition, including the START of CCRWRBRF, with the current above the set current value.
4. Verify that back-up trip is obtained without intentional delay (i.e. independent of set time delay of *t2*).

10.5.7.6 Verifying the case *FunctionMode* = *Contact*

It is assumed that re-trip without current check is selected, *FunctionMode* = *Contact*.

1. Set *FunctionMode* = *Contact*
2. Apply the input signal for CB closed to the relevant input or inputs CBCLDL1 or CBCLD2.
3. Apply the input signal START of CCRWRBRF.
4. Verify that the re-trip and back-up trip are achieved after set times.
5. Disconnect the start signal. Keep the CB closed signal(s).
6. Apply the input signal START of CCRWRBRF.
7. Arrange disconnection of CB closed signal(s) well before set back-up trip time *t2*.
8. Verify that back-up trip is not achieved.

10.5.7.7 Verifying the function mode *Current/Contact*

To be made only when *FunctionMode* = *Current/Contact* is selected.

Checking the case with fault current above set value *IP>*

The operation shall be as in *FunctionMode* = *Current*.

1. Set *FunctionMode* = *Current/Contact*.
2. Leave the inputs for CB close inactivated. These signals should not influence.
3. Apply the fault condition, including the START of CCRWRBRF, with the current above the set *IP>* value.
4. Check that the re-trip, if selected, and back-up trip commands are achieved.

Checking the case with fault current below set value *I>BlkCont*

It simulates a case where the fault current is very low and operation will depend on CB position signal from CB auxiliary contact. It is suggested that re-trip without current check is used, setting *RetripMode* = *No CBPos Check*.

1. Set *FunctionMode* = *Current/Contact*.
2. Apply the input signal for CB closed to the relevant input or inputs CBCLDL1 or CBCLDL2.
3. Apply the fault condition with input signal START of CCRWRBRF. The value of current should be below the set value *I>BlkCont*.
4. Verify that the re-trip (if selected) and back-up trip are achieved after set times. Failure to trip is simulated by keeping the signal(s) CB closed activated.
5. Disconnect the input signal START. Keep the CB closed signal(s).
6. Apply the fault and the start again. The value of current should be below the set value *I>BlkCont*.
7. Arrange disconnection of BC closed signal(s) well before set back-up trip time *t2*. It simulates a correct CB tripping.
8. Verify that back-up trip is not achieved. Re-trip can appear for example, due to selection “Re-trip without current check”.

10.5.7.8 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.8 Overcurrent protection with binary release BRPTOC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Logical signals for BRPTOC protection are available on the local HMI under**Main menu/Settings/IED Settings/Current protection/OvercurrBinRel (50, 2I>)/ BRPTOC (50, 2I>):x**.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

10.5.8.1 Measuring the operate limit of set values

1. Check that the input logical signals BLOCK and BLKTR and the output logical signal TRIP are all logical zero.
2. If required, activate the input RELEASE on the BRPTOC function block.
3. For a short while inject a current (fault current) in one phase to about 110% of the set operating current *I>*, and switch the current off.

Observe to not exceed the maximum permitted overloading of the current circuits in the IED.

4. Switch the fault current on and measure the operating time of BRPTOC.
   Use the TRIP signal from the configured binary output to stop the timer.
5. Activate the input BLOCK on the BRPTOC function block.
6. Switch on the fault current (110% of the setting).
   No TRIP signal should appear.
7. Switch off the fault current.
8. For a short while inject a current (fault current) in same phase to about 90% of the set operating current, and switch the current off.
9. Switch the fault current on.
   No TRIP signal should appear.
10. Switch off the fault current.
11. If required, reset the RELEASE binary input.
12. Switch the fault current on.
    No TRIP signal should appear.
13. Switch the fault current off.

10.5.8.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.9 Tank overcurrent protection TPPIOC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for TPPIOC are available on the local HMI under **Main menu/Test/Function status/Current Protection/TPPIOC (64, IN>>>)/ TPPIOC: 1**

Ensure that the maximum continuous current, supplied from the current source used for the test of the IED, does not exceed four times the rated current value of the IED.

10.5.9.1 Verifying the signals and settings

1. Inject current into the IED with an initial value below set value *I>*.
2. Increase the injected current until the TRIP signal appears and note the operate value of the tested functionality.
3. Decrease the current slowly and note the reset value with TRIP signal resets.

10.5.9.2 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.6 Voltage protection

10.6.1 Two step undervoltage protection U2RWPTUV

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for U2RWPTUV are available on the local HMI under **Main menu/Tests/Function status/Voltage protection/UnderVoltage2Step(27, 2(2U<))/U2RWPTUV(27,2(2U<)):x**, where x = 1, 2.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

10.6.1.1 Verifying the settings

Verification of start value and time delay to operate for Step 1

1. Check that the IED settings are appropriate, i.e. *U1<* and *t1*.
2. Set *OpMode1* to *Any phase* mode. Also, set *ConnType* to *PhNDFT*.
3. Supply the IED with two-phase voltages at their rated values.
4. Slowly decrease the voltage in one of the phases, until the START signal appears.
5. Note the operate value and compare it with the set value.
6. Observe that the TRIP signal appears after set time delay of *t1* s.

The operate value in secondary volts is calculated according to the following equations:

For phase-to-earth measurement:

$$\frac{U1<}{100} \times \frac{UBase}{2} \times \frac{VT\sec}{VTprim}$$

(Equation 6)

For phase-to-phase measurement:

$$\frac{U1<}{100} \times UBase \times \frac{VT\sec}{VTprim}$$

(Equation 7)

7. Increase the measured voltage to rated load conditions.
8. Check that the START signal resets.
9. Instantaneously decrease the voltage in one phase to a value about 20% lower than the measured operate value.
10. Measure the operate time for the TRIP signal.
11. Repeat the above described steps for Step 2 of the function.

Extended testing

The tests above can be repeated for *All phases* operation mode.

10.6.1.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.6.2 Two step overvoltage protection O2RWPTOV

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for O2RWPTOV are available on the local HMI under **Main menu/Tests/Function status/Voltage protection/OverVoltage2Step(59, 2(2U>))/O2RWPTOV(59;2(2U>)):x**, where x = 1, 2.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

10.6.2.1 Verifying the settings

Verification of start value and time delay to operate for Step 1

1. Check that IED settings are appropriate i.e. *U1>* and *t1* and set *OpMode1* to *Any phase* mode. Also, set *ConnType* to *PhNDFT*.
2. Supply the IED with two-phase voltages at their rated values.
3. Slowly increase the voltage in one of the phases until the START signal appears.
4. Note the operate value and compare it with the set value *U1>*.
5. Observe that TRIP signal appears after set time delay of *t1* s.

The operate value in secondary volts is calculated according to the following equations:

For phase-to-earth measurement:

$$\frac{U1>}{100} \times \frac{UBase}{2} \times \frac{VT\sec}{VTprim}$$

(Equation 8)

For phase-to-phase measurement:

$$\frac{U1>}{100} \times UBase \times \frac{VT\sec}{VTprim}$$

(Equation 9)

6. Decrease the phase voltage to a value lower than set *U1>* value.
7. Observe that the START signal resets.
8. Set and apply about 20% higher voltage than *U1>* value for one phase.
9. Measure the operate time for TRIP Signal.
10. Repeat the above described steps for Step 2 of the function.

10.6.2.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.6.3 Two step residual overvoltage protection ROV2PTOV

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for ROV2PTOV are available on the local HMI under **Main menu/Tests/Function status/Voltage protection/ ResidualOverVoltage2Step(59N, 2(U0>))/ROV2PTOV(59N;2(U0>)):x**, where x = 1, 2.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

10.6.3.1 Verifying the settings

1. Apply a single-phase voltage either to a single-phase voltage input or to a residual voltage input with the start value below the set value *U1>*.
2. Slowly increase the value beyond the *U1>* setting until ST1 appears.
3. Note the operate value and compare it with the set value *U1>*.
4. Decrease the voltage slowly and note the reset value.
5. Set and apply a 20% higher voltage than the measured operate value for one phase.
6. Measure the time delay for the TR1 signal and compare it with the set value *t1*.
7. Repeat the test 1–6 above for Step 2 of the function.

10.6.3.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.7 Frequency protection

10.7.1 Underfrequency protection SAPTUF

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.7.1.1 Verifying the settings

Verification of START value and time delay to operate

1. Check that the IED settings are appropriate, for example the start value and the time delay.
2. Supply the IED with two-phase voltages at their rated values and initial frequency.
3. Slowly decrease the voltage frequency by steps of 40 mHz until the START signal appears; during each step apply the voltage signal for a time that is either at least 10% longer than (*tDelay*+100ms) or a suitable time to monitor the function.
4. Note the frequency value at which the START signal appears and compare it with the set value *StartFrequency*.
5. Increase the frequency until its rated value is reached.
6. Check that the START signal resets.
7. Supply the IED with three-phase voltages at their rated values and frequency 20 mHz over the set value *StartFrequency*.
8. Decrease the frequency with a 40 mHz step, applying it for a time that is at least 10% longer than (*tDelay*+100ms).
9. Measure the time delay of the *TRIP* signal, and compare it with the set value *tDelay*. Note that the measured time consists of the set value for time delay plus minimum operate time of the start function (80 - 90 ms).

Extended testing

1. The test above can be repeated to check the time to reset.

10.7.1.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.8 Secondary system supervision

10.8.1 Current circuit supervision CCSSPVC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for CCSSPVC are available on the local HMI under **Main menu/Tests/Function status/Secondary system supervision/ CurrentCircuitSupervision(87,INd/I)/CCSSPVC(87;INd/I):x**, where x = 1, 2 and 3.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

The condition for this procedure is that the set value of *IMinOp* is lower than the set value of *Ip>Block*.

10.8.1.1 Verifying the settings

1. Check the input circuits and the operate value of the *IMinOp* current level detector by injecting current, one phase at a time and zero current for reference current input ISIREF.
2. Check the phase current blocking function for both the phases by injecting current, one phase at a time. The output signals (FAIL and ALARM) shall reset with a delay of 3 second when the current exceeds set *IP>Block* value.
3. Inject a current 0.1 · *IBase* to the reference current input ISIREF.
4. Increase slowly the current in one of the phases and check that FAIL output is obtained when the current is above 0.9 · *IBase*.

10.8.1.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.8.2 Fuse failure supervision FRWSPVC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for FRWSPVC are available on the local HMI under **Main menu/Tests/Function status/Secondary system supervision/ FuseFailure(U>/I<)/FRWSPVC(U>/I<):x**, where x = instance number.

The verification is divided in two main parts. The first part is common to all fuse failure supervision options, and checks that binary inputs and outputs operate as expected according to actual configuration. In the second part the relevant set operate values are measured.

10.8.2.1 Checking that the binary inputs and outputs operate as expected

1. Simulate normal operating conditions with the two-phase currents in phase with their corresponding phase voltages and with all of them equal to their rated values.
2. Connect the nominal dc voltage to the DISCPOS binary input.
   - The signal BLKU should appear with almost no time delay.
   - The signal BLKZ should not appear on the IED.
   - Only the distance protection function can operate.
   - Undervoltage-dependent functions must not operate.
3. Disconnect the dc voltage from the DISCPOS binary input terminal.
4. Connect the nominal dc voltage to the MCBOP binary input.
   - The BLKUand BLKZ signals should appear without any time delay.
   - All undervoltage-dependent functions must be blocked.
5. Disconnect the dc voltage from the MCBOP binary input terminal.
6. Disconnect one of the phase voltages and observe the logical output signals on the binary outputs of the IED. BLKU and BLKZ signals should appear simultaneously.

10.8.2.2 Measuring the operate value for the dead line detection function

1. Apply two-phase voltages with their rated value and zero currents.
2. Decrease the measured voltage in both phases until the DLD2PH signal appears.
3. This is the point at which the dead line condition is detected. Check the value of the decreased voltage with the set value *UDLD<* (*UDLD<* is in percent of the base voltage *UBase*).

4. Apply two-phase currents with their rated value and zero voltages.
5. Decrease the measured current in both phases until the DLD2PH signal appears.
6. This is the point at which the dead line condition is detected. Check the value of the decreased current with the set value *IDLD<* (*IDLD<* is in percent of the base current *IBase*).

10.8.2.3 Checking the operation of the du/dt and di/dt based function

Check the operation of the du/dt and di/dt based function if included in the IED.

1. Simulate normal operating conditions with the two-phase currents in phase with their corresponding phase voltages and with all of them equal to their rated values.
2. Change the voltages and currents in all phases simultaneously.
   The voltage change must be higher than the set value *DU>* and the current change must be lower than the set value *DI<*.
   The BLKU and BLKZ signals appear without any time delay.
3. Apply normal conditions as in step 1
   The BLKU and BLKZ signals should reset, if activated, see step 1 and 2.
4. Change the voltages and currents in all phases simultaneously.
   The voltage change must be higher than the set value *DU>* and the current change must be higher than the set value *DI<*.
   The BLKU and BLKZ signals should not appear.
5. Repeat step 2.
6. Connect the rated voltages in all phases and feed a current below the operate level in all phases.
7. Keep the current constant. Disconnect the voltage in both two phases simultaneously.
   The BLKU and BLKZ signals should not appear.

10.8.2.4 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.8.3 Voltage based delta supervision DELVSPVC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.8.3.1 Verifying the signals and settings

Make sure that the function is connected to SMAI function with U2P signal.

Delta supervision function has 6 different modes of operation. Proceed as follows to test the function in a particular mode.

1. Set the following parameters:
   - *Operation* = On
   - *MeasMode* = Phase-to-ground
   - *Umin* = 10% of *UBase*
   - *DelU>* = 50% of *UBase*
   - *DelUang>* = 10°
   - *DeltaT* = 2
   - *tHold* = 100
2. Set the constant voltage input of UL1 = 63.5V at 0° and UL2 = 63.5V at 180° secondary at rated frequency.
3. Based on the mode of operation, carry out the following changes on input condition of Step 2 to detect start condition.
   Each mode is given for increase and decrease operation. (3-a and 3-b)

Step No.	OpMode	Changes after step 2	Expected output
3-a	Instantaneous 1 cycle or Instantaneous 2 cycle	Change UL1 to 20V	STL1 , STLOW, START signal should be TRUE for 100 ms
3-b	Instantaneous 1 cycle or Instantaneous 2 cycle	Change UL1 back to 63.5V	STL1 , STRISE, START signal should be TRUE for 100 ms
3-a	RMS or DFT Mag	Change UL1 to 20V	STL1, STLOW, START signal should be TRUE for 100 ms
3-b	RMS or DFT Mag	Change UL1 back to 63.5V	STL1 , STRISE, START signal should be TRUE for 100 ms
3-a	DFT Angle (vector shift)	Change UL1 to 63.5V at 15° without changing frequency	STL1, START signal will be TRUE for 100 ms.
3-b	DFT Angle (Vector shift)	Change UL1 to 63.5V at 0° without changing frequency	STL1, START signal will be TRUE for 100 ms

4. Repeat Step 3 with UL2 changes for different mode.

10.8.3.2 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.8.4 Current based delta supervision DELISPVC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.8.4.1 Verifying the signals and settings

Make sure that the function is connected to SMAI function with I2P signal.

Delta supervision function has four different modes of operation. Proceed as follows to test the function in a particular mode.

1. Set the following parameters:
   - *Operation* = ON
   - *MeasMode* = Phase-to-ground
   - *Imin* = 10% of *IBase*
   - *DelI>* = 80% of *IBase*
   - *DeltaT* = 2
   - *tHold* = 100
2. Set the constant current input of IL1 = 1A at 0° and IL2 = 1A at 180° secondary at rated frequency.
3. Based on the mode of operation, carry out the following changes on input condition of Step 2 to detect start condition.
   Each mode is given for increase and decrease operation. (3-a and 3-b)

Step No.	OpMode	Changes after step 2	Expected output
3-a	Instantaneous 1 cycle or Instantaneous 2 cycle	Change IL1 to 2 A	STL1 , STRISE, START signal should be TRUE for 100 ms
3-b	Instantaneous 1 cycle or Instantaneous 2 cycle	Change IL1 back to 1A	STL1 , STLOW, START signal should be TRUE for 100 ms
3-a	RMS or DFT Mag	Change IL1 to 2 A	STL1, STRISE, START signal should be TRUE for 100 ms
3-b	RMS or DFT Mag	Change IL1 back to 1A	STL1 , STLOW, START signal should be TRUE for 100 ms

4. Repeat Step 3 with IL2 changes for different mode.

10.8.4.2 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.8.5 Delta supervision of real input DELSPVC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.8.5.1 Verifying the signals and settings

Make sure that the function is connected to any of the available real derived outputs, for example the P output signal of the CMMXU function.

1. Set the following parameters:
   - *Operation* = ON
   - *MinStVal* = 10
   - *DelSt>* = 100
   - *DeltaT* = 7
   - *tHold* = 100
2. Set a constant voltage input of UL1 = 63.5 V at 0° and UL2 = 63.5 V at 180° secondary and a current signal at IL1 = 1A at 0° and IL2 = 1A at 180°.
3. Ensure that the P output of CMMXU function has exceeded 10 MW and remains stable.
4. Change the current signal at IL1= 2A at 0° and IL2= 2A at 180°. Both START and STARTRISE signals should be active for 100 ms.
5. Change the current signal at IL1= 1A at 0° and IL2= 1A at 180°. Both START and STARTLOW signals should be active for 100 ms.

10.8.5.2 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.9 Control

10.9.1 Synchrocheck, energizing check, and synchronizing SESRSYN

This section contains instructions on how to test the synchrocheck, energizing check, and synchronizing function SESRSYN.

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

At commissioning and periodical checks, the functions shall be tested with the used settings. To test a specific function, it might be necessary to change some setting parameters, for example:

- *AutoEnerg* = *Off*/*DLLB*/*DBLL*/*Both*
- *ManEnerg* = *Off*
- *Operation* = *Off*/*On*

The tests explained in the test procedures below describe the settings, which can be used as references during testing before the final settings are specified. After testing, restore the equipment to the normal or desired settings.

A secondary injection test set with the possibility to alter the phase angle and amplitude of the voltage is needed. The test set must also be able to generate different frequencies on different outputs.

Figure 27 shows the general test connection principle, which can be used during testing.

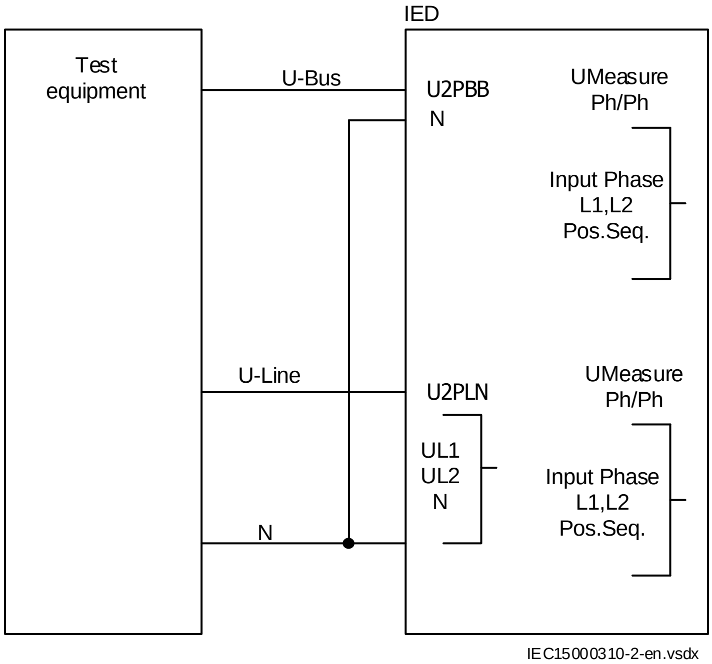


Figure 27: General test connection with two-phase voltage connected to the line side

10.9.1.1 Testing the synchronizing function

The voltage inputs used are:

U2PLN	UL1 or UL2 line voltage inputs on the IED
U2PBB	Busbar voltage input on the IED

Testing the frequency difference

The frequency difference test should verify that operation is achieved when the frequency difference between bus and line is less than set value of *FreqDiffMax* and above set value of *FreqDiffMin*. The test procedure below will depend on the settings used. Input STARTSYN must be activated during the test.

FreqDiffMax = 0.2 Hz

FreqDiffMin = 0.01 Hz

tBreaker = 0.080 s

1. Apply voltages
   1.1. U-Line = 100% *UBaseLine* and f-Line = 16.7 Hz
   1.2. U-Bus = 100% *UBaseBus* and f-Bus = 16.85 Hz
2. Check that a closing pulse is submitted at a closing angle equal to calculated phase angle value from the formula below. Modern test sets will evaluate this automatically.
   Closing Angle = |((f_{Bus}– f_{Line}) * tBreaker * 360 degrees) |
   f_{Bus}= Bus frequency
   f_{Line}= Line frequency
   tBreaker = Set closing time of the breaker
3. Repeat with
   3.1. U-Bus = 100% *UBaseBus* and f-bus = 16.95 Hz, to verify that the function does not operate when frequency difference is above limit.
4. Verify that the closing command is not issued as the frequency difference is not within the limits.

10.9.1.2 Testing the synchrocheck functionality

During the test of SESRSYN for a single bay arrangement, these voltage inputs are used:

U-Line	UL1 or UL2 line voltage input on the IED according to the connection in SMT
U-Bus	Bus voltage input on the IED according to the connection in SMT

Testing the voltage difference

Set the voltage difference to 0.15 p.u. on the local HMI, and the test should check that operation is achieved when the voltage difference *UDiffSC* is lower than 0.15 p.u.

The settings used in the test shall be final settings. The test shall be adapted to site setting values instead of values in the example below.

Test with no voltage difference between the inputs.

Test with a voltage difference higher than the set *UDiffSC*.

1. Apply voltages U-Line (for example) = 80% *GblBaseSelLine* and U-Bus = 80% *GblBaseSelBusGblBaseSelBus* with the same phase-angle and frequency.
2. Check that the AUTOSYOK and MANSYOK outputs are activated.
3. The test can be repeated with different voltage values to verify that the function operates within the set *UDiffSC*. Check with both U-Line and U-Bus respectively lower than the other.
4. Increase the U-Bus to 110% *GblBaseSelBus*, and the U-Line = 90% *GblBaseSelLine* and also the opposite condition.
5. Check that the two outputs for manual and auto synchronism are not activated.

Testing the phase angle difference

The phase angle differences *PhaseDiffM* and *PhaseDiffA* respectively are set to their final settings and the test should verify that operation is achieved when the phase angle difference is lower than this value both leading and lagging.

Test with no voltage difference.

1. Apply voltages U-Line (for example) = 100% *GblBaseSelLine* and U-Bus = 100% *GblBaseSelBus*, with a phase difference equal to 0 degrees and a frequency difference lower than *FreqDiffA* and *FreqDiffM*.
2. Check that the AUTOSYOK and MANSYOK outputs are activated.
   The test can be repeated with other phase difference values to verify that the function operates for values lower than the set ones, *PhaseDiffM* and *PhaseDiffA*. By changing the phase angle on the voltage connected to U-Bus, between ± dφ degrees, the user can check that the two outputs are activated for a phase difference lower than the set value. It should not operate for other values. See figure 28.

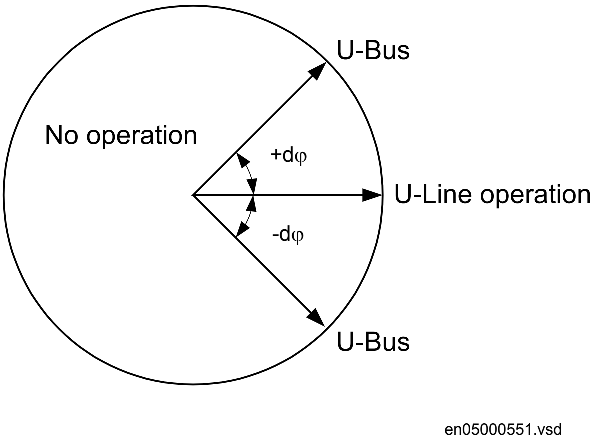


Figure 28: Test of phase difference

3. Change the phase angle between +dφ and -dφ and verify that the two outputs are activated for phase differences between these values but not for phase differences outside, see figure 28.

Testing the frequency difference

The frequency difference test should verify that operation is achieved when the *FreqDiffA* and *FreqDiffM* frequency difference is lower than the set value for manual and auto synchronizing check, *FreqDiffA* and *FreqDiffM* respectively and that operation is blocked when the frequency difference is greater.

Test with frequency difference = 0 mHz

Test with a frequency difference outside the set limits for manual and auto synchronizing check respectively.

1. Apply voltages U-Line equal to 100% *GblBaseSelLine* and U-Bus equal to 100% *GblBaseSelBus*, with a frequency difference equal to 0 mHz and a phase difference lower than the set value.
2. Check that the AUTOSYOK and MANSYOK outputs are activated.
3. Apply voltage to the U-Line equal to 100% *GblBaseSelLine* with a frequency equal to 16.7 Hz and voltage U-Bus equal to 100% *GblBaseSelBus*, with a frequency outside the set limit.
4. Check that the two outputs are not activated. The test can be repeated with different frequency values to verify that the function operates for values lower than the set ones. If a modern test set is used, the frequency can be changed continuously.

Testing the reference voltage

1. Use the same basic test connection as in figure 27.

The voltage difference between the voltage connected to U-Bus and U-Line should be 0%, so that the AUTOSYOK and MANSYOK outputs are activated first.

2. Change the U-Line voltage connection to U-Line2 without changing the setting on the local HMI. Check that the two outputs are not activated.

10.9.1.3 Testing the energizing check

During the test of the energizing check function for a single bay arrangement, these voltage inputs are used:

U-Line	UL1 or UL2 line voltage inputs on the IED
U-Bus	Bus voltage input on the IED

General

When testing the energizing check function for the applicable bus, arrangement shall be done for the energizing check functions. The voltage is selected by activation of different inputs in the voltage selection logic.

Live voltage level is fixed to 80% *UBase* and dead voltage level to fixed 40% *UBase*.

The test shall be performed according to the settings for the station. Test the alternatives below that are applicable.

Testing the dead line live bus (DLLB)

The test should verify that the energizing check function operates for a low voltage on the U-Line and for a high voltage on the U-Bus. This corresponds to the energizing of a dead line to a live bus.

1. Apply a single-phase voltage 100% *GblBaseSelBus* to the U-Bus, and a single-phase voltage 30% *GblBaseSelLine* to the U-Line.
2. Check that the AUTOENOK and MANENOK outputs are activated after set *tAutoEnerg* respectively *tManEnerg*.
3. Increase the U-Line to 60% *GblBaseSelLine* and U-Bus to be equal to 100% *GblBaseSelBus*. The outputs should not be activated.
4. The test can be repeated with different values on the U-Bus and the U-Line.

Testing the dead bus live line (DBLL)

The test should verify that the energizing check function operates for a low voltage on the U-Bus and for a high voltage on the U-Line. This corresponds to an energizing of a dead bus to a live line.

1. Verify the settings *AutoEnerg* or *ManEnerg* to be *DBLL*.
2. Apply a single-phase voltage of 30% *GblBaseSelBus* to the U-Bus and a single-phase voltage of 100% *GblBaseSelLine* to the U-Line.
3. Check that the AUTOENOK and MANENOK outputs are activated after set *tAutoEnerg* respectively *tManEnerg*.
4. Decrease the U-Line to 60% *GblBaseSelLine* and keep the U-Bus equal to 30% *GblBaseSelBus*. The outputs should not be activated.
5. The test can be repeated with different values on the U-Bus and the U-Line.

Testing both directions (DLLB or DBLL)

1. Verify the local HMI settings *AutoEnerg* or *ManEnerg* to be *Both*.
2. Apply a single-phase voltage of 30% *GblBaseSelLine* to the U-Line and a single-phase voltage of 100% *GblBaseSelBus* to the U-Bus.
3. Check that the AUTOENOK and MANENOK outputs are activated after set *tAutoEnerg* respectively *tManEnerg*.
4. Change the connection so that the U-Line is equal to100% *GblBaseSelLine* and the U-Bus is equal to 30% *GblBaseSelBus*. The outputs should still be activated.
5. The test can be repeated with different values on the U-Bus and the U-Line.

Testing the dead bus dead line (DBDL)

The test should verify that the energizing check function operates for a low voltage on both the U-Bus and the U-Line, that is, closing of the breaker in a non-energized system. Test is valid only when this function is used.

1. Verify the local HMI setting *AutoEnerg* to be *Off* and *ManEnerg* to be *DBLL*.
2. Set the parameter *ManEnergDBDL* to *On*.
3. Apply a single-phase voltage of 30% *GblBaseSelBus* to the U-Bus and a single-phase voltage of 30% *GblBaseSelLine* to the U-Line.
4. Check that the MANENOK output is activated after set *tManEnerg*.
5. Increase the U-Bus to 80% *GblBaseSelBus* and keep the U-Line equal to 30% *GblBaseSelLine*. The outputs should not be activated.
6. Repeat the test with *ManEnerg* set to *DLLB* with different values on the U-Bus and the U-Line voltage.

10.9.1.4 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.9.2 Autoreclosing for railway system SMBRREC

The verification of the auto recloser function for railway system consists of two parts:

- One part to verify the internal logic and timing of the function
- One part to verify its interaction with the protection system

This section deals with verification of SMBRREC itself. However, it is practical to start SMBRREC by activating a protection function, for example, by secondary injection tests.

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

The purpose of verification before commissioning is to check that entered selections, setting parameters and configuration render the intended result. The function is flexible with many options and facilities. At commissioning only the selections and settings intended for use are verified. If one chooses to reduce some time settings in order to speed up verification, be careful to set the parameters at intended operational values at the end of the verification procedure. One such parameter is the *tReclaim* time that must be timed out before a new test sequence can be performed.

The verification test is performed together with protection and trip functions. Figure 29 illustrates a suggested testing arrangement, where the circuit-breaker (CB) is simulated by an external bi-stable relay (BR), for example a relay type RXMVB2 or RXMD or Breaker Simulator of ABB. The following manual switches are used:

- Switch or push-button to close (SC)
- Switch or push-button to trip (ST)
- Switch for CB ready condition (SRY)

If no bi-stable relay or breaker simulator is available, replace it with two self-reset auxiliary relays and use a self-holding connection.

Use a secondary injection IED test set to operate the protection function. The test set shall be switched off when a trip signal is given or when the BR comes to open position to simulate real conditions.

The CB simulation can be made more elaborate, including simulation of the operating gear condition, CBREADY of either the type ready for a Close-Open (CO) cycle, or the type ready for an Open-Close -Open (OCO) cycle.

The CB condition CBREADY of a type, CO, shall be high (true) until a closing operation is performed. It then goes low (false) for a recharging time of about 5 - 10s. After that it is high again.

A CB condition CBREADY of a type, OCO shall be high (true) before and during tripping (Start reclosing). During tripping it goes low for a recharging time, for example, 10s. It may thus be low at the instant of reclosing. After each Open or Close operation it may need a recharging period before it goes high again.

In the example of CB simulation arrangement, the CBREADY condition is simulated by a manual switch, SRY.

Information and material for the verification:

- Protection or control unit, IED, configured and with settings entered.
- Configuration diagram for the IED
- Terminal diagram for the IED, or plant circuit diagram including the IED
- Technical reference manual for the IED
- IED test set for secondary injection
- Means to indicate, measure and record operation and times, for example an event recording facility
- A bi-stable relay (BR) or two auxiliary relays to simulate a CB
- Two push-buttons (SC, ST) to operate the BR and a change-over switch (SRY) to simulate CBREADY
- Possibly a switch simulation the synchronizing check SESRSYN condition

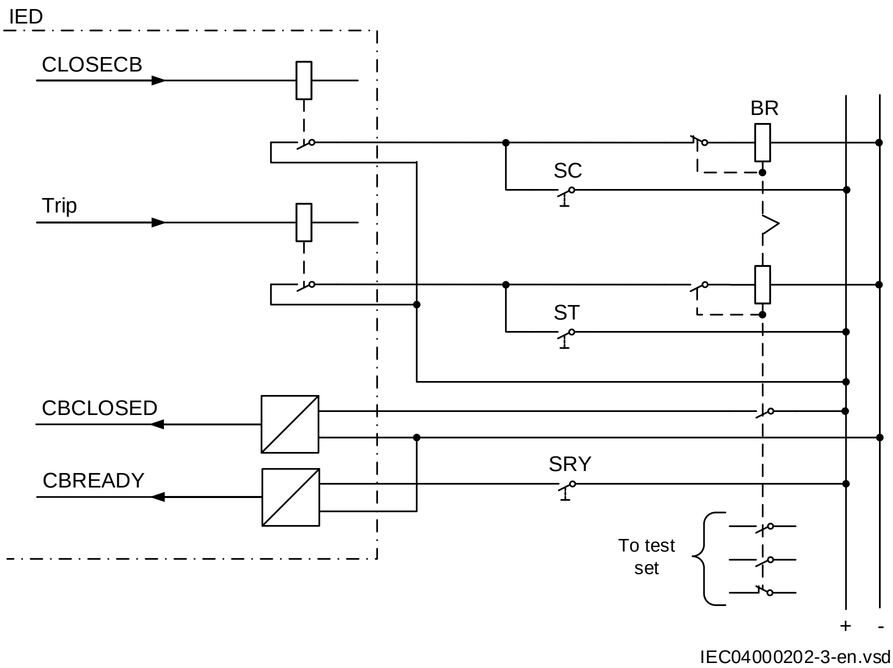


Figure 29: Simulating the CB operation by a bi-stable relay/breaker simulator and manual switches

10.9.2.1 Preparation of the verification

1. Check the function settings on the local HMI under **Main menu/ Settings/IED Settings/Control/Autorecloser79,5(0–>1)/ SMBRREC:x(79,5(0–>)):x**
   If any timer settings are reduced to speed up or facilitate the testing, they shall be set to normal after testing. A temporary label on the IED can be a reminder to restore normal settings after which a verification test should be performed.
2. Decide if a synchrocheck function SESRSYN shall be included in the test.
   If SESRSYN as an internal function or external device is not operated by the injection, input signal SYNC must be connected as a permanent high signal or controlled by a switch.
3. Read and make notes of the reclosing operation counters on the local HMI under **Main menu/Test/Function status/Control/AutoRecloser79,5(0–>1)/ SMBRREC(79,5(0–>1)):x**
   Possibly reset the counters to *Zero*. Counters are reset in the reset menu.
4. Make arrangements for the simulation of the CB, for example as in Figure 29.
5. Make arrangements for indication, recording and time measurements.
   The signals for CBCLOSED, START, CLOSECB, READY and other relevant signals should preferably be arranged for event recording with time tagging. If that is not possible, other means of time measurement and recording should be arranged.

10.9.2.2 Switching the auto recloser to *On* and *Off*

1. Set the *Operation* setting to *Off* and check the state.
2. Set the *Operation* setting to *On* and check the state, including *SETON* and *READY*.
   The circuit breaker should be closed and ready.
3. If external control inputs OFF/ON are used, check that they work. Set *ExternalCtrl* = *On* and use the control inputs to switch On and Off, and check the state of the function.

10.9.2.3 Verifying the auto recloser

Select the test cases to be run according to what is applicable to the particular application. It can be, for example,

- single-shot reclosing
- two-shot reclosing

Below, a case with single-shot reclosing is described.

1. Set *Operation* = *On*.
2. If the synchrocheck SESRSYN is not to be operated, ensure that the signal SYNC input is activated. If SESRSYN is to be included, ensure that it is supplied with the appropriate AC quantities.
3. Simulate CB closed position by closing switch SC to make the BR relay start.

4. Simulate CBREADY by closing the switch SRY, and leave it closed.
5. Inject AC quantities to give a trip to the BR and to the START input.
   Observe and preferably record the operation. The BR relay shall trip and reclose (start). After reclosing, the SRY switch can be opened for about 5s and then closed again.
   The auto reclosing open time and the sequence should be checked, for example in the event recording. Check also the operation indications (disturbance report) and the operation counters on the local HMI under **Main menu/Test/Function status/Control/AutoRecloser79,5(0–>1)/ SMBRREC(79,5(0–>)):x**
   Should the operation not be as expected, this should be investigated. It could be caused by an inappropriate setting or missing condition such as *CBREADY*.
6. Repeat the sequence by simulating a permanent fault.
   Shortly after the reclosing shot, a new fault is applied. There shall be one reclosing operation and then blocking of the auto recloser for the set reclaim time.
   Before a new reclosing sequence can be run, the *CBREADY* and *CBCLOSED* must be set manually.
7. Repeat the sequence by simulating transient and permanent faults, and other applicable cases, such as signal to *STARTHS* and high-speed auto reclosing.

10.9.2.4 Checking the auto reclosing conditions

When checking the influence of a releasing condition it is suggested to first run an auto reclosing sequence with the condition fulfilled. When the condition signal is removed, and a new sequence is run, it indicates that the result was due to the changed condition. In case of a blocking signal the procedure should be similar. Start without the blocking or inhibit signal, and then run a sequence with the blocking or inhibit signal added.

Checking the influence of the INHIBIT signal

1. Check that the auto recloser is operative, for example, by making a reclosing shot without the *INHIBIT* signal.
2. Apply a fault and thereby a *START* signal. At the same time, or during the dead time, apply a signal to the input *INHIBIT*.
3. Check that the auto reclosing sequence is interrupted and no auto reclosing takes place.

Check closing onto a fault

1. Check that the auto recloser is operative, for example by making a reclosing shot.

Keep the *CBREADY* signal high.
2. Set the breaker simulating relay BR in Open position.
3. Close the BR relay and immediately apply a fault and thereby a START signal.
4. Check that no auto reclosing takes place.

Checking the influence of circuit breaker not ready for reclosing

1. Check that the auto recloser function is operative, for example by making an auto reclosing shot.
   Keep the CB simulator BR closed. Remove the *CBREADY* signal by opening SRY.
2. Apply a fault and thereby a START signal.
3. Check that no auto reclosing takes place.

Checking the influence of synchrocheck

1. Check that the auto recloser function SMBRREC is operative, for example, by making a reclosing shot with the SESRSYN synchrocheck conditions fullfilled.
   Set the SESRSYN function to *Off* to eliminate the signal connected to input signal SYNC.
2. Apply a fault causing a trip and, thereby, a START signal to the auto recloser.
3. Wait for the *tSync* time-out limit.
   Check that no reclosing is made.

Restoring equipment

After the tests, restore the equipment to normal or desired state. Check the following items in particular:

1. Check the operation counters.
   Reset the counters to zero, if that is the user's preference. The counter reset function is found on the local HMI under **Main menu/Reset/Reset counters/AutoRecloser79,5(0–>1)/SMBRREC(79,5(0–>1)):x**
2. Restore settings that may have been modified for the tests back to normal.
3. Disconnect the test switch, circuit breaker simulating arrangement and test circuits.
   Reconnect any links or connection terminals, which may have been opened for the tests.
4. Reset indications, alarms and disturbance recordings.
   Clearing of the disturbance report can be done via the Disturbance Handling in PCM600 or the local HMI.

10.9.2.5 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.9.3 Apparatus control APC

The apparatus control function consists of four types of function blocks, which are connected in a delivery-specific way between bays and to the station level. For that reason, test the total function in a system, that is, either in a complete delivery system as an acceptance test (FAT/SAT) or as parts of that system.

If a block/unblock command is sent from remote to function, while the IED is shut down, this command will not be recognized after the start up, thus the command that was sent prior to the shut down is used. In such cases, where there is a mismatch, the user is advised to make a complete cycle of block/unblock operations to align the statuses.

10.9.4 Tap changer control and supervision TCMYLTC, TCLYLTC

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

The automatic voltage control for tap changer, single control TR1ATCC is based on a transformer configuration that consists of one tap changer on a single two-winding power transformer.

The automatic voltage control for tap changer, parallel control TR8ATCC, if installed, may be set to operate in Master Follower (MF) mode, or Minimise Circulating Current (MCC) mode. The commissioning tests for each parallel control mode are addressed separately in the following procedure.

Secondary injection of load current (I_L) and secondary bus voltage (U_B) equivalent quantities are required during installation and commissioning tests. The test consists mainly of:

1. Increasing or decreasing the injected voltage or current at the analogue inputs of the IED.
2. Checking that the corresponding commands (Lower or Raise) are issued by the voltage control function.

Setting confirmation is an important step for voltage control in the installation and commissioning phase to ensure consistency of power systems base quantities, alarm/blocking conditions and parallel control settings for each transformer control function.

Before starting any test, verify the following settings in PCM600 or the local HMI for TR1ATCC, TR8ATCC and TCMYLTC and TCLYLTC.

- Confirm power system base quantities *I1Base*, *I2Base*, *UBase*.

Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC, 90)/TR1ATCC:x/TR8ATCC:x/General

and

Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC, 90)/TR1ATCC:x

.

- Confirm that the setting for short circuit impedance *Xr2* for TR1ATCC or TR8ATCC is in accordance with transformer data:
  - Short circuit impedance, available on the local HMI under **Main menu/ Settings/IED settings/Control/TransformerVoltageControl(ATCC, 90)/TR1ATCC:x/TR8ATCC:x/Xr2**.
- Confirm that the setting for TCMYLTC or TCLYLTC is in accordance with transformer data:
  - Tap change timeout duration - effectively the maximum transformer tap change time, *tTCTimeout*, available on the local HMI under **Main menu/ Settings/IED Settings/Control/TransformerTapControl(YLTC,84)/ TCMYLTC:x/TCLYLTC:x/tTCTimeout**.
  - Load tap changer pulse duration - required length of pulse from IED to load tap changer, *tPulseDur*, available on the local HMI under **Main menu/Settings/IED Settings/Control/TransformerTapControl(YLTC, 84)/TCMYLTC:x/TCLYLTC:x/tPulseDur**.
  - Transformer tap range, *LowVoltTap* and *HighVoltTap*, available on the local HMI under **Main menu/Settings/IED Settings/Control/ TransformerTapControl(YLTC,84)/TCMYLTC:x/TCLYLTC:x/ HighVoltTap** and .
  - Load tap changer code type - method for digital feedback of tap position, *CodeType*, available on the local HMI under **Main menu/Settings/ IED settings/Control/TransformerTapControl(YLTC,84)/TCMYLTC:x/ TCLYLTC:x/CodeType**.

During the installation and commissioning, the behavior of the voltage control functions for different tests may be governed by a parameter group, available on the local HMI under **Main menu/ Settings/IED Settings/Control/ TransformerVoltageControl(ATCC,90)/TR1ATCC:x/ TR8ATCC:x**. These parameter settings can cause a Total Block, Automatic Block or Alarm for a variety of system conditions including over and under voltage, over current and tap changer failure. It is important to review these settings and confirm the intended response of the voltage control function for different secondary injection tests.

Terminology

The busbar voltage U_B is a shorter notation for the measured voltages UL1, UL2, UL3 or Uij, where Uij is the phase-phase voltage, Uij = Ui -Uj, or Ui, where Ui is one single-phase-to-earth voltage.

I_L is a shorter notation for the measured load current; it is to be used instead of the three-phase quantities IL1, IL2, IL3 or the two-phase quantities Ii and Ij, or single-phase current Ii.

Also note that for simplicity, the Parameter Setting menu structures included in the following procedure are referred to universally as VCP1, for example, **Main menu/Settings/IED Settings/Control/ TransformerVoltageControl(ATCC,90)/TR1ATCC:x/ TR8ATCC:x/Time/t1 and t2l**.

For cases where single-mode voltage control is implemented, the Parameter Setting menu structure includes TR1ATCC:1 instead of the parallel designator TR8ATCC: 1.

10.9.4.1 Secondary test

The voltage control function performs basic voltage regulation by comparing a calculated load voltage (U_L) against a voltage range defined by setting *UDeadband* (with upper and lower limits U2 and U1 respectively). The calculated load voltage U_L represents the secondary transformer bus voltage U_B adjusted for Load drop compensation (LDC) where enabled in settings.

Note that when LDC is disabled, U_B equals U_L.

When the load voltage U_L stays within the interval between U1 and U2, no action will be taken.

If U_L < U1 or U_L > U2, a command timer will start, which is constant time or inverse time defined by setting *t1* and *t1Use*. The command timer will operate while the measured voltage stays outside the inner deadband (defined by setting *UDeadbandInner*).

If U_L remains outside of the voltage range defined by *UDeadband* and the command timer expires, the voltage control will execute a raise or lower command to the transformer tap changer. This command sequence will be repeated until U_L is brought back within the inner deadband range.

10.9.4.2 Check the activation of the voltage control operation

1. Confirm *Transformer Tap Control* = *On* and *Transformer Voltage Control* = *On*
   - Direct tap change control

   Main menu/Settings/IED Settings/Control/ TransformerTapChanger(YLTC,84)/TCMYLTC:x/TCLYLTC:x/ Operation
   - Automatic transformer voltage control

   Main menu/Settings/IED Settings/Control/ TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/ General/Operation
   - Enable Tap Command

   Main menu/Settings/IED Settings/Control/ TransformerTapChanger(YLTC,84)/TCMYLTC:x/TCLYLTC:x/ EnabTapCmd
   While the test set is connected to the IED but no voltage is applied, the voltage control functions will detect an undervoltage condition that may result in an alarm or blocking of the voltage-control operation. These conditions will be shown on the local HMI.
2. Apply the corresponding voltage
   Confirm the analog measuring mode prior to undertaking secondary injection (positive sequence, phase-to-phase, or phase-to-earth). This measuring mode is defined in the local HMI under **Main menu/Settings/IED Settings/ Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/ TR8ATCC:x/General/MeasMode**
   The application of nominal voltage *USet* according to set *MeasMode* to the IEDs should cause the alarm or blocking condition for undervoltage to reset.

10.9.4.3 Check the normal voltage regulation function

1. Review the settings for *UDeadband* (based on percentage of nominal bus voltage) and calculate the upper (U2) and lower (U1) voltage regulation limits for which a tap change command will be issued.
2. Review the expected time for first (*t1*) and subsequent (*t2*) tap change commands from the voltage control function on the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC, 90)/TR1ATCC:x/TR8ATCC:x/Time/t1 and t2l**
3. Lower the voltage 1% below U1 and wait for the issue of a Raise command from the voltage control after the expiry of a constant or inverse time delay set by *t1*. Detection of this command will involve locating the allocated

binary output for a raise pulse command in the Signal Matrix in PCM600 and monitoring a positive from this output.
4. After the issue of the raise command, return the applied voltage to *USet* (nominal value).
5. Raise the voltage 1% above the upper deadband limit U2 and wait for the issue of a lower command from the voltage control after the expiry of a constant or inverse time delay set by *t1*. Detection of this command will involve locating the allocated binary output for a low pulse command in the Signal Matrix in PCM600 and monitoring a positive from this output.
6. Return the applied voltage to *USet*.

10.9.4.4 Check the undervoltage block function

1. Confirm the setting for *Ublock*, nominally at 80% of rated voltage.
2. Confirm the voltage control function response to an applied voltage below *Ublock*, by reviewing the setting in the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/UVBk** that may cause an alarm, total or automatic block of the voltage control function to be displayed on the local HMI.
3. Apply a voltage slightly below *Ublock* and confirm the response of the voltage control function.

10.9.4.5 Check the upper and lower busbar voltage limit

1. Confirm the settings for *Umin* and *Umax* in the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/Voltage/Umax or Umin** and **Main menu/Settings/IED Settings/Control/TR8ATCC (90)/TR8ATCC:n/Voltage/Umax**
2. Confirm the voltage control function response to an applied voltage below *Umin* and above *Umax*, by reviewing the settings in the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/UVPartBk** and **Main menu/IED Settings/Control/TransformerVoltageControl/TR1ATCC:x/TR8ATCC:x/OVPartBk**. These conditions may cause an alarm or total block of the voltage control function to be displayed on the local HMI.
3. Decrease the injected voltage slightly below the *Umin* value and check for the corresponding blocking or alarm condition on the local HMI. For an alarm condition, the voltage regulation function is not blocked and a raise command should be issued from the IED.
4. Increase the applied voltage slightly above the *Umax* value and check for the corresponding blocking or alarm condition on the local HMI. For an alarm

condition, the voltage regulation function is not blocked and a lower command should be issued from the IED.

10.9.4.6 Check the overcurrent block function

1. Confirm the setting for *Iblock* in the local HMI under **Main menu/ Settings/IED Settings/Control/TransformerVoltageControl(ATCC,91)/ TR1ATCC:x/TR8ATCC:x/TCCtrl/Iblock**
2. Confirm the voltage control function response to an applied current above *Iblock*, by reviewing the settings in the local HMI under **Main menu/ Settings/IED Settings/Control/TransformerVoltageControl(ATCC,91)/ TR1ATCC:x/TR8ATCC:x/OVPartBk**. This condition may cause an alarm or total block of the voltage control function to be displayed on the local HMI.
3. Inject a current higher than the *Iblock* setting and confirm the alarm or blocking condition is present on the local HMI. If an automatic or total blocking condition occurs, change the applied secondary voltage and confirm that no tap change commands are issued from the associated binary outputs. This situation can also be confirmed through reviewing the disturbance and service reports on the local HMI.

10.9.4.7 Single transformer

Load drop compensation

1. Confirm that *OperationLDC* is set to *On*.
2. Confirm settings for *Rline* and *Xline*.
3. Calculate the expected load voltage U_L (displayed as a measured value on the local HMI) based on secondary injection of transformer secondary voltage (U_B = *USet*) and rated load current (I_L = *I1Base*), in accordance with equation 10.

$$U_L = U_B - (Rline + jXline) \cdot I_L$$

(Equation 10)

where:

U_L, $I_L = Re(I_L) + jIm(I_L)$ are complex phase quantities

When all secondary phase-to-earth voltages are available, use the positive-sequence components of voltage and current. By separation of real and imaginary parts:

$$ul,re = ub,re - rline \cdot il,re + xline \cdot il,im$$

(Equation 11)

$$ul,im = ub,im - xline \cdot il,re - rline \cdot il,im$$

(Equation 12)

where:

ub	is the complex value of the busbar voltage
il	is the complex value of the line current (secondary side)
rline	is the value of the line resistance
xline	is the value of the line reactance

For comparison with the set-point value, the modulus of U_L are according to equation 13.

$$|U_L| = \sqrt{(ul, re)^2 + (ul, im)^2}$$

(Equation 13)

4. Inject voltage for U_B equal to setting *USet*.
5. Inject current equal to rated current *I2Base*.
6. Confirm on the local HMI that service values for bus voltage and load current are equal to injected quantities.
7. Confirm that the calculated value for load voltage, displayed on the local HMI, is equal to that derived through hand calculations.
8. When setting *OperationLDC* set to *On*, the voltage regulation algorithm uses the calculated value for load voltage as the regulating quantity to compare against *USet* and the voltage deadband limits *UDeadband* and *UDeadbandInner*.
9. While injecting rated current *I2Base* into the IED, inject a quantity for U_B that is slightly higher then *USet* + |(*Rline*+j*XLine*) · I_L|. This will ensure that the regulating voltage U_L is higher than *USet*, and hence no tap change command should be issued from the IED.
10. Reduce the injected voltage for U_B slightly below *USet* + |(*Rline*+j*XLine*) · I_L| and confirm that the calculated value for load voltage is below *USet* and a tap change command is issued from the IED.

10.9.4.8 Parallel voltage regulation

Master follower voltage regulation

1. For the transformers connected in the parallel group, confirm that *OperationPAR* is set to *MF*.
2. For parallel operation, it is also recommended to confirm for parallel group membership, defined by setting *TnRXOP* in the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR8ATCC:x/ParCtrl**
   The general parallel arrangement of transformers are defined by setting *TnRXOP* to *On* or *Off*. The following rules are applicable on the settings *T1RXOP* – *T4RXOP*.
   If IED *T1* and *T2* are connected,
   - *T1RXOP* shall be set to *On* in instance 2 of TR8ATCC,
   - *T2RXOP* shall be set to *On* in instance 3 of TR8ATCC,
   - *T2RXOP* and *T3RXOP* shall be set to *On* in instance 1 of TR8ATCC, and so on.

   The parameter corresponding to the own IED **must not** be set. *T1RXOP* should thus not be set in IED *T1*, *T2RXOP* **not** in IED *T2*, and so on.

3. The lowest transformer number in the parallel group is by default set as the Master – confirm that this is the case by reviewing the setting in the local HMI.
4. Review the settings for *UDeadband* (based on percentage of nominal bus voltage) and calculate the upper (U2) and lower (U1) voltage regulation limits for which a tap change command will be issued from the master transformer in the group.
5. Review the expected time for first (*t1*) and subsequent (*t2*) tap change commands from the master transformer in the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/Time/t1 and t2**
6. Apply a voltage 1% below U1 and wait for the issue of a raise command from the voltage control after the expiry of a constant or inverse time delay set by *t1*. Detection of this command will involve locating the allocated binary output for a raise command in the Signal Matrix in PCM600 and monitoring a positive from this output. Confirm the timing of this command correlates with the setting *t1*.
7. After the issue of the raise command, confirm that all follower transformers in the group change tap in accordance with the command issued from the master transformer.
8. Inject a voltage U_B for the master transformer that is 1% above the upper deadband limit U2 and wait for the issue of a lower command from the voltage control after the expiry of a constant or inverse time delay set by *t2*.
9. Confirm that all follower transformers in the group change tap in accordance with this command.

Circulating current voltage regulation

This instruction for confirmation of circulating current voltage regulation assumes two transformers in the parallel group. Setting confirmation through secondary injection requires calculation of circulating currents for each transformer based on impedance values and respective compensating factors, and is therefore more complex for greater than two transformers.

1. Confirm that *OperationPAR* is set to *CC* for the transformers in the parallel group.
2. For parallel operation, it is also recommended that settings be confirmed for parallel group membership, governed by setting *TnRXOP* in the local HMI under **Main menu/Settings/IED Settings/Control/ TransformerVoltageControl(ATCC,90)/TR8ATCC:x/ParCtrl**
   The general parallel arrangement of transformers are defined by setting *TnRXOP* to *On* or *Off*. The following rules are applicable on the settings *T1RXOP* - *T4RXOP*.
   If IED *T1* and *T2* are connected,
   - *T1RXOP* shall be set to *On* in instance 2 of TR8ATCC, and
   - *T2RXOP* shall be set to *On* in instance 1 of TR8ATCC.

   If *T1* - *T3* are available,
   - *T1RXOP* and *T2RXOP* shall be set to *On* in instance 3 of TR8ATCC,
   - *T2RXOP* and *T3RXOP* shall be set to *On* in instance 1 of TR8ATCC and so on.

   The parameter corresponding to the own IED **must not** be set. *T1RXOP* should thus **not** be set in IED *T1*, *T2RXOP***not** in IED *T2* and so on.

3. Review the settings for *UDeadband* (based on percentage of nominal bus voltage) and calculate the upper (U2) and lower (U1) voltage regulation limits for which a tap change command will be issued from the master transformer in the group.
4. Review the expected time for first (*t1*) and subsequent (*t2*) tap change commands from the master transformer in the local HMI under **Main menu/ Settings/IED Settings/TransformerVoltageControl(ATCC,90)/ TR1ATCC:x/TR8ATCC:x/Time/t1 and t2**
5. Inject a voltage U_B equal to *USet* for each transformer.
6. Inject a load current for Transformer 1 that is equal to rated load current *I2Base* and a load current for Transformer 2 that is equal to 95% of rated load current *I2Base*. This will have the effect of producing a calculated circulating current that flows from HV to LV side for Transformer 1 and LV to HV side for Transformer 2.
7. Confirm that a circulating current is measured on the local HMI that is equal in magnitude to 5% of *I2Base*, with polarity as discussed in step 6.
8. Confirm the settings for C*i* (Compensation Factor) and X*i* (Transformer Short Circuit Impedance). Using these setting values and the measured quantity of

circulating current from the local HMI (I*cc_i*), calculate the value for circulating current voltage adjustment U*ci*.

$$Udi = Ci \cdot Icc\_i \cdot Xi$$

(Equation 14)

The voltage regulation algorithm then increases (for transformer *T2*) or decreases (for transformer *T1*) the measured voltage by Udi and compares Ui against the voltage deadband limits U1 and U2 for the purposes of voltage regulation.

$$U_i = U_B + Udi$$

(Equation 15)

9. To cause a tap change, the calculated value for circulating current voltage adjustment must offset the injected quantity for bus voltage U_B so that Ui is outside the voltage deadband created by setting *UDeadband*. Expressed by equation 16 and equation 17.

$$Udi > U2 - U_B$$

(Equation 16)

$$U_B = Uset$$

(for the purposes of this test procedure)

(Equation 17)

Therfore:

$$Ci \cdot Icc\_i \cdot Xi > U2 - Uset$$

(Equation 18)

$$\left|Icc\_i\right| > {(U2 - Uset)}/{(Ci \cdot Xi)}$$

(Equation 19)

10. Using the settings for *USet*, *UDeadband*, C (Compensating factor) and *Xr2* (transformer short circuit impedance) calculate the magnitude of Icc_*i* necessary to cause a tap change command.
11. Inject current equal to *I2Base* for Transformer 1 and (*I2Base* - |Icc_*i*|) for Transformer 2 so that the magnitude of calculated circulating current will cause a raise command to be issued for Transformer 2 and a lower command for Transformer 1. Magnitude and direction of circulating currents measured for each transformer can be observed as service values on the local HMI and

raise/lower commands detected from the binary output mapped in the Signal Matrix.

The voltage injection equal to *USet* is required for both transformers during this test.

12. Confirm that a tap change command is issued from the voltage control function to compensate for the circulating current.
13. Injected currents can be reversed such that the direction of calculated circulating currents change polarity, which will cause a lower command for Transformer 2 and a raise command for Transformer 1.

Circulating current limit

1. Confirm that *OperationPAR* is set to *CC* for each transformer in the parallel group.
2. Confirm that *OperCCBlock* is set to *On* for each transformer in the parallel group.
3. Review the setting for *CircCurrLimit*.
4. Review the setting for *CircCurrBk* to confirm whether a circulating current limit will result in an *Alarm* state, *Auto Block* or *Auto&Man Block* of the automatic voltage control for tap changer, for parallel control function TR8ATCC.
5. Inject a voltage U_B equal to *USet* for each transformer.
6. Inject a load current for Transformer 1 that is equal to rated load current *I2Base* and a load current for Transformer 2 that is 1% less than (*I2Base* – (*I2Base* · CircCurrLimit))
7. Confirm that the automatic voltage control for tap changer, for parallel control function TR8ATCC responds in accordance with the setting for *CircCurrBk*. Alarm and blocking conditions can be confirmed through interrogation of the event menu or the control menu on the local HMI.

VTmismatch during parallel operation

1. Confirm that *OperationPAR* is set to *MF* for each transformer in the parallel group.
2. Review the setting for *VTmismatch* and *tVTmismatch*.
3. Inject a voltage U_B equal to *USet* for Transformer 1 and a voltage less than (*USet* – (*VTmismatch* · *USet*)) for Transformer 2.
4. This condition should result in a *VTmismatch* which will mutually block the operation of the automatic voltage control for tap changer, parallel control function TR8ATCC for all transformers connected in the parallel group, which can be confirmed through interrogation of the local HMI.
5. Confirm that the automatic voltage control for tap changer, parallel control function TR8ATCC responds in accordance with the setting for *CircCurrBk*.

10.9.4.9 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.9.5 Single command, 16 signals SINGLECMD

For the single command function block, it is necessary to configure the output signal to corresponding binary output of the IED. The operation of the single command function (SINGLECMD) is then checked from the local HMI by applying the commands with *Mode* = *Off*, *Steady* or *Pulse*, and by observing the logic statuses of the corresponding binary output. Command control functions included in the operation of different built-in functions must be tested at the same time as their corresponding functions.

10.9.6 Interlocking

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals are available on the local HMI under **Main menu/ Tests/Function status/Control/Apparatus control/Interlocking**. The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

The interlocking function consists of a bay-level part and a station-level part. The interlocking is delivery specific and is realized by bay-to-bay communication over the station bus. For that reason, test the function in a system, that is, either in a complete delivery system as an acceptance test (FAT/SAT) or as parts of that system.

10.9.7 Transformer energizing control XENCPOW

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.9.7.1 Verifying the signals and settings

The voltage injection can be done using a common test equipment.

Verifying the high and low voltage settings *ULowLimit* and *UHighLimit*

1. Supply the IED with rated voltage value.
2. Decrease the voltage slowly and wait for 300 ms until the ULOW signal appears.
3. Compare the voltage value with the set voltage low limit value.

4. Increase the voltage slowly until the ULOW signal disappears.
5. Compare the reset value to the set voltage low limit value.
6. Increase the voltage further until the UHIGH signal appears.
7. Compare the voltage value with the set voltage high limit value.
8. Decrease the voltage slowly until the UHIGH signal disappears.
9. Compare the reset value to the set voltage high limit value.

Verifying the circuit breaker operate time setting *tBreaker*

1. Supply the IED with rated voltage value.
2. Ensure that the settings in the IED are appropriate, especially the *UHighLimit* and *ULowLimit* settings.
3. Set an appropriate value for the *tBreaker* setting based on the circuit breaker characteristics.
4. Activate the START input and wait for the CLOSECB output signal.
5. Check in the captured disturbance file by the IED that the time difference between the appearance of the CLOSECB output and the voltage peak is equal to the set *tBreaker* time.

Verifying the pulse duration (*tPulse*) of output CLOSECB

1. Supply the IED with rated voltage value.
2. Ensure that the settings in the IED are appropriate, especially the *UHighLimit*, *ULowLimit* and *tBreaker* settings.
3. Set the appropriate value for the *tPulse* setting based on the circuit breaker characteristics.
4. Activate the START input and wait for the CLOSECB output signal.
5. Once the CLOSECB output signal appears wait until it disappears.
6. Compare the time between the CLOSECB appearance and disappearance with the set pulse duration.

10.9.7.2 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.10 Scheme communication

10.10.1 Scheme communication logic for distance or overcurrent protection ZCPSCH

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Check the scheme logic during the secondary injection test of the impedance or overcurrent protection functions.

Activation of the different zones verifies that the CS signal is issued from the intended zones. The CS signal from the independent tripping zone must have a *tSendMin* minimum time.

Check the tripping function by activating the CR and CRG inputs with the overreaching zone used to achieve the CACC signal.

It is sufficient to activate the zones with only one type of fault with the secondary injection.

10.10.1.1 Testing permissive underreaching

1. Activate the receive (CR) signal in the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the permissive zone.
4. Check that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.
5. Check that other zones operate according to their zone timers and that the send (CS) signal is obtained only for the zone configured to generate the actual signal.
6. Deactivate the receive (CR) signal in the IED.
7. Check that the trip time complies with the zone timers and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

10.10.1.2 Testing permissive overreaching

1. Activate the receive (CR) signal in the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the permissive zone.
4. Check that correct trip outputs, external signals, and indication are obtained for the actual type of fault generated.
5. Check that the other zones operate according to their zone timer and that the send (CS) signal is obtained only for the zones that are configured to give the actual signal. Also the zone connected to CS underreach is giving CS in this mode.
6. Deactivate the IED receive (CR) signal.
7. Apply healthy normal load conditions to the IED for at least two seconds.
8. Apply a fault condition within the permissive zone.
9. Check that trip time complies with the zone timers and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

10.10.1.3 Testing blocking scheme

1. Deactivate the receive (CR) signal of the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the forward directed zone used for scheme communication tripping.
4. Check that correct trip outputs and external signals are obtained for the type of fault generated and that the operate time complies with the *tCoord* timer (plus relay measuring time).
5. Check that the other zones operate according to their zone times and that a send (CS) signal is only obtained for the reverse zone.
6. Activate the IED receive (CR) signal.
7. Apply a fault condition in the forward directed zone used for scheme communication tripping.
8. Check that the no trip from scheme communication occurs.
9. Check that the trip time from the forward directed zone used for scheme communication tripping complies with the zone timer and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

10.10.1.4 Checking of unblocking logic

Check the unblocking function (if the function is required) when checking the communication scheme.

Command function with continuous unblocking

Procedure

1. Activate the guard input signal (CRG) of the IED.
2. Using the scheme selected, check that a signal accelerated trip (TRIP) is obtained when the guard signal is deactivated.

10.10.1.5 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.10.2 Current reversal and Weak-end infeed logic for distance protection 2-phase ZCRWPSCH

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Values of the logical signals for ZCRWPSCH are available on the local HMI under Main menu/Tests/Function status / Scheme communication / ZCRWPSCH(85) / ZCRWPSCH:1.

The Signal Monitoring in PCM600 shows signals that are available on the Local HMI.

The current reversal logic and the weak-end infeed functions are tested during the secondary-injection test of the impedance or overcurrent protection zones together with the scheme communication logic for the distance protection function ZCPSCH.

10.10.2.1 Current reversal logic

It is possible to check the delay of the CS send signal with *tDelayRev* by changing from a reverse to a forward fault.

By continuously activating the CR input and changing from a reverse to a forward fault, the delay *tDelayRev* can be checked.

Checking of current reversal

The reverse zone timer must not operate before the forward zone fault is applied. The user might need to block the reverse zone timer setting during testing of current reversal.

The forward zone timer must be set longer than the *tDelayRev* set value.

1. Set the condition to an impedance at 50% of the reach of the reverse zone connected to IRV.
2. Activate the receive (CRL) signal.
3. After the start condition is obtained for reverse zone, apply a fault at 50% of the reach of the forward zone connected to IRVBLK.
4. Check that correct trip outputs and external signals are obtained for the type of fault generated. The operation time should be about the *tDelayRev* setting longer than the carrier accelerated trip (TRIP) recorded for the permissive overreach scheme communication.
5. Restore the forward and reverse zone timer to its original setting.

10.10.2.2 Weak end infeed logic

Weak-end infeed logic at permissive overreach schemes

1. Check the blocking of the echo with the injection of a CRL signal >40ms after a reverse fault is applied.
2. Measure the duration of the echoed CS signal by applying a CRL receive signal.
3. Check the trip functions and the voltage level for trip by reducing a phase voltage and applying a CRL receive signal.

Testing conditions

Only one type of fault is sufficient, with the current reversal and weak-end infeed logic for distance protection function ZCRWPSCH. Apply two faults (one in each phase). For phase L1-N fault, set these parameters:

Table 25: Phase L1-N parameter values

Phase	I (Amps)	Phase-angle (Deg)	V (Volts)	Phase-angle (Deg)
L1	0	0	Set less than *UPN<*	0
L2	0	180	63	180

For L2-N fault, change all settings cyclically.

The setting parameter *WEI* is set to *Echo & Trip*.

1. Apply input signals according Table 25.
2. Activate the receive (CR) signal.
3. After the IED has operated, turn off the input signals.
4. Check that trip and send signal are obtained.

The ECHO output gives only a 200 ms pulse.

10.10.2.3 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.10.3 Scheme communication logic for residual overcurrent protection ECPSCH

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

Before testing the communication logic for residual overcurrent protection function ECPSCH, the four step residual overcurrent protection function EF4PTOC has to be tested according to the corresponding instruction. Once this is done, continue with the instructions below.

If the current reversal and weak-end infeed logic for earth-fault protection is included, proceed with the testing according to the corresponding instruction after testing the communication logic for residual overcurrent protection. The current reversal and weak-end-infeed functions shall be tested together with the permissive scheme.

10.10.3.1 Testing the directional comparison logic function

Blocking scheme

1. Inject the polarizing voltage 2U0 at 5% of *UBase* (EF4PTOC) where the current is lagging the voltage by 65°.
2. Inject current (65° lagging the voltage) in one phase at about 110% of the set operating current, and switch the current off with the switch.
3. Switch the fault current on and measure the operating time of the communication logic.
   Use the TRIP signal from the configured binary output to stop the timer.
4. Compare the measured time with the set value *tCoord*.
5. Activate the CR binary input.
6. Check that the CRL output is activated when the CR input is activated.
7. Switch the fault current on (110% of the set operating current) and wait longer than the set value *tCoord*.

   No TRIP signal should appear.

8. Switch the fault current off.
9. Reset the CR binary input.
10. Activate the BLOCK digital input.
11. Switch the fault current on (110% of the set operating current) and wait for a period longer than the set value *tCoord*.

    No TRIP signal should appear.

12. Switch the fault current and the polarizing voltage off.
13. Reset the BLOCK digital input.

Permissive scheme

1. Inject the polarizing voltage 2U0, which is 5% of *UBase* (EF4PTOC) where the current is lagging the voltage by 65°.
2. Inject current (65° lagging the voltage) into one phase at about 110% of the set operating current, and switch the current off with the switch.
3. Switch the fault current on, (110% of the set operating current) and wait longer than the set value *tCoord*.

   No TRIP signal should appear, and the CS binary output should be activated.

4. Switch the fault current off.
5. Activate the CR binary input.
6. Switch the fault current on (110% of the set operating current) and measure the operating time of the ECPSCH logic.
   Use the TRIP signal from the configured binary output.
7. Compare the measured time with the setting for *tCoord*.
8. Activate the BLOCK digital input.
9. Switch the fault current on (110% of the set operating current) and wait for a period longer than the set value *tCoord*.

   No TRIP signal should appear.

10. Switch the fault current and the polarizing voltage off.
11. Reset the CR binary input and the BLOCK digital input.

10.10.3.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.10.4 Current reversal and weak-end infeed logic for residual overcurrent protection ECRWPSCH

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.

Values of the logical signals for ECRWPSCH are available on the Local HMI under Main menu/Tests/Function status/Scheme communication/ECRWPSCH(85)/ECRWPSCH:1.

The Signal Monitoring in PCM600 shows service values that are available on the Local HMI as well.

First, test the two step residual overcurrent protection function EF2PTOC and then the current reversal and weak-end infeed logic according to the corresponding instructions. Then continue with the instructions below.

10.10.4.1 Testing the current reversal logic

1. Inject the polarizing voltage 2U0 to 5% of *UBase* and the phase angle between voltage and current to 155°, the current leads the voltage.
2. Inject current (*180° — AngleRCA*) in one phase to about 110% of the set operating current of the four step residual overcurrent protection (*IN>Dir*).
3. Check that the IRVL output is activated in the disturbance recorder after the set time *tPickUpRev*.
4. Abruptly reverse the current to *AngleRCA* setting lagging the voltage, to operate the forward directional element.
5. Check that the IRVL output still is activated after the reversal with a time delay that complies with the setting *tDelayRev*.
6. Switch off the polarizing voltage and the current.

10.10.4.2 Testing the weak-end infeed logic

If setting *WEI* = *Echo*

1. Inject the polarizing voltage 2U0 to (180° — *AngleRCA*) of *UBase* and the phase angle between voltage and current to 155°, the current leads the voltage.
2. Inject current (180° — *AngleRCA*) in one phase to about 110% of the setting operating current (*IN>Dir*).
3. Activate the CRL binary input.

   No ECHO and CS should appear.

4. Abruptly reverse the current to the setting of *AngleRCA* setup lagging the voltage, to operate the forward directional element.

   No ECHO and CS should appear.

5. Switch off the current and check that the ECHO and CS appear on the corresponding binary output during 200ms after resetting the directional element.
6. Switch off the CRL binary input.
7. Activate the BLOCK binary input.
8. Activate the CRL binary input.

No ECHO and CS should appear.

9. Switch off the polarizing voltage and reset the BLOCK and CRL binary input.

If setting *WEI* = *Echo & Trip*

1. Inject the polarizing voltage 2U0 to about 90% of the setting (*2U0>*) operating voltage.
2. Activate the CRL binary input.

No ECHO, CS and TRWEI outputs should appear.

3. Increase the injected voltage to about 110% of the setting (*2U0*) operating voltage.
4. Activate the CRL binary input.
5. Check that the ECHO, CS and TRWEI appear on the corresponding binary output or on the local HMI.
6. Reset the CRL binary input.
7. Activate the BLOCK binary input.
8. Activate the CRL binary input.

No ECHO, CS and TRWEI outputs should appear.

9. Reset the CRL and BLOCK binary input.
10. Inject the polarizing voltage 2U0 to about 110% of the setting (*2U0>*) and adjust the phase angle between the voltage and current to (180°- *AnglRCA*) setting, the current leads the voltage.
11. Inject current in one phase to about 110% of the set operate current (*IN>Dir*).
12. Activate the CRL binary input.

No ECHO and TRWEI should appear.

13. Abruptly reverse the current to 65° lagging the voltage to operate the forward directional element.

No ECHO and TRWEI should appear.

14. Switch the current off and check that the ECHO, CS and TRWEI appear on the corresponding binary output during 200ms after resetting the directional element.
15. Switch the polarizing voltage off and reset the CRL binary input.

10.10.4.3 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.11 Logic

10.11.1 Tripping logic

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

This function is functionally tested together with other protection functions (line differential protection,earth-fault overcurrent protection, and so on) within the IED. It is recommended that the function is tested together with the autorecloser function, when built into the IED or when a separate external unit is used for reclosing purposes. The instances of SMPPTRC are identical.

10.11.1.1 Test for trip

1. Check that *AutoLock* and *TripLockout* are both set to *Off*.
2. Initiate faults one at a time.
   An adequate time interval between the faults should be considered, to overcome a reclaim time caused by the possible activation of the auto recloser function SMBRREC. The function must issue a trip in all cases, when trip is initiated by any protection or some other built-in or external function.

10.11.1.2 Circuit breaker lockout

The following tests should be carried out when the built-in lockout function is used in addition to possible other tests, which depends on the complete configuration of an IED.

1. Check that *AutoLock* and *TripLockout* are both set to *Off*.
2. Activate shortly the lockout SETLKOUT input in the IED.
3. Check that the circuit breaker lockout CLLKOUT output is set.
4. Activate shortly thereafter, the reset lockout RSTLKOUT input in the IED.
5. Check that the circuit breaker lockout CLLKOUT output is reset.
6. Initiate a fault.
   The TRIP output should be active. The output CLLKOUT should not be set.
7. Activate the automatic lockout function, set *AutoLock* = *On* and initiate a fault.
   Besides the TRIP output, CLLKOUT should be set.
8. Reset the lockout signal by activating the reset lockout RSTLKOUT input.
9. Activate the trip signal lockout function, set *TripLockout* = *On* and initiate a fault.
   The TRIP output must be active and stay active, CLLKOUT should be set.
10. Reset the lockout.
    All outputs should reset.
11. Deactivate the trip signal lockout function, set *TripLockout* = *Off* and the automatic lockout function, set *AutoLock* = *Off*.

10.11.1.3 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.12 Monitoring

10.12.1 Gas medium supervision SSIMG

Prepare the IED for verification of settings as outlined in Section "Preparing the IED to verify settings" in this chapter.

Values of logical signals for SSIMG protection are available on the local HMI under **Main menu/Tests/Function status/Monitoring/InsulationGas(63)/SSIMG(63):x**, where x = 1, 2,....21.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

Check that the input logical signal `BLOCK` is logical zero and that on the local HMI, the logical signals `PRESALM`, `PRESLO`, `TEMPALM`, `TEMPLO`, `ALARM` and `LOCKOUT` are logical zero.

Using service kit. prepare the IED for verification of settings as outlined in Section "Preparing the IED to verify settings" in this chapter.

10.12.1.1 Testing the gas medium supervision for pressure alarm and pressure lockout conditions

1. Connect binary inputs to consider gas pressure and gas density to initiate the alarms.
2. Consider the analogue pressure input SENPRES and set SENPRES to a value lower than *PresAlmLimit* or activate binary input signal SENPRESALM, check that outputs PRESALM and ALARM are activated after a set time delay of *tPressureAlarm*.
3. Gas pressure lockout input SETPLO can be used to set PRESLO.
4. Also, reduce further the pressure level input below *PresLOLimit* or activate the binary input signal SENPRESLO, check that PRESLO signal appears after a set time delay of *tPressureLO*.
5. Activate BLOCK binary input and check that the outputs PRESALM, PRESLO, ALARM and LOCKOUT disappear.
6. Reset the BLOCK binary input.
7. Make sure that pressure lockout condition exists and then activate the reset lock out input RESETLO and check that the outputs PRESLO and LOCKOUT reset.

10.12.1.2 Testing the gas medium supervision for temperature alarm and temperature lock out conditions

1. Consider the analogue temperature input SENTEMP and set SENTEMP to a value higher than *TempAlarmLimit*, check that outputs TEMPALM and ALARM are activated after a set time delay of *tTempAlarm*.
2. Temperature lockout input SETTLO can be used to set TEMPLO signal.
3. Also, increase further the temperature input above *TempLOLimit*, check that the outputs TEMPLO and LOCKOUT appears after a set time delay of *tTempLockOut*.
4. Activate BLOCK binary input and check that the outputs TEMPALM, TEMPLO, ALARM and LOCKOUT disappear.
5. Reset the BLOCK binary input.
6. Make sure that temperature lockout condition exists and then activate the reset lock out input RESETLO and check that the outputs TEMPLO and LOCKOUT reset.

10.12.1.3 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.12.2 Liquid medium supervision SSIML

Prepare the IED for verification of settings as outlined in section "Preparing the IED to verify settings" in this chapter.

Values of logical signals for SSIMG protection are available on the local HMI under **Main menu/Tests/Function status/Monitoring/InsulationLiquid(71)/ SSIML(71):x**, where x = 1, 2,....4.

Check that the input logical signal BLOCK is logical zero and that on the local HMI, the logical signals LVLALM, LVLLO, TEMPALM, TEMPLO, ALARM and LOCKOUT are logical zero.

10.12.2.1 Testing the liquid medium supervision for level alarm and level lockout conditions

1. Connect the binary inputs to consider liquid level to initiate the alarms.
2. Consider the analogue level input SENLEVEL and set SENLEVEL to a value lower than *LevelAlmLimit* or activate binary input signal SENLVLALM, check that outputs LVLALM and ALARM are activated after a set time delay of *tLevelAlarm*.
3. Liquid level lockout input SENLVLLO can be used to set LVLLO.
4. Also, reduce the liquid level input below *LevelLOLimit* or activate the binary input signal SENLVLLO, check that LVLLO signal after a set time delay of *tLevelLockOut*.
5. Activate BLOCK binary input and check that the outputs LVLALM, LVLLO, ALARM and LOCKOUT disappears.
6. Reset the BLOCK binary input.
7. Make sure that level lockout condition exists and then activate the reset lock out input RESETLO and check that the outputs PRESLO and LOCKOUT reset.

10.12.2.2 Testing the liquid medium supervision for temperature alarm and temperature lock out conditions

1. Consider the analogue temperature input SENTEMP and set SENTEMP to a value higher than *TempAlarmLimit*, check that outputs TEMPALM and ALARM are activated after a set time delay of *tTempAlarm*.
2. Temperature lockout input SETTLO can be used to set TEMPLO signal.
3. Also, increase further the temperature input above *TempLOLimit*, check that the outputs TEMPLO and LOCKOUT appears after a set time delay of *tTempLockOut*.

4. Activate BLOCK binary input and check that the outputs TEMPALM, TEMPLO, ALARM and LOCKOUT disappear.
5. Reset the BLOCK binary input.
6. Make sure that temperature lockout condition exists and then activate the reset lock out input RESETLO and check that the outputs TEMPLO and LOCKOUT reset.

10.12.2.3 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.12.3 Breaker monitoring SSCBR

Prepare the IED for verification of settings outlined in section “Testing the IED operation”.

The Signal Monitoring tool in PCM600 shows the service values that are available on the Local HMI as well.

Values of the logical signals belong to the breaker monitoring are available on the local HMI under: **Main menu/Test/Function status/Monitoring/ BreakerMonitoring/SSCBR:x**

10.12.3.1 Verifying the settings

1. Connect the test set for the injection of a three-phase current to the appropriate current terminals of the IED.Connect the test set for the injection of a two-phase current to the appropriate current terminals of the IED.
2. If current need to be injected for a particular test, it should be done in the phase selected by the *PhSel* parameter.
3. Follow the sequence for positioning the auxiliary contacts before testing:

POSCLOSE	0	1	0
POSOPEN	0	0	1

4. Test of CB contact travel time
   4.1. Test the set timing defined by *OpenTimeCorr*, *CloseTimeCorr*, *tTrOpenAlm* and *tTrCloseAlm*.
   4.2. Change the status of the auxiliary contacts such that travel time to open TTRVOP and travel time to close TTRVCL exceed the respective set values (*tTrOpenAlm* and *tTrCloseAlm*). The measured travel time for opening and closing is shown on TTRVOP and TTRVCL respectively.
   4.3. Check that TRVTOPAL and TRVTCLAL are activated.
5. Test of CB status

5.1. Test the set current level defined by *AccStopCurr*.
5.2. Check the CLOSEPOS output by changing the *POSOPEN* to *0* and *POSCLOSE* to *1*.
5.3. Check the OPENPOS output by changing the *POSOPEN* to *1* and *POSCLOSE* to *0* and also inject the current in the selected phase slightly lower and higher than *AccStopCurr* set value. Only for a current lower than set *AccStopCurr* should activate the output POSOPEN.
5.4. Check the circuit breaker is in INVDPOS if auxiliary contacts read same value or CB is open and inject the current in selected phase more than *AccStopCurr* set value.

6. Test of remaining life of CB
   6.1. Test the set timing defined by*RatedOperCurr*, *RatedFltCurr*, *OperNoRated*, *OperNoFault*, *DirCoef*, *CBLifeAlmLevel*.
   6.2. Vary the phase current in the selected phase from below rated operated current, *RatedOperCurr* to above rated fault current, *RatedFltCurr* of a breaker.
   6.3. The remaining life of CB output CBLIFEPH is estimated when the CB is changed from closed to open position. Check that the output CBLIFEPH is decreased with a value that corresponds to the injected current.
   6.4. CBLIFEAL is activated as soon as CBLIFEPH is below the set *CBLifeAlmLevel* value.
7. Test of accumulated energy
   7.1. Test the actual set values defined by *AccSelCal* to *Aux Contact*, *ContTrCorr* and *AlmAccCurrPwr*.
   7.2. Inject phase current in the selected phase such that its value is greater than set *AccStopCurr* value.
   7.3. When the breaker goes to open position, accumulated energy IPOWPH is calculated. The calculated value can be seen on the output IPOWPH.
   7.4. Alarm signal IPOWALPH appears when IPOWPH is greater than set *AlmAccCurrPwr* value.
   7.5. Lockout signal IPOWLOPH appears if IPOWPH exceeds further to the threshold value *LOAccCurrPwr*.
   7.6. Calculation of accumulated energy IPOWPH is stopped when injected current is lower than set *AccStopCurr* value.
8. Test of CB operation cycles
   8.1. Test the actual set values defined by *OperAlmLevel* and *OperLOLevel*.
   8.2. The operation counter, NOOPER is updated for every close-open sequence of the breaker by changing the position of auxiliary contacts *POSCLOSE* and *POSOPEN*.
   8.3. OPERALM is activated when NOOPER value exceeds the set *OperAlmLevel* value. The actual value can be read on the output NOOPER.
   8.4. OPERLO is activated when NOOPER value exceeds the set *OperLOLevel* value.
9. Test of CB spring charge monitoring

   9.1. Test the actual set value defined by *SpChAlmTime*.
   9.2. Enable SPRCHRST input. Also activate SPRCHRD after a time greater than set time *SpChAlmTime*.
   9.3. At this condition, SPCHALM is activated.
10. Test of CB gas pressure indication
   10.1. Test the actual set value defined by*tDGasPresAlm* and *tDGasPresLO*.
   10.2. The output GPRESALM is activated after a time greater than set time of *tDGasPresAlm* value if the input PRESALM is enabled.
   10.3. The output GPRESLO is activated after a set time of *tDGasPresLO* value if the input PRESLO is enabled.

10.12.3.2 Completing the test

1. Continue to test another function or end the test by changing the *Test mode* setting to *Off*.
2. Restore connections and settings to their original values if they were changed for testing purposes.

10.12.4 Event function EVENT

Prepare the IED for verification of settings as outlined in section "Preparing for test" in this chapter.

During testing, the IED can be set when in test mode from PST. The functionality of the event reporting during test mode is set in the Parameter Setting tool in PCM600.

- Use event masks
- Report no events
- Report all events

In test mode, individual event blocks can be blocked from PCM600.

10.12.5 Limit counter L4UFCNT

The Limit counter function L4UFCNT can be tested by connecting a binary input to the counter and applying pulses to the counter. The speed of the pulses must not exceed the cycle time of the function. Normally the counter will be tested when testing the function that the counter is connected to, such as the trip function. When the function is configured, test it together with the function that operates it. Trigger the function and check that the counter result corresponds to the number of operations.

10.12.5.1 Completing the test

Continue to test another function or end the test by changing the Test mode setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.12.6 Fault locator RWRFLO

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.12.6.1 Verifying signals and settings

The fault locator (RWRFLO) relies on information from two other functions:

- Phase selection information provided by the distance protection function
- Analog information provided by the trip value recorder function

Check that binary start and phase selection signals are connected, and that voltage and current signals are configured (parameter settings).

The result is displayed on the local HMI or via PCM600. Distance-to-faults for the last 1000 recorded disturbances can be found on the local HMI under **Main menu/ Disturbance records/Disturbance #n (n = 1-100)/General Information**.

In PCM600, including loop selection information the result is displayed on the recording list after upload.

The function can be selected for *2Phase* or *ATCatenary* using the setting *SystemType*. Sequence of voltage and current to be applied for verifying signals and settings.

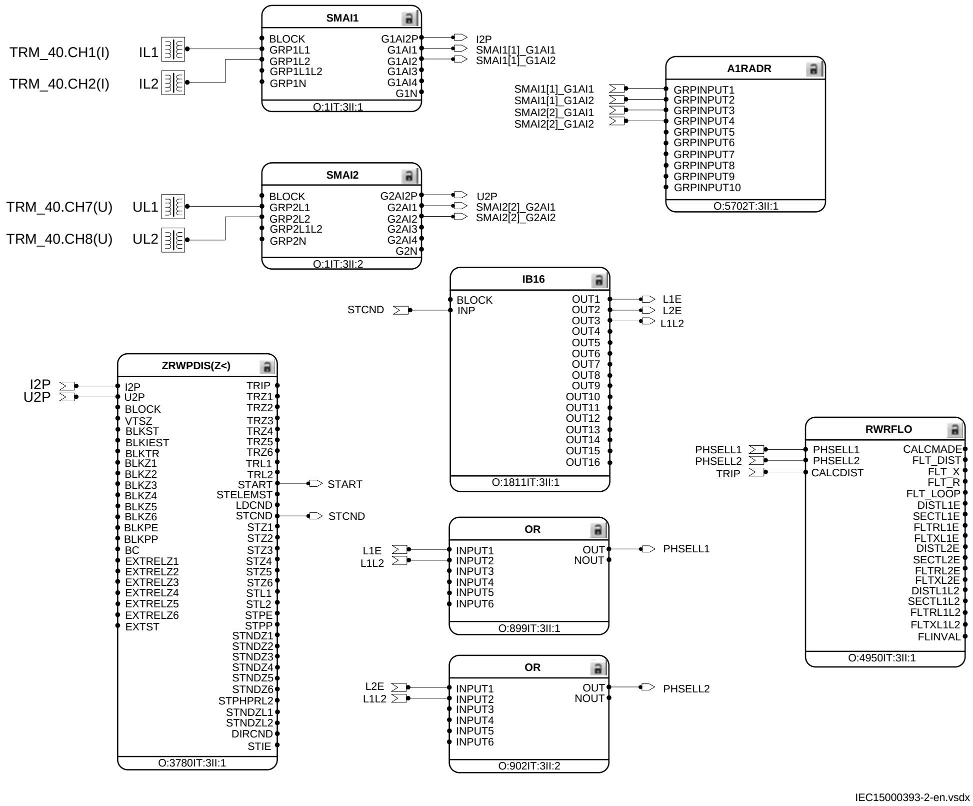


Figure 30: ACT configuration in PCM600 for 2Phase type

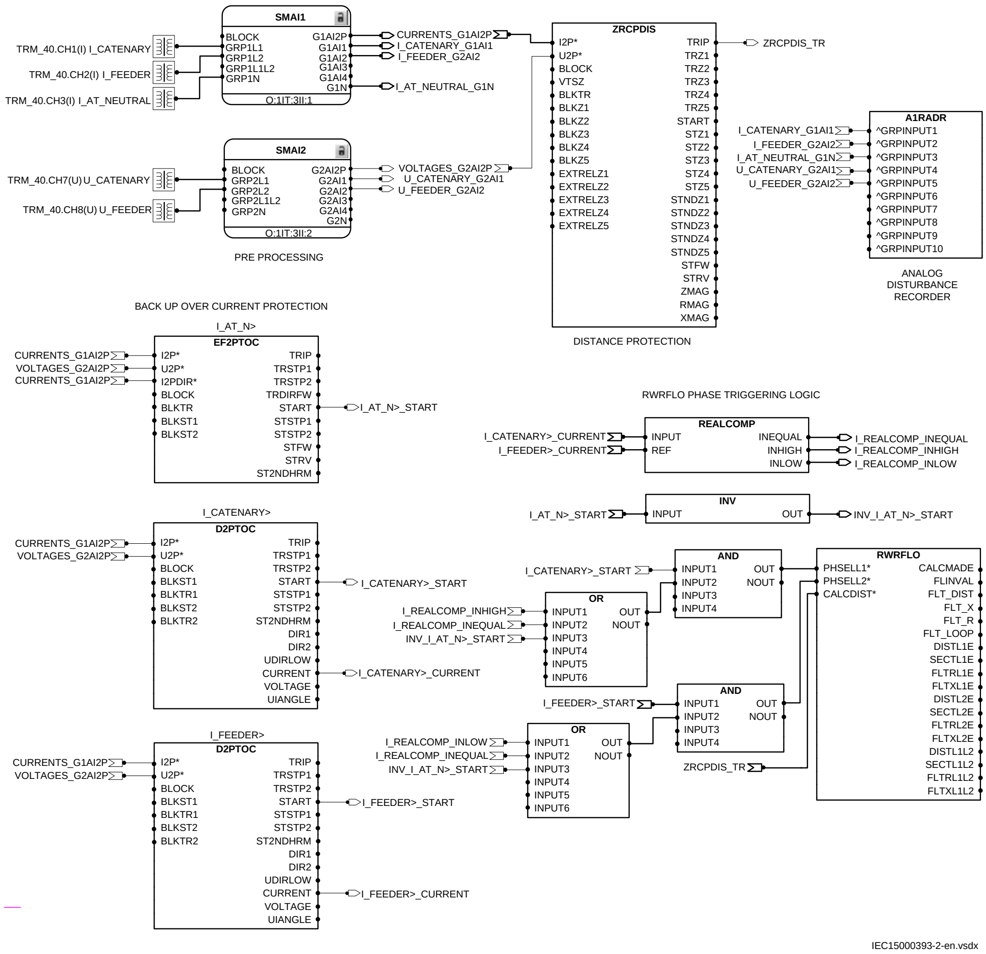


Figure 31: ACT configuration in PCM600 for ATCatenary type

Verifying the case *SystemType* = *2Phase*

1. Apply the voltage and current as shown in Table 26:

Table 26: Pre-fault voltages and current

Signal	*Magnitude (Volts)*	*Angle (Degrees)*
$\overline{UL1}$	55	0
$\overline{UL2}$	55	180
$\overline{IL1}$	0	0
$\overline{IL2}$	0	180

2. Wait for a few seconds and apply voltage and current according to Table 27 depending on which fault loop is to be verified.

Table 27: Fault voltage and current for L1N / L2N / L1L2 faults

Signal	L1E		L2E		L1L2	
	Magnitude (Volt or Amps)	Angle (Degrees)	Magnitude (Volt or Amps)	Angle (Degrees)	Magnitude (Volt or Amps)	Angle (Degrees)
$\overline{UL1}$	55	0	55	0	55	0
$\overline{UL2}$	55	180	55	180	55	180
$\overline{IL1}$	$\left\lvert\frac{2\times\overline{UL1}}{(\overline{ZA1}+\overline{ZA0})}\right\rvert$	$\angle\frac{2\times\overline{UL1}}{(\overline{ZA1}+\overline{ZA0})}$	0	0	$\left\lvert\frac{\overline{UL1}}{(\overline{ZA1})}\right\rvert$	$\angle\frac{\overline{UL1}}{(\overline{ZA1})}$
$\overline{IL2}$	0	180	$\left\lvert\frac{2\times\overline{UL2}}{(\overline{ZA1}+\overline{ZA0})}\right\rvert$	$\angle\frac{2\times\overline{UL2}}{(\overline{ZA1}+\overline{ZA0})}$	$\left\lvert\frac{\overline{UL2}}{(\overline{ZA1})}\right\rvert$	$\angle\frac{\overline{UL2}}{(\overline{ZA1})}$

Where:

$\overline{ZA1}$ = Positive sequence impedance from the point of measurement until the fault point.

This can be derived from:

$$\overline{ZA1} = RA1 + j \times XA1$$

(Equation 20)

Where:

$$RA1 = \left(\sum_{i=1}^{fault\ section-1} RLi\right) + (p \times RLj)$$

$$XA1 = \left(\sum_{i=1}^{fault\ section-1} XLi\right) + (p \times XLj)$$

(Equation 21)

$\overline{ZA0}$ = Positive sequence impedance from the point of measurement until the fault point.

This can be derived from,

$$\overline{ZA0} = RA0 + j \times XA0$$

(Equation 22)

Where:

$$RA0 = \left(\sum_{i=1}^{fault section-1}(RLi + 2 \times REOverRLi)\right) + (p \times (RLj + 2 \times REOverRLj))$$

$$XA0 = \left(\sum_{i=1}^{fault section-1}(XLi + 2 \times XEOverXLi)\right) + (p \times (XLj + 2 \times XEOverXLj))$$

(Equation 23)

Where:

RLi	The positive sequence resistance of i[th] section (Function setting)
RLj	The positive sequence of resistance of faulted section (function setting)
XLi	The positive sequence reactance of i[th] section (Function setting)
XLj	The positive sequence of reactance of faulted section (function setting)
REOverRLi	The positive sequence resistance of i[th] section
REOverRLj	The positive sequence of resistance of faulted section (function setting)
XEOverXLi	The positive sequence reactance of i[th] section (Function setting)
XEOverXLj	The positive sequence of reactance of faulted section (function setting)
p	Fault position in per unit of the respective section line length
Fault section	The section in which the fault exists

3. Wait for 0.09 seconds and update the voltage and current back to the values provided in table 26.
4. Wait for a few seconds, and check the distance-to-fault value in km displayed on the local HMI. This implies with:

$$FLTDIST = \left(\sum_{i=1}^{fault\ section-1} \left(LineLength\,i \right) \right) + \left(p \times \left(LineLength\,j \right) \right)$$

(Equation 24)

Where:

Linelengthi	Line length in Km of the i[th] section
Linelengthj	Line length in Km of the faulted section
p	Fault position in per unit of the respective section

Verifying the case *SystemType* = *ATCatenary*

1. Apply the voltage and current as shown in Table 28:

Table 28: Pre-fault voltages and current

Signal	*Magnitude (Volts)*	*Angle (Degrees)*
$\overline{UL1}$	55	0
$\overline{UL2}$	55	180
$\overline{IL1}$	0	0
$\overline{IL2}$	0	180

2. Wait for a few seconds and apply voltage and current according to Table 29 depending on which fault loop is to be verified.

Table 29: Fault voltage and current for L1N / L2N / L1L2 faults

Signal	L1E		L2E		L1L2	
	Magnitude (Volt or Amps)	Angle (Degrees)	Magnitude (Volt or Amps)	Angle (Degrees)	Magnitude (Volt or Amps)	Angle (Degrees)
$\overline{UL1}$	55	0	55	0	55	0
$\overline{UL2}$	55	180	55	180	55	180
$\overline{IL1}$	$\left\lvert \frac{\overline{UL1}}{(\overline{ZC1}+\overline{ZR1})} \right\rvert$	$\angle \frac{\overline{UL1}}{(\overline{ZC1}+\overline{ZR1})}$	0	0	$\left\lvert \frac{(\overline{UL1}-\overline{UL2})}{(\overline{ZC1}+\overline{ZF1})} \right\rvert$	$\angle \frac{(\overline{UL1}-\overline{UL2})}{(\overline{ZC1}+\overline{ZF1})}$
$\overline{IL2}$	0	00	$\left\lvert \frac{\overline{UL2}}{(\overline{ZF1}+\overline{ZR1})} \right\rvert$	$\angle \frac{\overline{UL2}}{(\overline{ZF1}+\overline{ZR1})}$	$\left\lvert \frac{(\overline{UL2}-\overline{UL1})}{(\overline{ZC1}+\overline{ZF1})} \right\rvert$	$\angle \frac{(\overline{UL2}-\overline{UL1})}{(\overline{ZC1}+\overline{ZF1})}$

Where;
Catenary impedance ZC1 = RC1 + j*C1
Feeder impedance ZF1 = RF1 + j*F1
Rail impedance ZR1 = RR1 + j*R1
RC1 : Catenary resistance in ohms provided as setting
XC1 : Catenary reactance in ohms provided as setting
RF1 : Feeder resistance in ohms provided as setting
XF1 : Feeder reactance in ohms provided as setting
RR1: Return conductor resistance in ohms provided as setting
XR1: Return conductor reactance in ohms provided as setting

3. Wait for 0.09 seconds and update the voltage and current back to the values provided in Table 28.
4. Wait for a few seconds, and check the distance-to-fault value in km displayed on the local HMI.

10.12.6.2 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values if they were changed for testing purposes.

10.12.7 Current harmonic monitoring CHMMHAN

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.12.7.1 Verifying the signals and settings

The current can be injected using common test equipment.

Verifying the warning and alarm time limit of *THD*, *WrnLimitTHD* and *tDelayAlmTHD*

1. Supply the IED with current at rated value.
2. Apply harmonics at the numerical multiple of fundamental frequency along with the injected current signal.
3. Slowly increase the harmonic amplitudes until the THDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the THDALM signal appears and note down the time from THDWRN set to THDALM set.
6. Compare the noted time value with the set time limit value of alarm.

Verifying the warning and alarm time limit of *TDD*, *WrnLimitTDD* and *tDelayAlmTDD*

1. Supply the IED with current at rated value.
2. Apply harmonics at the numerical multiple of fundamental frequency along with the injected current signal.
3. Slowly increase the harmonic amplitudes until the TDDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the TDDALM signal appears and note down the time from TDDWRN set to TDDALM set.
6. Compare the noted time value with the set time limit value of alarm.

Verifying the warning and alarm time limit of individual harmonic distortions *IHD*, *WrnLimit#HD* and *tDelayAlm#HD* (where # = 2^{nd}, 3^{rd}…5^{th})

1. Supply the IED with current at rated value.
2. Apply 2^{nd} order harmonic along with injected current signal.
3. Slowly increase the harmonic amplitude until the 2NDHDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the 2NDHDALM signal appears and note down the time from 2NDHDWRN signal set to 2NDHDALM signal set.
6. Compare the noted time value with the set time limit value of alarm.
7. Repeat Steps 2 to 6 for the harmonics until 5^{th} order.

10.12.7.2 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.12.8 Voltage harmonic monitoring VHMMHAN

Prepare the IED for verification of settings outlined in Section "Preparing the IED to verify settings".

10.12.8.1 Verifying the signals and settings

The voltage can be injected using common test equipment.

Verifying the warning and alarm time limit of *THD*, *WrnLimitTHD* and *tDelayAlmTHD*

1. Supply the IED with voltage at rated value.
2. Apply harmonics at the numerical multiple of fundamental frequency along with the injected voltage signal.
3. Slowly increase the harmonic amplitudes until the THDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the THDALM signal appears and note down the time from THDWRN set to THDALM set.
6. Compare the noted time value with the set time limit value of alarm.

Verifying the warning and alarm time limit of individual harmonic distortions *IHD*, *WrnLimit#HD* and *tDelayAlm#HD* (where # = 2^{nd}, 3^{rd}…5^{th})

1. Supply the IED with voltage at rated value.
2. Apply 2^{nd} order harmonic along with injected voltage signal.
3. Slowly increase the harmonic amplitude until the 2NDHDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the 2NDHDALM signal appears and note down the time from 2NDHDWRN signal set to 2NDHDALM signal set.
6. Compare the noted time value with the set time limit value of alarm.
7. Repeat Steps 2 to 6 for the harmonics until 5^{th} order.

10.12.8.2 Completing the test

Continue to test another function or end the test by changing the *TestMode* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.13 Metering

10.13.1 Pulse-counter logic PCFCNT

The test of the Pulse-counter logic function PCFCNT requires the Parameter Setting tool in PCM600 or an appropriate connection to the local HMI with the necessary functionality. A known number of pulses with different frequencies are connected to the pulse counter input. The test should be performed with settings *Operation* = *On* or *Operation* = *Off* and the function blocked or unblocked. The pulse counter value is then checked in PCM600 or on the local HMI.

10.13.2 Function for energy calculation and demand handling ETPMMTR

Prepare the IED for verification of settings as outlined in section ”Overview “ and section ”Preparing for test“ in this chapter.

10.13.2.1 Verifying the settings

Common test equipment can be used to determine the injection of current and voltage and time measurement.

Verification of EAFACC & ERFACC output

1. Connect the test set for injection of two-phase currents and two-phase voltage to the appropriate current and voltage terminals of the IED.
2. Ensure the instantaneous values of active and reactive power from CVMMXN function block are connected to ETPMMTR function block active and reactive power inputs.
3. Enable the *EnaAcc* setting and set *tEnergy* as 1 minute.
4. Activate the `STARTACC` input and supply the IED with two-phase currents and voltages at their rated value.
5. Check that the `ACCINPRG` signal appears continuously.
6. Note the `EAFACC` and `ERFACC`value after 1 minute and compare it with calculated energy value.
7. Similarly check after each 1 minute whether the calculated integrated energy value and `EAFACC` and `ERFACC` outputs are matching.
8. After some time (multiple of minute) remove the current and voltage input from CVMMXN function block.
9. Check the `EAFACC` and `ERFACC` output in the next 1 minute cycle for the retaining the same value.

10. Activate STOPACC input after some time and supply the IED with same current and voltage.
11. Check that the ACCINPRG signal disappears immediately and EAFACC and ERFACC outputs also stop updating.
12. Similarly the testing can be done for EAFACC and ERFACC outputs by changing the power inputs directions through direction settings.

Verification of MAXPAFD & MAXPRFD outputs

1. Repeat the above test steps 1 to 2.
2. Set *tEnergy* setting as 1 minute and supply the IED with two-phase currents and voltages at their rated value till 1 minute.
3. Check the MAXPAFD and MAXPRFD outputs after 1 minute and compare it with last 1 minute average power values.
4. Increase either two-phase current or voltage above the last 1 minute value.
5. After 1 minute check the MAXPAFD and MAXPRFD whether it is showing the last 1 minute average power value as maximum.
6. Next 1 minute cycle reduce the current or voltage below previous value.
7. Check after 1 minute whether the MAXPAFD and MAXPRFD outputs are retaining the old maximum value.
8. Similarly the testing can be done for MAXPAFD and MAXPRFD outputs by changing the power inputs directions through direction settings.

Verification of EAFALM & ERFALM outputs

1. Repeat the above test steps 1 to 2.
2. Set *tEnergy* setting as 1 minute and supply the IED with two-phase currents and voltages at their rated value till 1 minute.
3. Ensure that the active and reactive energy values are less than the *EALim* and *ERLim* setting default values respectively.
4. Check that EAFALM and ERFALM are low.
5. Increase the supply currents or voltage in next 1 minute cycle such that the active or reactive energy values are greater than the *EALim* and *ERLim* setting default values respectively.
6. Check that EAFALM and ERFALM are high after 1 minute.
7. Similarly the testing can be done for EARALM and ERRALM outputs by changing the power inputs directions through direction settings.

10.13.2.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.14 Station communication

10.14.1 Multiple command and transmit MULTICMDRCV / MULTICMDSND

The multiple command and transmit function (MULTICMDRCV / MULTICMDSND) is only applicable for horizontal communication.

Test of the multiple command function block and multiple transmit is recommended to be performed in a system, that is, either in a complete delivery system as an acceptance test (FAT/SAT) or as parts of that system, because the command function blocks are connected in a delivery-specific way between bays and the station level and transmit.

Command and transmit function blocks included in the operation of different built-in functions must be tested at the same time as their corresponding functions.

10.15 Remote communication

10.15.1 Binary signal transfer

Prepare the IED for verification of settings as outlined in section "Preparing the IED to verify settings".

To perform a test of the binary signal transfer functions, the hardware (LDCM) and binary input and output signals to transfer must be configured as required by the application.

There are two types of internal self-supervision of the binary signal transfer:

- The I/O-circuit board is supervised as an I/O module. For example it generates FAIL if the board is not inserted. I/O-modules not configured are not supervised.
- The communication is supervised and the signal COMFAIL is generated if a communication error is detected.

Status for inputs and outputs as well as self-supervision status are available from the local HMI under

- Self-supervision status: **Main menu/Diagnostics/Internal events**
- Status for inputs and outputs: **Main menu/Test/Function status**, browse to the function group of interest.
- Remote communication related signals: **Main menu/Test/Function status/ Communication/Remote communication**

Test the correct functionality by simulating different kind of faults. Also check that sent and received data is correctly transmitted and read.

A test connection is shown in figure 32. A binary input signal (BI) at End1 is configured to be transferred through the communication link to End2. At End2 the received signal is configured to control a binary output (BO). Check at End2 that the BI signal is received and the BO operates.

Repeat the test for all the signals configured to be transmitted over the communication link.

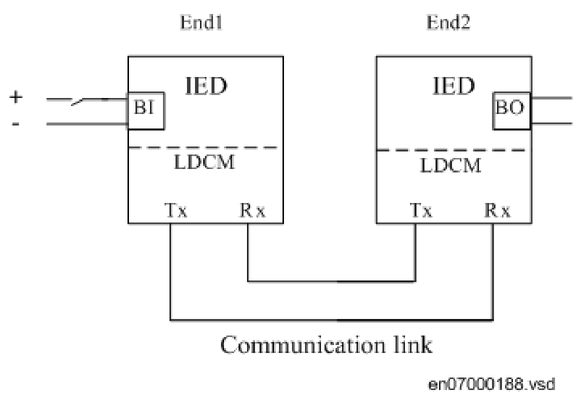


Figure 32: Test of RTC with I/O

10.16 Basic IED functions

10.16.1 Parameter setting group handling SETGRPS

Prepare the IED for verification of settings as outlined in section "Preparing for test" in this chapter.

10.16.1.1 Verifying the settings

1. Check the configuration of binary inputs that control the selection of the active setting group.
2. Browse to the **ActiveGroup** menu to achieve information about the active setting group.

The **ActiveGroup** menu is located on the local HMI under**Main menu/Test/Function status/Setting groups/ActiveGroup**
The **ActiveGroup** menu is located on the PCM600 under**Main menu/Test/Function status/Setting groups/ActiveGroup**

3. Connect the appropriate dc voltage to the corresponding binary input of the IED and observe the information presented on the local HMI.
   The displayed information must always correspond to the activated input.
4. Check that the corresponding output indicates the active group.
   Operating procedures for the PC aided methods of changing the active setting groups are described in the corresponding PCM600 documents and instructions for the operators within the SCS are included in the SCS documentation.

10.16.1.2 Completing the test

continue to test another function or end the test by changing the *TESTMODE* setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.17 Exit test mode

The following procedure is used to return to normal operation.

> After exiting the IED test mode, make sure that the MU is returned to normal mode.

1. Navigate to the test mode folder.
2. Change the *On* setting to *Off*. Press the 'E' key and the left arrow key.
3. Answer *YES*, press the 'E' key and exit the menus.

Section 11 Commissioning and maintenance of the fault clearing system

11.1 Commissioning tests

During commissioning all protection functions shall be verified with the setting values used at each plant. The commissioning tests must include verification of all circuits by green-lining the circuit diagrams and the configuration diagrams for the used functions.

Further, the settings for protection functions are tested and recorded carefully as outlined for the future periodic maintenance tests.

The final testing includes primary verification of all directional functions where load currents is checked on the local HMI and in PCM600. The amplitudes and angles of all currents and voltages should be checked and the symmetry verified.

Directional functions have information about the measured direction and, for example, measured impedance. These values must be checked and verified as correct with the export or import of power available.

Finally, final trip tests must be performed. This involves activation of protection functions or tripping outputs with the circuit breaker closed and the tripping of the breaker verified. When several breakers are involved, each breaker must be checked individually and it must be verified that the other involved breakers are not tripped at the same time.

11.2 Periodic maintenance tests

The periodicity of all tests depends on several factors, for example the importance of the installation, environmental conditions, simple or complex equipment, static or electromechanical IEDs, and so on.

The normal maintenance praxis of the user should be followed. However, ABB's recommendation is as follows:

Every second to third year

- Visual inspection of all equipment.
- Removal of dust on ventilation louvres and IEDs if necessary.
- Periodic maintenance test for protection IEDs of object where no redundant protections are provided.

Every four to six years

- Periodic maintenance test for protection IEDs of objects with redundant protection system.

First maintenance test should always be carried out after the first half year of service.

When protection IEDs are combined with built-in control, the test interval can be increased drastically, up to for instance 15 years, because the IED continuously reads service values, operates the breakers, and so on.

11.2.1 Visual inspection

Prior to testing, the protection IEDs should be inspected to detect any visible damage that may have occurred (for example, dirt or moisture deposits, overheating).

Make sure that all IEDs are equipped with covers.

11.2.2 Maintenance tests

To be made after the first half year of service, then with the cycle as proposed above and after any suspected maloperation or change of the IED setting.

Testing of protection IEDs shall preferably be made with the primary circuit de-energized. The IED cannot protect the circuit during testing. Trained personnel may test one IED at a time on live circuits where redundant protection is installed and de-energization of the primary circuit is not allowed.

ABB protection IEDs are preferably tested by aid of components from the COMBITEST testing system described in information B03-9510 E. Main components are RTXP 8/18/24 test switch usually located to the left in each protection IED and RTXH 8/18/24 test handle, which is inserted in test switch at secondary testing. All necessary operations such as opening of trip circuits, short-circuiting of current circuits and opening of voltage circuits are automatically performed in the right order to allow for simple and safe secondary testing even with the object in service.

11.2.2.1 Preparation

Before starting maintenance testing, the test engineers should scrutinize applicable circuit diagrams and have the following documentation available:

- Test instructions for protection IEDs to be tested
- Test records from previous commissioning and maintenance tests
- List of valid settings
- Blank test records to fill in measured values

11.2.2.2 Recording

It is of utmost importance to carefully record the test results. Special test sheets covering the frequency of test, date of test and achieved test values should be used. IED setting list and protocols from previous tests should be available and all results should be compared for differences. At component failures, spare equipment is used and set to the requested value. A note of the exchange is made and the new measured values are recorded. Test records for several years of testing should be stored in a common file for a station, or a part of a station, to give a simple overview of the period of testing and achieved test values. These test records are valuable when analysis of service disturbances shall be done.

11.2.2.3 Secondary injection

The periodic maintenance test is done by secondary injection from a portable test set. Each protection shall be tested according to the secondary injection test information for the specific protection IED. Only the setting values adopted shall be checked for each protection function. If the discrepancy between obtained value and requested set value is too big the setting should be adjusted, the new value recorded and a note should be made in the test record.

11.2.2.4 Alarm test

When inserting the test handle the alarm and event signalling is normally blocked. This is done in the IED by setting the event reporting to *Off* during the test. This can be done when the test handle is inserted or the IED is set to test mode from the local HMI. At the end of the secondary injection test it should be checked that the event and alarm signalling is correct by activating the events and performing some selected tests.

11.2.2.5 Self supervision check

Once secondary testing has been completed, it should be checked that no self-supervision signals are activated continuously or sporadically. Especially check the time synchronization system, GPS or other, and communication signals, both station communication and remote communication.

11.2.2.6 Trip circuit check

When the protection IED undergoes an operational check, a tripping pulse is normally obtained on one or more of the output contacts and preferably on the test switch. The healthy circuit is of utmost importance for the protection operation. If the circuit is not provided with a continuous trip-circuit supervision, it is possible to check that circuit is really closed when the test-plug handle has been removed by using a high-ohmic voltmeter and measuring between the plus and the trip output on the panel. The measurement is then done through the trip coil of the circuit breaker and therefore the complete trip circuit is checked.

Note that the breaker must be closed.

Please observe that the test system does not provide built-in security during this test. If the instrument should be set on Amp instead of Volts, the circuit breaker naturally is tripped, therefore, great care is necessary.

Trip circuit from trip IEDs to circuit breaker is often supervised by trip-circuit supervision. It can then be checked that a circuit is healthy by opening tripping output terminals in the cubicle. When the terminal is opened, an alarm shall be achieved on the signal system after a delay of some seconds.

Remember to close the circuit directly after the test and tighten the terminal carefully.

11.2.2.7 Measurement of service currents

After a maintenance test it is recommended to measure the service currents and service voltages recorded by the protection IED. The service values are checked on the local HMI or in PCM600. Ensure that the correct values and angles between voltages and currents are recorded. Also check the direction of directional functions such as Distance and directional overcurrent functions.

For transformer differential protection, the achieved differential current value is dependent on the tap changer position and can vary between less than 1% up to perhaps 10% of rated current. For line differential functions, the capacitive charging currents can normally be recorded as a differential current.

The zero-sequence current to earth-fault protection IEDs should be measured. The current amounts normally very small but normally it is possible to see if the current circuit is "alive".

The neutral-point voltage to an earth-fault protection IED is checked. The voltage is normally 0.1 to 1V secondary. However, voltage can be considerably higher due to harmonics. Normally a CVT secondary can have around 2.5 - 3% third-harmonic voltage.

11.2.2.8 Restoring

Maintenance is very important to improve the availability of the protection system by detecting failures before the protection is required to operate. There is however little point in testing healthy equipment and then putting it back into service with an open terminal, with a removed fuse or open miniature circuit breaker with an open connection, wrong setting, and so on.

Thus a list should be prepared of all items disturbed during test so that all can be put back into service quickly and without overlooking something. It should be put back into service item by item and signed by the responsible engineer.

Section 12 Troubleshooting

12.1 Checking the self supervision signals

12.1.1 Checking the self supervision function

12.1.1.1 Determine the cause of an internal failure

This procedure describes how to navigate the menus in order to find the cause of an internal failure when indicated by the flashing green LED on the HMI module.

Procedure

1. Display the general diagnostics menu.
   Navigate the menus to:
   Diagnostics/IED status/General
2. Scroll the supervision values to identify the reason for the failure.
   Use the arrow buttons to scroll between values.

12.1.2 Self supervision HMI data

12.1.2.1 General IED status

The following table shows the general IED status signals.

Table 30: Signals from the General menu in the diagnostics tree.

Indicated result	Possible reason	Proposed action
Internal fail Off	No problem detected.	None.
Internal fail On	A failure has occurred.	Check the rest of the indicated results to find the fault.
Internal warning Off	No problem detected.	None.
Internal warning On	A warning has been issued.	Check the rest of the indicated results to find the fault.
Time synch Ready	No problem detected.	None.
Time synch Fail Real time clock Ready	No time synchronization. No problem detected.	Check the synchronization source for problems. If the problem persists, contact your ABB representative for service. None.
Real time clock Fail	The real time clock has been reset.	Set the clock.
Table continues on next page		

Indicated result	Possible reason	Proposed action
ADC-module OK	No problem detected.	None.
ADC-module Fail	The AD conversion module has failed.	Contact your ABB representative for service.
(Protocol name) Ready	No problem detected.	None.
(Protocol name) Fail	Protocol has failed.	
(I/O module name) Ready	No problem detected.	None.
(I/O module name) Fail	I/O modules has failed.	Check that the I/O module has been configured and connected to the IOP1- block. If the problem persists, contact your ABB representative for service.

12.2 Fault tracing

12.2.1 Internal fault indications

If an internal fault has occurred, the local HMI displays information under **Main menu/Diagnostics/IED status/General**

Under the Diagnostics menus, indications of a possible internal failure (serious fault) or internal warning (minor problem) are listed.

Indications regarding the faulty unit are outlined in table 31.

Table 31: Self-supervision signals on the local HMI

HMI Signal Name:	Status	Description
INT Fail	OFF / ON	This signal will be active if one or more of the following internal signals are active; INT--LMDERROR, INT--WATCHDOG, INT--APPERROR, INT--RTEERROR, or any of the HW dependent signals
INT Warning	OFF / ON	This signal will be active if one or more of the following internal signals are active; INT--RTCERROR, INT--IEC61850ERROR, INT--TIMESYNCHERROR
ADMnn	READY / FAIL	Analog input module n failed. Signal activation will reset the IED
BIMnn	READY / FAIL	BIM error. Binary input module Error status. Signal activation will reset the IED
BOMn	READY / FAIL	BOM error. Binary output module Error status.
IOMn	READY / FAIL	IOM-error. Input/Output Module Error status.
MIMn	READY / FAIL	mA input module MIM1 failed. Signal activation will reset the IED
Table continues on next page		

HMI Signal Name:	Status	Description
RTC	READY / FAIL	This signal will be active when there is a hardware error with the real time clock.
Time Sync	READY / FAIL	This signal will be active when the source of the time synchronization is lost, or when the time system has to make a time reset.
Application	READY / FAIL	This signal will be active if one or more of the application threads are not in the state that Runtime Engine expects. The states can be CREATED, INITIALIZED, RUNNING, etc.
RTE	READY / FAIL	This signal will be active if the Runtime Engine failed to do some actions with the application threads. The actions can be loading of settings or parameters for components, changing of setting groups, loading or unloading of application threads.
IEC61850	READY / FAIL	This signal will be active if the IEC 61850 stack did not succeed in some actions like reading IEC 61850 configuration, startup etc.
LMD	READY / FAIL	LON network interface, MIP/DPS, is in an unrecoverable error state.
LDCMxxx	READY / FAIL	Line Differential Communication Error status
OEM	READY / FAIL	Optical Ethernet Module error status

Also the internal signals, such as INT--FAIL and INT--WARNING can be connected to binary output contacts for signalling to a control room.

In the IED Status - Information, the present information from the self-supervision function can be viewed. Indications of failure or warnings for each hardware module are provided, as well as information about the external time synchronization and the internal clock. All according to table 31. Loss of time synchronization can be considered as a warning only. The IED has full functionality without time synchronization.

When settings are changed in the IED, the protection and control applications restart in order to take effect of the changes. During restart, internal events get generated and Runtime App error will be displayed. These events are only indications and will be for short duration during the restart.

IED will not be operational during applications restart.

12.2.2 Using front-connected PC

When an internal fault has occurred, extensive information about the fault can be retrieved from the list of internal events available in the SMS part:

TRM-STAT TermStatus - Internal Events

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

The internal events are time tagged with a resolution of 1ms and stored in a list. The list can store up to 40 events. The list is based on the FIFO principle, when it is full, the oldest event is overwritten. The list cannot be cleared and its content cannot be erased.

The internal events in this list not only refer to faults in the IED, but also to other activities, such as change of settings, clearing of disturbance reports, and loss of external time synchronization.

The information can only be retrieved from the Parameter Setting software package. The PC can be connected either to the port at the front or at the rear of the IED.

These events are logged as internal events.

Table 32: Events available for the internal event list in the IED

Event message:		Description	Generating signal:
INT--FAIL	Off	Internal fail status	INT--FAIL (reset event)
INT--FAIL			INT--FAIL (set event)
INT--WARNING	Off	Internal warning status	INT--WARNING (reset event)
INT--WARNING			INT--WARNING (set event)
IOn--Error	Off	In/Out module No. n status	IOn--Error (reset event)
IOn--Error			IOn--Error (set event)
ADMn-Error	Off	Analog/Digital module No. n status	ADMn-Error (reset event)
ADMn-Error			ADMn-Error (set event)
MIM1-Error	Off	mA-input module status	MIM1-Error (reset event)
MIM1-Error			MIM1-Error (set event)
INT--RTC	Off	Real Time Clock (RTC) status	INT--RTC (reset event)
INT--RTC			INT--RTC (set event)
INT--TSYNC	Off	External time synchronization status	INT--TSYNC (reset event)
INT--TSYNC			INT--TSYNC (set event)
INT--SETCHGD		Any settings in IED changed	
DRPC-CLEARED		All disturbances in Disturbance report cleared	

The events in the internal event list are time tagged with a resolution of 1ms.

This means that, when using the PC for fault tracing, it provides information on the:

- Module that should be changed.
- Sequence of faults, if more than one unit is faulty.
- Exact time when the fault occurred.

12.2.3 Diagnosing the IED status via the LHMI hint menu

In order to help the user, there is an LHMI page labeled ‘Hints’. This page is located under **Main menu/Diagnostics/IED status/Hints**. For each activated hint there is a headline. From the headline view, an explanation page can be entered, giving the user more information and hints about the particular topic.

For example, if there is a configuration to use IEC 61850 9–2 analog data, but no data arrives on the access point, then the IED will use substituted data and most protection functions will be blocked. This condition will be indicated with a sub-menu under Hints, where details about this condition are shown. The Hint menu is a way to assist the user in troubleshooting.

The Hint menu is currently only available in English. All the entries are in English, regardless of which language is selected.

The supported list of hints are as follows:

Table 33: Hint menu

Headline	Explanation
Incorrect setting of SyncLostMode	There are two explanations possible: *SyncLostMode* is set to *Block*, no time source is configured to achieve the required accuracy. Unless a high accuracy time source is selected, the function dependent on high time accuracy will be blocked. *SyncLostMode* is set to *BlockOnLostUTC*, but there is no UTC capable synch source (GPS, IRIG-B) used. Unless a UTC capable time source is selected, the function dependent on high time accuracy will be blocked.
Sampled value substituted	<Access Point><Hardware Module Identifier><svID> Where the Hardware Module Identifier is the same as given in PCM600, e.g. AP1: MU1_9201 svID: <ABB_MU0101>
Table continues on next page	

Headline	Explanation
Time diff: IED vs Sampled value	<Access Point><Hardware Module Identifier><svID> Where the Hardware Module Identifier is the same as given in PCM600, e.g. AP1: MU1_9201 svID: <ABB_MU0101>
Frequency diff: IED vs Sampled value	<Access Point><Hardware Module Identifier><svID> Where the Hardware Module Identifier is the same as given in PCM600, e.g. AP1: MU1_9201 svID: <ABB_MU0101>
Wrong cycle time for PMU report	Wrong cycle time on SMAI or 3PHSUM block connected to Phasor Report block. The SMAI or 3PHSUM block should have the same cycle time as that of Phasor Report.
PMU not connected to 3ph output	The PMU phasor report input(s) must be connected to the 3ph output of SMAI or 3PHSU.
Invalid value set for PMU Parameters	There are two explanations possible: Check if the following parameters are set correctly on PMUREPORT: *ReportRate* or *SvcClass* or parameter PRIMVAL: 1.FrequencySel is not set as 50Hz / 60Hz. Check if the following parameters are set correctly on PMUREPORT: *ReportRate* or *SvcClass* or *RptTimetag* or parameter PRIMVAL: 1.FrequencySel is not set as 50Hz / 60Hz.
Invalid phase angle reference	The selected *PhaseAngleRef* corresponds to an analog channel that is not configured. Please configure a valid reference channel.
GOOSE is configured on a disabled port	At least one of the access points configured for GOOSE is disabled. The port can be disabled either through changing the access point operation to off or by unchecking the GOOSE protocol from the access point in the Ethernet configuration in PCM600 or LHMI. Please enable GOOSE on access points: AP_FRONT, AP_1
LDCM not running the application image	<slot number> is running the factory image instead of the application image. The factory image is older and does not contain the latest updates and fixes. Please reboot the IED. If the problem persists update the LDCM firmware or replace the board.
LDCM version is not accepted	<device name> firmware version <version string> is not accepted. The minimum accepted version is <version string>. Please update the LDCM firmware or replace the board.
OEM not running the application image	OEM in slot <slot number> is running the factory image instead of the application image. The factory image is older and does not contain the latest updates and fixes. Please reboot the IED. If the problem persists, update the OEM firmware or replace the board.

Table continues on next page

Headline	Explanation
SFP unplugged from the slot	SFP has been unplugged from the slot Please check the connection. Corresponding hardware(s) is set to fail.
SFP replaced with other type	Configured and the detected SFP(s) are different. Corresponding hardware(s) is set to fail. Please restart IED and consider Reconfigure HW modules to get updated hardware list.
Non ABB vendor SFP detected	Non ABB vendor SFP detected. Corresponding hardware(s) is set to fail. Please use ABB approved SFP's.

12.2.4 Hardware re-configuration

When adding, removing or moving a hardware modules in an IED (for example, I/O modules, communication modules or time synchronization modules) a set of procedures must be followed.

Adding a new module in to an IED

Procedure:

1. Switch the IED off and insert the new module.
2. Switch the IED on, wait for it to start, and then perform a HW reconfig.
3. Perform a license update in PCM600.

The new module is now available in PCM600 and is ready to be configured.

Removing a module from an IED

Procedure:

1. Remove all existing configuration for the module in PCM, and write that configuration to the IED.
2. Switch the IED off and remove the HW module.
3. Switch the IED on, wait for it to start, and then perform a HW reconfig.
4. Perform a license update in PCM 600.

If any configuration that makes the module needed remains, then the HW reconfig will not remove the module.
The module will still be needed. An error indication for the module will appear, if the module is physically removed from the IED and the IED is restarted with some part of the configuration still requiring the module.

Moving a module in an IED from one position to another

Procedure:

1. Remove all existing configuration for the module in PCM, and write that configuration to the IED.
2. Switch the IED off and move the HW module.
3. Switch the IED on, wait for it to start, and then perform a HW reconfig.
4. Perform a license update in PCM600.

The new module is now available in PCM600 at the new position and is ready to be configured.

12.3 Repair instruction

Never disconnect the secondary connection of a current transformer circuit without short-circuiting the transformer's secondary winding. Operating a current transformer with the secondary winding open will cause a massive potential build up that may damage the transformer and may cause injuries to humans.

Never connect or disconnect a wire and/or a connector to or from a IED during normal service. Hazardous voltages and currents are present that may be lethal. Operation may be disrupted and IED and measuring circuitry may be damaged.

An alternative is to open the IED and send only the faulty circuit board to ABB for repair. When a printed circuit board is sent to ABB, it must always be placed in a metallic, ESD-proof, protection bag. The user can also purchase separate replacement modules.

Strictly follow the company and country safety regulations.

Most electronic components are sensitive to electrostatic discharge and latent damage may occur. Please observe usual procedures for handling electronics and also use an ESD wrist strap. A semi-conducting layer must be placed on the workbench and connected to earth.

Disassemble and reassemble the IED accordingly:

1. Switch off the dc supply.
2. Short-circuit the current transformers and disconnect all current and voltage connections from the IED.
3. Disconnect all signal wires by removing the female connectors.
4. Disconnect the optical fibers.

5. Unscrew the main back plate of the IED.
6. If the transformer module is to be changed:
   - Remove the IED from the panel if necessary.
   - Remove the rear plate of the IED.
   - Remove the front plate.
   - Remove the screws of the transformer input module, both front and rear.
7. Pull out the faulty module.
8. Check that the new module has a correct identity number.
9. Check that the springs on the card rail are connected to the corresponding metallic area on the circuit board when the new module is inserted.
10. Reassemble the IED.

If the IED has been calibrated with the system inputs, the calibration procedure must be performed again to maintain the total system accuracy.

12.4 Repair support

If an IED needs to be repaired, the whole IED must be removed and sent to an ABB Logistic Center. Before returning the material, an inquiry must be sent to the ABB Logistic Center.

e-mail: offer.selog@se.abb.com

12.5 Maintenance

The IED is self-supervised. No special maintenance is required.

Instructions from the power network company and other maintenance directives valid for maintenance of the power system must be followed.

Section 13 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 fiber 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 fiber 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
HLV circuit	Hazardous Live Voltage according to IEC60255-27
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
MIM	Milli-ampere 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
OEM	Optical Ethernet module
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
PELV circuit	Protected Extra-Low Voltage circuit type according to IEC60255-27
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
SELV circuit	Safety Extra-Low Voltage circuit type according to IEC60255-27
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
X.21	A digital signalling interface primarily used for telecom equipment
$3I_O$	Three times zero-sequence current.Often referred to as the residual or the earth-fault current
$3U_O$	Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage

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