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Relion 670 SERIES

Phasor measurement unit RES670 Version 2.2 ANSI

Commissioning manual

Hitachi Energy

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Warranty

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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 Hitachi Energy 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 and ANSI C37.90. The DNP protocol implementation in the IED conforms to "DNP3 Intelligent Electronic Device (IED) Certification Procedure Subset Level 2", available at www.dnp.org.

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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

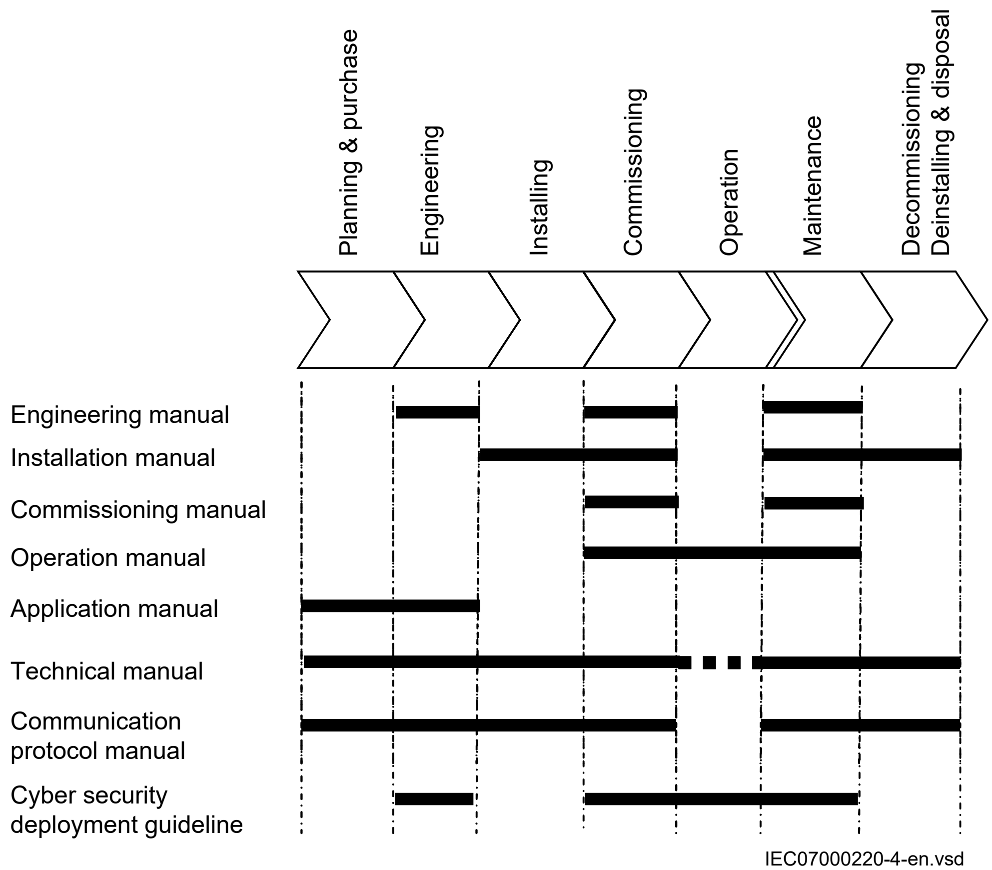


Figure 1: The intended use of manuals throughout the product lifecycle

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	Product version	History
-	2017-05	2.2.0	First release for product version 2.2
A	2017-10	2.2.1	Ethernet ports with RJ45 connector added.
B	2018-03	2.2.1	Document enhancements and corrections
C	2018–06	2.2.2	LDCM galvanic X.21 added. Ordering section updated.
D	2018-11	2.2.3	Functions CHMMHAI, VHMMHAI, DELVSPVC, DELISPVC and DELSPVC added. Updates/enhancements made to REALCOMP, and FNKEYMDx. Ordering section updated.
E	2019-05	2.2.3	PTP enhancements and corrections
F			Document not released
G			Document not released
H	2020-09	2.2.4	Functions ZMBURPSB, IEC 61850SIM and ALGOS added. Updates/enhancements made to functions EF4PTOC, SAPTUF, SAPTOF, CCSSPVC, FUFSPVC, SMPPTRC, SSIMG, and SSIML.
J	2021-06	2.2.5	Function RSTP, HOLDMINMAX, INT_REAL, CONST_INT, INTSEL, LIMITER, ABS, POL_REC, RAD_DEG, CONST_REAL, REALSEL, STOREINT, STOREREAL and DEG_RAD added. Updates/enhancements made to functions VHMMHAI, CHMMHAI, OC4PTOC, EF4PTOC, NS4PTOC, CVGAPC, SXCBR and DRPRDRE.

Table continues on next page

Document revision	Date	Product version	History
K	2022-07	2.2.5	Introduced RIA600, which is a software implementation of the IED LHMI panel.
L			Document not released
M	2023-06	2.2.6	SNMP support, IEC 61850 Ed2.1, new variants of single mode SFP added. Functions C1RADR, C2RADR, C3RADR, GOOSEACRCV, SNMPSERVERCONF, and SNMPUSERCONF added. Functions INTERRSIG, SETGRPS, TERMINALID, OC4PTOC, EF4PTOC, NS4PTOC, LCPTTR, LFPTTR, CVGAPC, SCSWI, SXSWI, VSGAPC, SMPPTRC, BTIGAPC, IB16, ITBGAPC, CVMMXN, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU, SSCBR, SPGAPC, SP16GAPC, IEC61850-8-1, LD0LLN0, GOOSEACRCV, AP_1, AP_FRONT, LDCMTRN, and MVGAPC updated.

1.3.3 Related documents

Documents related to RES670	Document numbers
Application manual	ANSI: 1MRK511407-UUS
Commissioning manual	ANSI: 1MRK511409-UUS
Product guide	1MRK511410-BEN
Technical manual	ANSI: 1MRK511408-UUS
Type test certificate	ANSI: 1MRK511410-TUS

670 series manuals	Document numbers
Operation manual	ANSI: 1MRK500127-UUS
Engineering manual	ANSI: 1MRK511398-UUS
Installation manual	ANSI: 1MRK514026-UUS
Communication protocol manual, DNP3	1MRK511391-UUS
Communication protocol manual, IEC 61850 Edition 2 and Edition 2.1	1MRK511393-UEN
Point list manual, DNP3	1MRK511397-UUS
Accessories guide	ANSI: 1MRK514012-BUS
Connection and Installation components	1MRK513003-BEN
Test system, COMBITEST	1MRK512001-BEN

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.

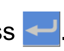
The caution icon indicates important information or warning related to the concept discussed in the text. It might indicate the presence of a hazard which could result in corruption of software or damage to equipment or property.

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, and Edition 2.1 mapping

Function block names are used in **ACT** and **PST** to identify functions. Respective function block names of Edition 1, Edition 2, and Edition 2.1 logical nodes are shown in the table below.

Table 1: IEC 61850 Edition 1, Edition 2, and Edition 2.1 mapping

Function block name	Edition 1 logical nodes	Edition 2 and Edition 2.1 logical nodes
-	-	ALGOS
-	-	ALSVS
AGSAL	AGSAL SECLLN0	AGSAL
ALMCALH	ALMCALH	ALMCALH
ALTIM	-	ALTIM
ALTMS	-	ALTMS
ALTRK	-	ALTRK
BTIGAPC	B16IFCVI	BTIGAPC
CCSSPVC	CCSRDIF	CCSSPVC
CHMMHAI	CHMMHAI	CHMMHAI
CMMXU	CMMXU	CMMXU
CMSQI	CMSQI	CMSQI
CVGAPC	GF2LLN0 GF2MMXN GF2PHAR GF2PTOV GF2PTUC GF2PTUV GF2PVOC PH1PTRC	GF2MMXN GF2PHAR GF2PTOV GF2PTUC GF2PTUV GF2PVOC PH1PTRC
CVMMXN	CVMMXN	CVMMXN
DELISPVC	DELISPVC	DELISPVC
DELSPVC	DELSPVC	DELSPVC
DELVSPVC	DELVSPVC	DELVSPVC
DPGAPC	DPGGIO	DPGAPC
DRPRDRE	DRPRDRE	DRPRDRE
EF4PTOC	EF4LLN0 EF4PTRC EF4RDIR GEN4PHAR PH1PTOC	EF4PTRC EF4RDIR GEN4PHAR PH1PTOC
ETPMMTR	ETPMMTR	ETPMMTR
FTAQFVR	FTAQFVR	FTAQFVR
FUFSPVC	SDDRFUF	FUFSPVC SDDSPVC
GOPPDOP	GOPPDOP	GOPPDOP PH1PTRC
GUPPDUP	GUPPDUP	GUPPDUP PH1PTRC
INDCALH	INDCALH	INDCALH
ITBGAPC	IB16FCVB	ITBGAPC
Table continues on next page		

Function block name	Edition 1 logical nodes	Edition 2 and Edition 2.1 logical nodes
L4UFCNT	L4UFCNT	L4UFCNT
LCPTTR	LCPTTR	LCPTTR
LD0LLN0	LLN0	-
LFPTTR	LFPTTR	LFPTTR
LPHD	LPHD	
MVGAPC	MVGGIO	MVGAPC
NS4PTOC	EF4LLN0 EF4PTRC EF4RDIR GEN4PHAR PH1PTOC	EF4PTRC EF4RDIR PH1PTOC
OC4PTOC	OC4LLN0 GEN4PHAR PH3PTOC PH3PTRC	GEN4PHAR PH3PTOC PH3PTRC
OOSPPAM	OOSPPAM	OOSPPAM OOSPTRC
OV2PTOV	GEN2LLN0 OV2PTOV PH1PTRC	OV2PTOV PH1PTRC
PCFCNT	PCGGIO	PCFCNT
QCBAY	QCBAY	BAY/LLN0
RCHLCCH	RCHLCCH	RCHLCCH
SAPFRC	SAPFRC	SAPFRC
SAPTOF	SAPTOF	SAPTOF
SAPTUF	SAPTUF	SAPTUF
SCHLCCH	SCHLCCH	SCHLCCH
SDEPSDE	SDEPSDE	SDEPSDE SDEPTOC SDEPTOV SDEPTRC
SLGAPC	SLGGIO	SLGAPC
SMPPTRC	SMPPTRC	SMPPTRC
SP16GAPC	SP16GGIO	SP16GAPC
SPC8GAPC	SPC8GGIO	SPC8GAPC
SPGAPC	SPGGIO	SPGAPC
SSCBR	SSCBR	SSCBR
SSIMG	SSIMG	SSIMG
SSIML	SSIML	SSIML
SXCBR	SXCBR	SXCBR
TEIGAPC	TEIGGIO	TEIGAPC TEIGGIO
TEILGAPC	TEILGGIO	TEILGAPC
TMAGAPC	TMAGGIO	TMAGAPC
UV2PTUV	GEN2LLN0 PH1PTRC UV2PTUV	PH1PTRC UV2PTUV

Table continues on next page

Function block name	Edition 1 logical nodes	Edition 2 and Edition 2.1 logical nodes
VHMMHAI	VHMMHAI VHMQVHA	VHMMHAI VHMQVHA
VMMXU	VMMXU	VMMXU
VMSQI	VMSQI	VMSQI
VNMMXU	VNMMXU	VNMMXU
VSGAPC	VSGGIO	VSGAPC
WRNCALH	WRNCALH	WRNCALH
ZMBURPSB	ZMBURPSB	ZMBURPSB

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.

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 ground, 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 grounded.

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 ground 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 IED's 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.

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)
C30	=1/2 CB application. For the pre-configured variants

3.1 Wide area measurement functions

IEC 61850 or function name	ANSI	Function description	Phasor measurement
			RES670 (Customized)
PMUCONF		Configuration parameters for C37.118 2011 and IEEE1344 protocol	1
PMUREPORT		Protocol reporting via IEEE1344 and C37.118	1-2
PHASORREPORT1		Protocol reporting of phasor data via IEEE 1344 and C37.118, phasors 1-8	1-2
PHASORREPORT2		Protocol reporting of phasor data via IEEE 1344 and C37.118, phasors 9-16	0-2
PHASORREPORT3		Protocol reporting of phasor data via IEEE 1344 and C37.118, phasors 17-24	0-2
PHASORREPORT4		Protocol reporting of phasor data via IEEE 1344 and C37.118, phasors 25-32	0-2
ANALOGREPORT1		Protocol reporting of analog data via IEEE 1344 and C37.118, analogs 1-8	0-2
ANALOGREPORT2		Protocol reporting of analog data via IEEE 1344 and C37.118, analogs 9-16	0-2
ANALOGREPORT3		Protocol reporting of analog data via IEEE 1344 and C37.118, analogs 17-24	0-2
BINARYREPORT1		Protocol reporting of binary data via IEEE 1344 and C37.118, binary 1-8	0-2
BINARYREPORT2		Protocol reporting of binary data via IEEE 1344 and C37.118, binary 9-16	0-2
BINARYREPORT3		Protocol reporting of binary data via IEEE 1344 and C37.118, binary 17-24	0-2
PMUSTATUS		Diagnostics for C37.118 2011 and IEEE1344 protocol	1

3.2 Back-up protection functions

IEC 61850 or function name	ANSI	Function description	Phasor measurement unit
			RES670 (Customized)
Impedance protection			
ZMBURPSB	68	Power swing detection, blocking and unblocking	0-1
OOSPPAM	78	Out-of-step protection	0-2
Current protection			

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Phasor measurement unit
			RES670 (Customized)
OC4PTOC	51_67 1)	Directional phase overcurrent protection, four steps	0-6
EF4PTOC	51N_67N 2)	Directional residual overcurrent protection, four steps	0-6
NS4PTOC	46I2	Directional negative phase sequence overcurrent protection, four steps	0-6
SDEPSDE	67N	Sensitive directional residual overcurrent and power protection	0-6
LCPTTR	26	Thermal overload protection, one time constant, Celsius	0-6
LFPTTR	26	Thermal overload protection, one time constant, Fahrenheit	0-6
GUPPDUP	37	Directional underpower protection	0-4
GOPPDOP	32	Directional overpower protection	0-4
Voltage protection			
UV2PTUV	27	Two step undervoltage protection	0-4
OV2PTOV	59	Two step overvoltage protection	0-4
Frequency protection			
SAPTUF	81	Underfrequency protection	0-10
SAPTOF	81	Overfrequency protection	0-6
SAPFRC	81	Rate-of-change of frequency protection	0-6
FTAQFVR	81A	Frequency time accumulation protection	0-4
Multipurpose protection			
CVGAPC		General current and voltage protection	0-8
General calculation			
SMAIHPAC		Multipurpose filter	0-6

1) 67 requires voltage
2) 67N requires voltage

3.3 Control and monitoring functions

IEC 61850 or function name	ANSI	Function description	Phasor measurement unit
			RES670 (Customized)
Control			
QCBAY		Bay control	1
LOCREM		Handling of local/remote switch positions	1
LOCREMCTRL		LHMI control of the permitted source to operate (PSTO)	1
SXCBR		Circuit breaker	18
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	3
Table continues on next page			

IEC 61850 or function name	ANSI	Function description	Phasor measurement unit
			RES670 (Customized)
SINGLECMD		Single command, 16 inputs	8
I103CMD		Function commands for IEC 60870-5-103	1
I103GENCMD		Function commands for IEC 60870-5-103, generic	50
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	4
Secondary system supervision			
CCSSPVC	87	Current circuit supervision	0-5
FUFSPVC		Fuse failure supervision	0-4
DELVSPVC	7V_78V	Voltage delta supervision	4
DELISPVC	7I	Current delta supervision	4
DELSPVC	78	Real delta supervision, real	4
Logic			
SMPPTRC	94	Tripping logic	12
SMAGAPC		General start matrix block	12
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
AND, GATE, INV, LLD, OR, PULSETIMER, RSMEMORY, SRMEMORY, TIMERSET, XOR		Basic configurable logic blocks (see Table 3)	40-420
ANDQT, INDCOMBSPQT, INDEXTSPQT, INVALIDQT, INVERTERQT, ORQT, PULSETIMERQT, RSMEMORYQT, SRMEMORYQT, TIMERSETQT, XORQT		Configurable logic blocks Q/T (see Table 4)	0-1
AND, GATE, INV, LLD, OR, PULSETIMER, RSMEMORY, SLGAPC, SRMEMORY, TIMERSET, VSGAPC, XOR		Extension logic package (see Table 5)	0-1
FXDSIGN		Fixed signal function block	1
Table continues on next page			

IEC 61850 or function name	ANSI	Function description	Phasor measurement unit
			RES670 (Customized)
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	24
ITBGAPC		Integer to boolean conversion with logical node representation, 16 bit	16
TEIGAPC		Elapsed time integrator with limit transgression and overflow supervision	12
INTCOMP		Comparator for integer inputs	30
REALCOMP		Comparator for real inputs	30
HOLDMINMAX		Hold minimum and maximum of input	20
INT_REAL		Converter integer to real	20
CONST_INT		Definable constant for logic functions	10
INTSEL		Analog input selector for integer values	5
LIMITER		Definable limiter	20
ABS		Absolute value	20
POL_REC		Polar to rectangular converter	20
RAD_DEG		Radians to degree angle converter	20
CONST_REAL		Definable constant for logic functions	10
REALSEL		Analog input selctor for real values	5
STOREINT		Store value for integer inputs	10
STOREREAL		Store value for real inputs	10
DEG_RAD		Degree to radians angle converter	20
Monitoring			
CVMMXN		Power system measurement	6
CMMXU		Current measurement	10
VMMXU		Voltage measurement phase-phase	6
CMSQI		Current sequence measurement	6
VMSQI		Voltage sequence measurement	6
VNMMXU		Voltage measurement phase-ground	6
AISVBAS		General service value presentation of analog inputs	1
EVENT		Event function	20
DRPRDRE, A1RADR-A4RADR, B1RBDR-B22RBDR, C1RADR-C3RADR		Disturbance report	1
SPGAPC		Generic communication function for single point indication, 1 input	128
SP16GAPC		Generic communication function for single point indication, 16 inputs	16
MVGAPC		Generic communication function for measured values	60
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

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Phasor measurement unit
			RES670 (Customized)
SSCBR		Circuit breaker condition monitoring	0-18
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		Supervision status for IEC 60870-5-103	1
I103USRDEF		Status for user defined signals for IEC 60870-5-103	20
L4UFCNT		Event counter with limit supervision	30
TEILGAPC		Running hour meter	6
CHMMHAI	ITHD	Current harmonic monitoring, 3 phase	0-3
VHMMHAI	VTHD	Voltage harmonic monitoring, 3 phase	0-3
Metering			
PCFCNT		Pulse-counter logic	16
ETPMMTR		Function for energy calculation and demand handling	6

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: 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

Table continues on next page

Configurable logic blocks Q/T	Total number of instances
PULSETIMERQT	40
RSMEMORYQT	40
SRMEMORYQT	40
TIMERSETQT	40
XORQT	40

Table 5: 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

3.4 Communication

IEC 61850 or function name	ANSI	Function description	Phasor measurement unit
			RES670 (Customized)
Station communication			
LONSPA, SPA		SPA communication protocol	1
ADE		LON communication protocol	1
HORZCOMM		Network variables via LON	1
PROTOCOL		Operation selection between SPA and IEC 60870-5-103 for SLM	1
RS485PROT		Operation selection for RS485	1
RS485GEN		RS485	1
DNPGEN		DNP3.0 communication general protocol	1
CHSERRS485		DNP3.0 for EIA-485 communication protocol	1
CH1TCP, CH2TCP, CH3TCP, CH4TCP		DNP3.0 for TCP/IP communication protocol	1
CHSEROPT		DNP3.0 for TCP/IP and EIA-485 communication protocol	1
MSTSER		DNP3.0 serial master	1
MST1TCP, MST2TCP, MST3TCP, MST4TCP		DNP3.0 for TCP/IP communication protocol	1

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Phasor measurement unit
			RES670 (Customized)
DNPFREC		DNP3.0 fault records for TCP/IP and EIA-485 communication protocol	1
IEC 61850-8-1		IEC 61850	1
GOOSEINTLKRCV		Horizontal communication via GOOSE for interlocking	59
IEC 61850SIM		IEC 61850 simulation mode	1
GOOSEBINRCV		GOOSE binary receive	16
GOOSEDPRCV		GOOSE function block to receive a double point value	64
GOOSEINTRCV		GOOSE function block to receive an integer value	32
GOOSEMVRCV		GOOSE function block to receive a measurand value	60
GOOSESPRCV		GOOSE function block to receive a single point value	64
ALGOS		Supervision of GOOSE subscription	100
MULTICMDRCV, MULTICMDSND		Multiple command receive and send	60/10
OPTICAL103		IEC 60870-5-103 Optical serial communication	1
RS485103		IEC 60870-5-103 serial communication for RS485	1
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
SECALARM		Component for mapping security events on protocols such as DNP3 and IEC103	1
FSTACCSNA		Field service tool access via SPA protocol over Ethernet communication	1
FSTACCS		Field service tool access	1
GOOSEACRCV		GOOSE function block to receive a protection activation information	16
		IEC 61850-9-2 Process bus communication, 12 merging units	0-1
ACTIVLOG		Activity logging	1
ALTRK		Service tracking	1
PRP		IEC 62439-3 Parallel redundancy protocol	0-1
HSR		IEC 62439-3 High-availability seamless redundancy	0-1
RSTP		IEC 62439-3 Rapid spanning tree protocol	0-1
SNMPSERVERCONF		SNMPServerConfiguration	1
SNMPUSERCONF		SNMPUserConfiguration	2
PMUSTATUS		Diagnostics for IEC/IEEE 60255-118 (C37.118) and IEEE1344 protocol	1
AP_1-AP_6		AccessPoint_ABS	1
AP_FRONT		Access point front	1
PTP		Precision time protocol	1
ROUTE_1-ROUTE_6		Route_ABS1-Route_ABS6	1
FRONTSTATUS		Access point diagnostic for front Ethernet port	1
SCHLCCH		Access point diagnostic for non-redundant Ethernet port	6
RCHLCCH		Access point diagnostic for redundant Ethernet ports	3
DHCP		DHCP configuration for front access point	1

Table continues on next page

IEC 61850 or function name	ANSI	Function description	Phasor measurement unit
			RES670 (Customized)
QUALEXP		IEC 61850 quality expander	96
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
BSR2M_305 BSR2M_312 BSR2M_322 BSR2M_306 BSR2M_313 BSR2M_323		Binary signal transfer, 2Mbit receive	1
BST2M_305 BST2M_312 BST2M_322 BST2M_306 BST2M_313 BST2M_323		Binary signal transfer, 2Mbit transmit	1
LDCMTRN		Transmission of analog data from LDCM	1
LDCMTRN_2M_305 LDCMTRN_2M_306 LDCMTRN_2M_312 LDCMTRN_2M_313 LDCMTRN_2M_322 LDCMTRN_2M_323		Transmission of analog data from LDCM, 2Mbit	1
LDCMRecBinStat1 LDCMRecBinStat3		Receive binary status from remote LDCM	6/3
LDCMRecBinStat2		Receive binary status from LDCM	3
LDCM2M_305 LDCM2M_312 LDCM2M_322		Receive binary status from LDCM, 2Mbit	1
LDCM2M_306 LDCM2M_313 LDCM2M_323		Receive binary status from remote LDCM, 2Mbit	1

3.5 Basic IED functions

Table 6: Basic IED functions

IEC 61850 or function name	Description
INTERRSIG SELFSUPEVLST	Self supervision with internal event list
TIMESYNCHGEN	Time synchronization module
SYNCHCAN, SYNCHCMPPS, SYNCHPPS, SYNCHCMPPS, TIMEZONE	Time synchronization
DSTBEGIN	GPS time synchronization module
DSTENABLE	Enables or disables the use of daylight saving time
DSTEND	GPS time synchronization module
IRIG-B	Time synchronization
SETGRPS	Number of setting groups
ACTVGRP	Active parameter setting group
TESTMODE	Test mode functionality
CHNGLCK	Change lock function
TERMINALID	IED identifiers
PRODINF	Product information
SYSTEMTIME	System time
LONGEN	LON communication
RUNTIME	IED Runtime component
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
3PHSUM	Summation block 3 phase
ATHSTAT	Authority status
ATHCHCK	Authority check
AUTHMAN	Authority management
FTPACCS	FTP access with password
SPACOMMMAP	SPA communication mapping
SPATD	Date and time via SPA protocol
BCSCONF	Basic communication system
GBASVAL	Global base values for settings
PRIMVAL	Primary system values
SAFEFILECOPY	Safe file copy function
ALTMS	Time master supervision
ALTIM	Time management
CAMCONFIG	Central account management configuration
Table continues on next page	

IEC 61850 or function name	Description
CAMSTATUS	Central account management status
TOOLINF	Tools information
COMSTATUS	Protocol diagnostic

Table 7: Local HMI functions

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

Section 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 pickup. 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.

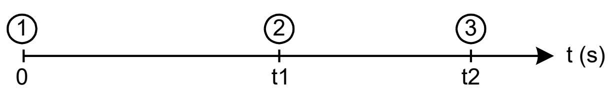
Set the IED time if no time synchronization source is configured.

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 ‘Available’ 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 ‘Available’ 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.

4.5.1 When IED has blank front panel

IED with blank front panel will not have front port. Instead in the IED's AP1 will be turned on which will have the default IP address 192.168.1.10 and subnet mask 255.255.255.0. If the user wants to change the default IP address, use RIA600 or PCM600.

DHCP is not available on this port.

4.5.2 When IED has front port with RJ-45

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/**

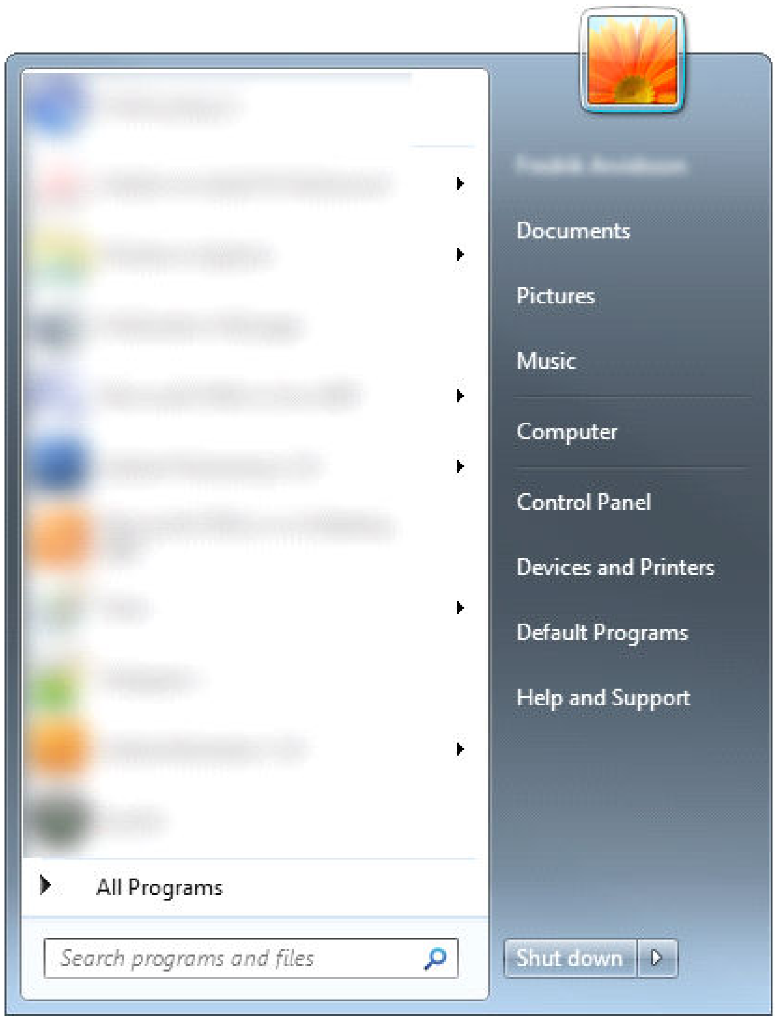
Communication/ TCP-IP configuration/ ETHFRNT:1Main menu/ Configuration/ Communication/ Ethernet configuration/ AP_FRONT.

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.

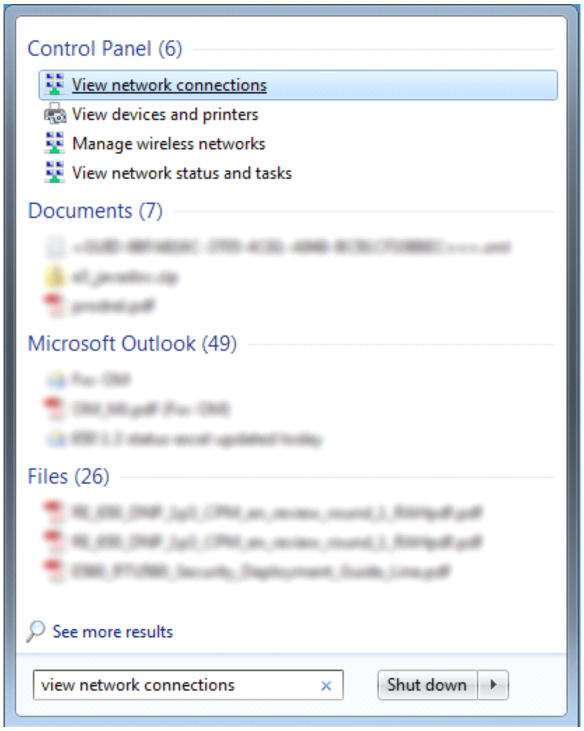
1. Select **Search programs and files** in the **Start menu** in Windows.



IEC13000057-1-en.vsd

Figure 3: Select: Search programs and files

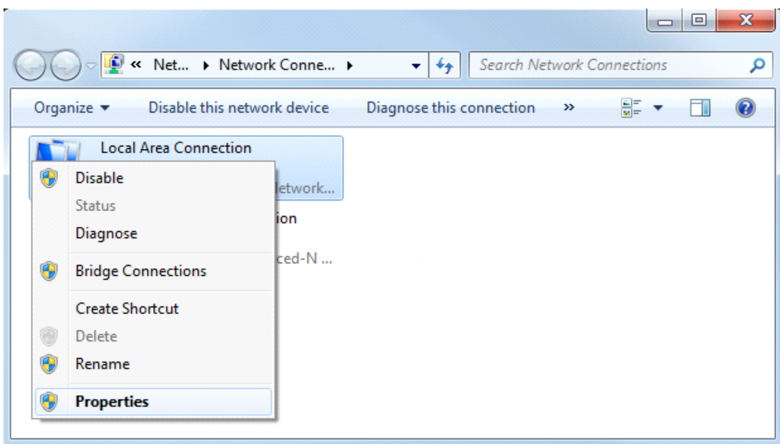
2. Type **View network connections** and click on the **View network connections** icon.



IEC13000058-1-en.vsd

Figure 4: Click View network connections

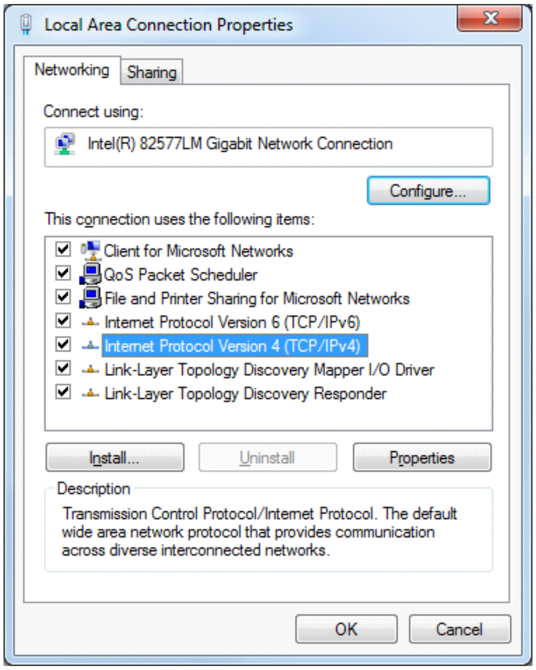
3. Right-click and select **Properties**.



IEC13000059-1-en.vsd

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

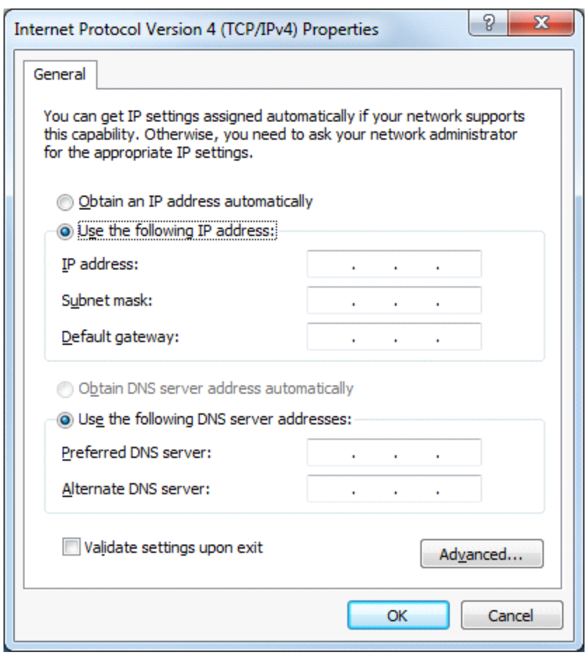
4. Select the TCP/IPv4 protocol from the list of configured components using this connection and click **Properties**.



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 A, B, C.)
- 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.
- Grounding check of the individual CT secondary circuits to verify that each three-phase set of main CTs is properly connected to the station ground 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 ground 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)
- Grounding 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.

4.10.2 Binary output circuits

Preferably, disconnect the binary output connector from the binary output cards. Check all connected signals so that both load and polarity are in accordance with 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 (7.2 inches) for plastic fiber cables and 275 mm (10.9 inches) 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 commissioning personnel 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 8: 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 neutral (WYE) 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 9: 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 10: 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.

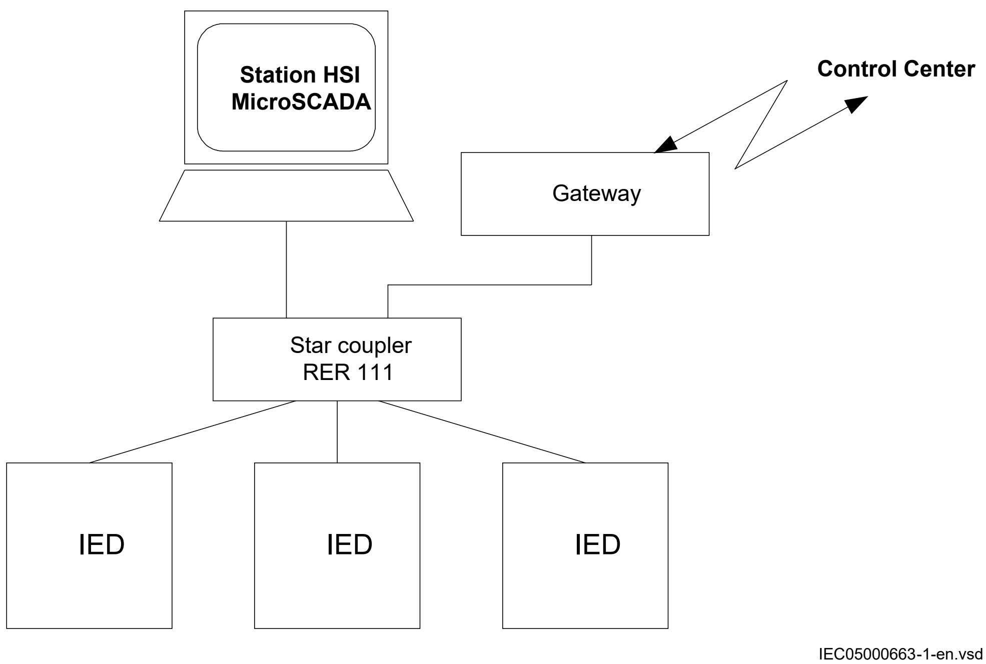


Figure 8: Example of LON communication structure for a substation automation system

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 11: 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

Table continues on next page

	Glass fiber	Plastic fiber
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 12: 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
- IEEE C37.118/1344 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.

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*. This is only applicable if redundant communication is used. 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 Establishing connection and verifying the IEEE C37.118/1344 communication

9.1 Overview

The IED can support synchrophasor data communication via IEEE C37.118 and/or IEEE1344 with maximum 8 TCP clients and 6 UDP client groups, simultaneously.

The rear OEM ports are used for IEEE C37.118/1344 communication. The same ports can also be used for substation bus (IEC 61850-8-1) communication and process bus (IEC/UCA 61850-9-2LE) communication where applicable.

In order to establish a connection between PMU and a TCP/UDP client (PDC client), an Ethernet communication link (e.g. optical fiber) shall be available and the required parameters on both PMU and the TCP/UDP client shall be set. For the purpose of this section, an Open PDC tool (PMU Connection Tester) installed on a PC is used as the TCP/UDP client.

9.2 Setting the PMU station communication (PMU Report)

1. Check the settings for the PMU Report parameters by navigating to: **Main menu /Configuration / Communication /Station communication /phasor measurement /PMU Report /PMUREPORT:1**
   1.1. Make sure that the operation of at least one PMU instance (e.g. PMU1) is *Enabled*.
   1.2. Enable sending the frequency data by setting the parameter *SendFreqInfo* to *Enabled*.
2. Check the operation of the required phasor channels (PHASORREPORT) by navigating to: **Main menu /Configuration /Communication /Station communication /phasor measurement /PMU Report /PHASORREPORT:x** .

9.3 Setting the PMU station communication (PMU configuration)

To enable IEEE C37.118/1344 communication, the corresponding OEM ports must be activated. The galvanic Ethernet front port and the rear optical ports can be used for IEEE C37.118/1344 communication.

To enable IEEE C37.118/1344 synchrophasor communication:

1. Enable communication for by navigating to: **Main menu /Configuration /Communication / Ethernet configuration** .
   1.1. Select the port.
   1.2. Set values for *Mode*, *IPAddress* and *IPMask*. *Mode* must be set to *Normal*.
   1.3. Check that the correct IP address is assigned to the port.
2. Set the TCP communication parameters by navigating to: **Main menu /Configuration / Communication /Station communication /phasor measurement /PMU Configuration / PMUCONF** . The first three parameters are related to TCP communication. The default TCP

parameters setting can be used. More information regarding TCP communication is available in the Application manual under section Short guidance for use of TCP.

3. Set the UDP communication parameters by navigating to: **Main menu /Configuration / Communication /Station communication /phasor measurement /PMU Configuration / PMUCONF** . The first three parameters are related to TCP communication and the rest of parameters are related to setting of six independent UDP client groups. Each UDP group has eight parameters. More information regarding UDP communication is available in the Application manual under section Short guidance for use of UDP. The following steps describes setting parameters for the first UDP group:
   3.1. Enable the first UDP group by setting the parameter *SendDataUDP1* to *Enabled*.
   3.2. Set the UDP client IP address by setting the parameter *UDPDestAddres1* to 192.168.1.99. For the purpose of the communication set-up in this section the LAN IP address of the PC is used, where the PDC client tool is installed.
   3.3. The default parameter settings can be used for the rest of parameters for the first UDP group.

9.4 Setting the TCP/UDP client communication

As an example of a TCP/UDP client, the openPDC tool (PMU Connection Tester Ver. 4.2.12) from Grid Protection Alliance is used in this section. Install PMU Connection Tester tool on a PC with Ethernet network adaptor available. The same PC used for PCM600 can be used to install the PMU Connection Tester tool.

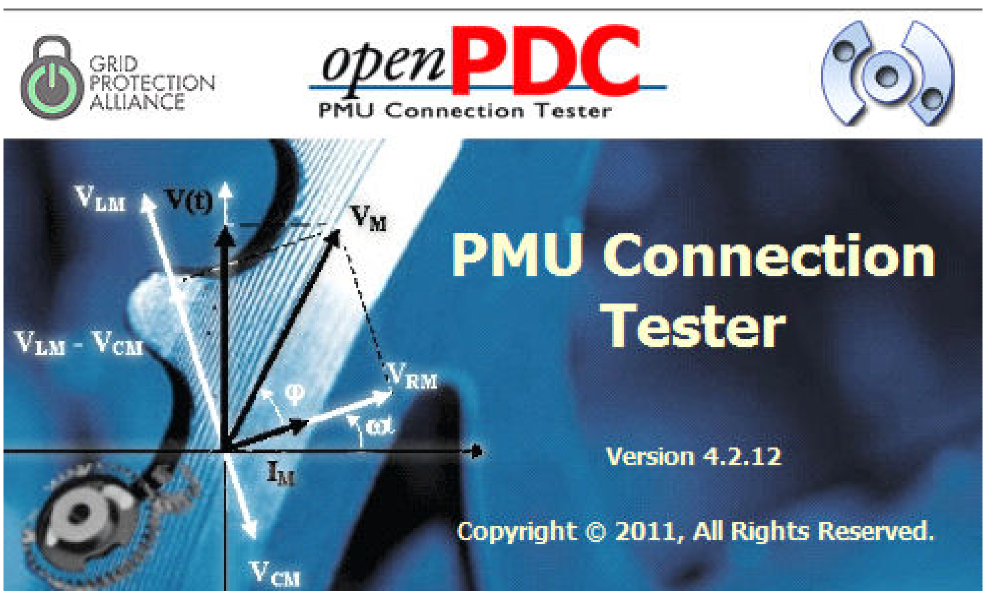


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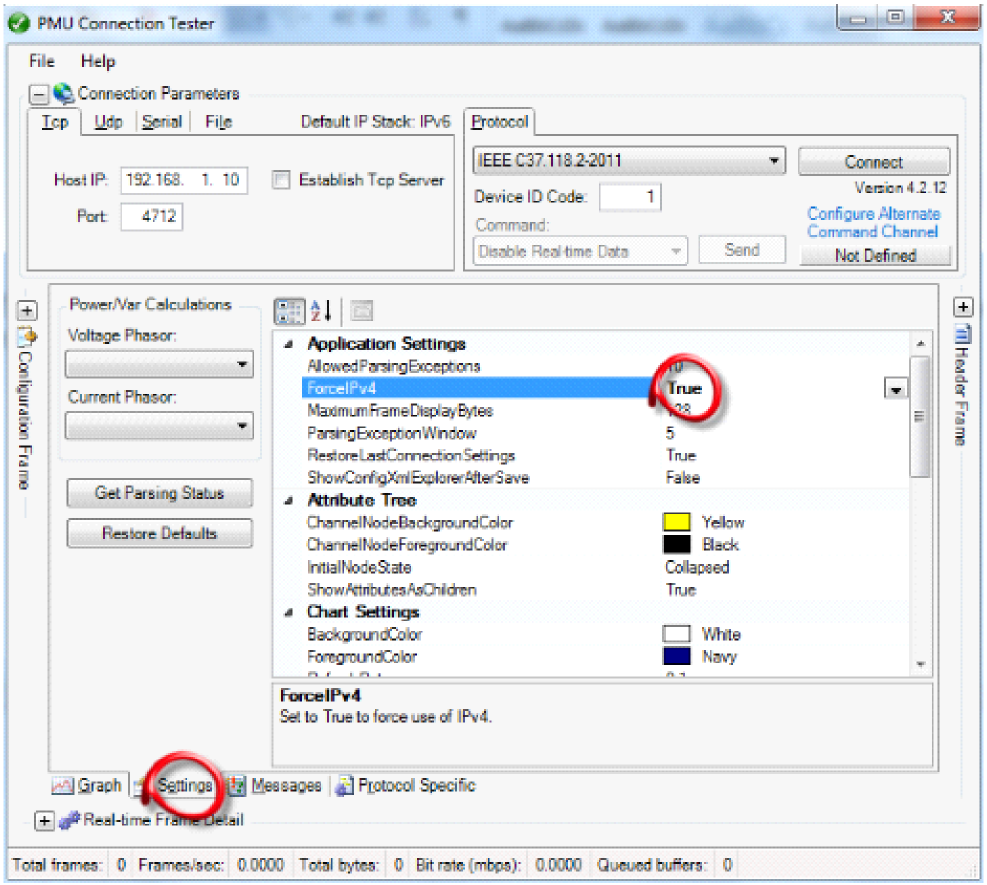
Figure 9: PMU Connection Tester tool

The following steps explain how to set the PMU Connection Tester parameters in order to establish an IEEE C37.118 connection with the PMU:

1. Set the IP stack on PMU Connection Tester to **IPv4**. Note that the default IP stack on PMU Connection Tester tool is IPv6.



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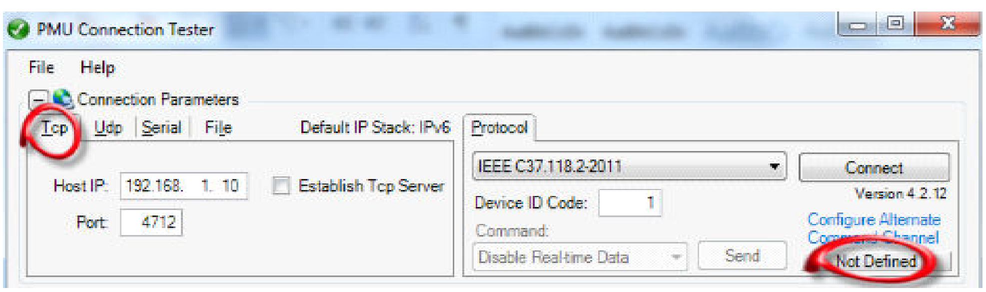
1.1. Navigate to the **Settings** tab.
1.2. Force the IP stack to IPv4 by setting the parameter *ForceIPv4* to *True*.

2. Set the Connection Parameters on PMU Connection Tester for TCP communication according to the PMU configuration.



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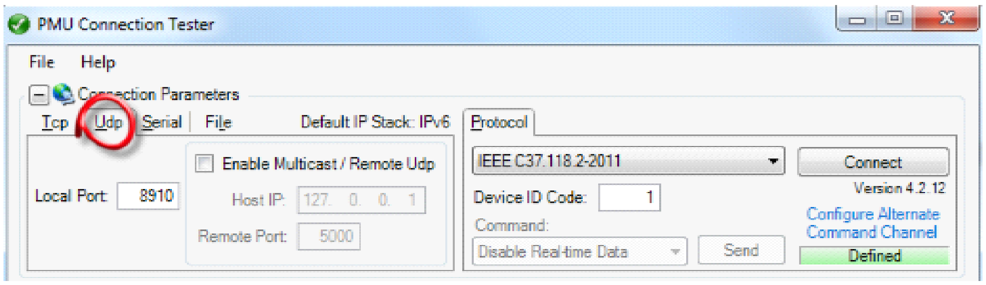
2.1. Set *Host IP* to the PMU IP address configured for the port in use. Here the LANAB:1 IPAddress (192.168.1.10) is set.
2.2. Set *Port* to the IED's TCP port set in the PMU under parameter C37.118TCPport (4712 is default). Alternatively, in order to make an IEEE1344 communication, the 1344TCPport parameter setting can be used (4713 is default).
2.3. Set the **Protocol** as IEEE C37.118.2-2011.

2.4. Set the *Device ID Code* in PMU Connection Tester per PMU Data Stream ID Number (IDCODE). The PMU Data Stream ID Number is a user assigned ID number (1-65534) for each data stream sent out from the PMU and it is defined under parameter *PMUdataStreamIDCODE*. (**Main menu /Configuration /Communication /Station communication /phasor measurement /PMU Report /PMUREPORT:1**)

2.5. Make sure that the *Configure Alternate Command Channel* is set as *Not Defined*. The *Configure Alternate Command Channel* is used to configure a TCP channel to control the UDP data communication and transfer the header, configuration and command frames.

2.6. Continue to the section Verifying the IEEE C37.118/1344 TCP communication.

3. Set the Connection Parameters on PMU Connection Tester for UDP communication according to the PMU configuration.



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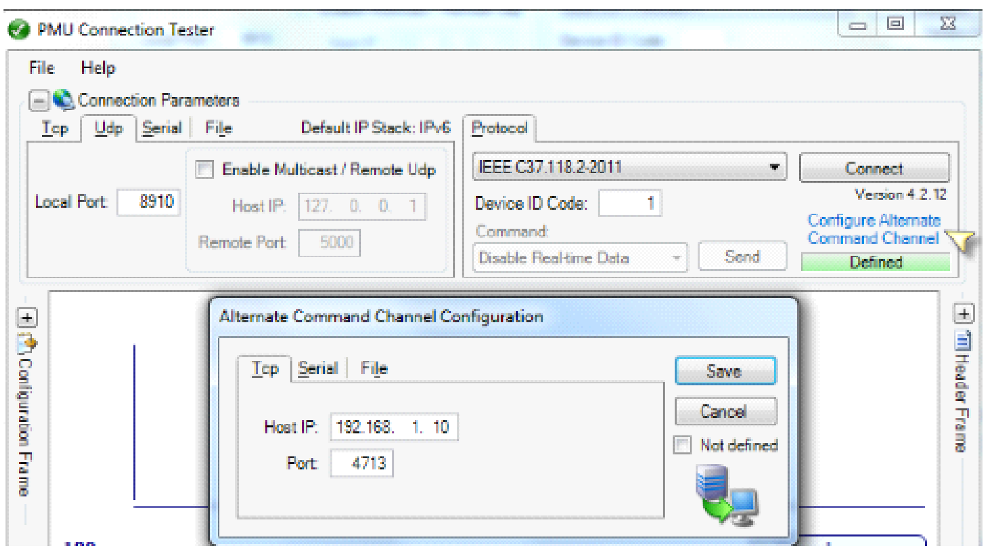
3.1. Set the *Local Port* to UDP destination port defined in the PMU under the parameter *UDPDestPort1* (Default value: 8910).

3.2. Click the **Configure Alternate Command Channel** to configure the TCP channel. A new window will pop up. A TCP channel needs to be configured in order to control the UDP data communicatiuon and transfer the header, configuration and command frames.



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3.3. Set the *Host IP* as the PMU IP address configured for the port in use. Here the LANAB:1 IPAddress (192.168.1.10) is set.

3.4. Set the *Port* as the TCP port defined in the PMU for control of data sent over UDP client group 1 (Default value: 4713). This can be found under the parameter *TCPportUDPdataCtrl1* as one of the UDP communication parameters.
3.5. **Save** the **Alternate Command Channel Configuration** settings.
3.6. Continue to the section Verifying the IEEE C37.118/1344 UDP communication

9.5 Verifying the communication

Connect your PC to the substation network and ping the connected IED and the Substation Master PC, to verify that the communication is working (up to the transport layer). Make sure that the optical fibers are connected correctly.

After checking the communication, it is time to verify the IEEE C37.118/1344 communication over both TCP and UDP protocols.

One way to verify the communication up to the application layer is to use a protocol analyzer connected to the substation bus, and monitor the communication. Alternatively, the PMU Connection Tester tool can be used to verify the IEEE C37.118/1344 communication. The section Setting the TCP/UDP client communication explains how to set the PMU Connection Tester parameters in order to establish an IEEE C37.118 connection with the PMU.

9.5.1 Verifying the IEEE C37.118/1344 TCP communication

After setting both PMU configuration and the TCP client configuration (As explained in sections Setting the PMU station communication (PMU Report), Setting the PMU station communication (PMU configuration) and Setting the TCP/UDP client communication) and making sure that the Ethernet communication is set up, click *Connect* on the PMU Connection Tester tool.

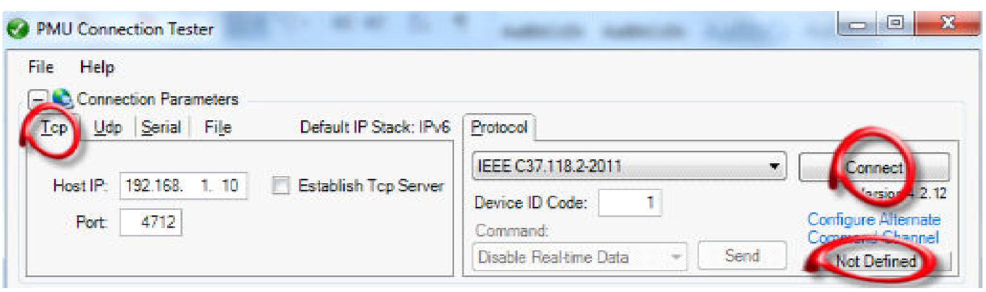

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Figure 10: Verifying the TCP communication using PMU Connection Tester

- Now it should be possible to see the streaming synchrophasor data. In the **Graph** tab, observe the Frequency, data Reporting Rate, Phasor names, and Phase angles of the reported synchrophasors. Observe the real-time frame details of the Data Frame in the bottom of the window.

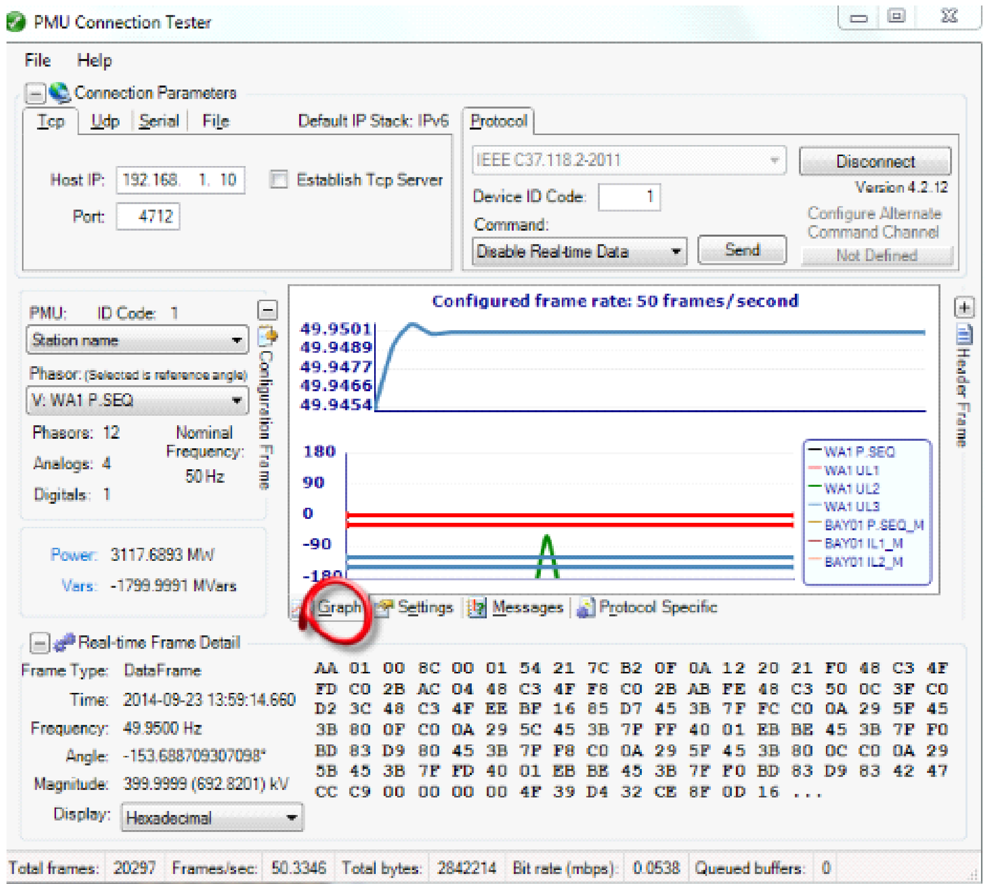

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Figure 11: Graphic view over streaming synchrophasor data

- Open the drop-down menu in the *Command* field. There is a list of commands that can be sent from the client (PMU Connection Tester) to the PMU. Try different commands and make sure that the PMU is receiving and responding to them.

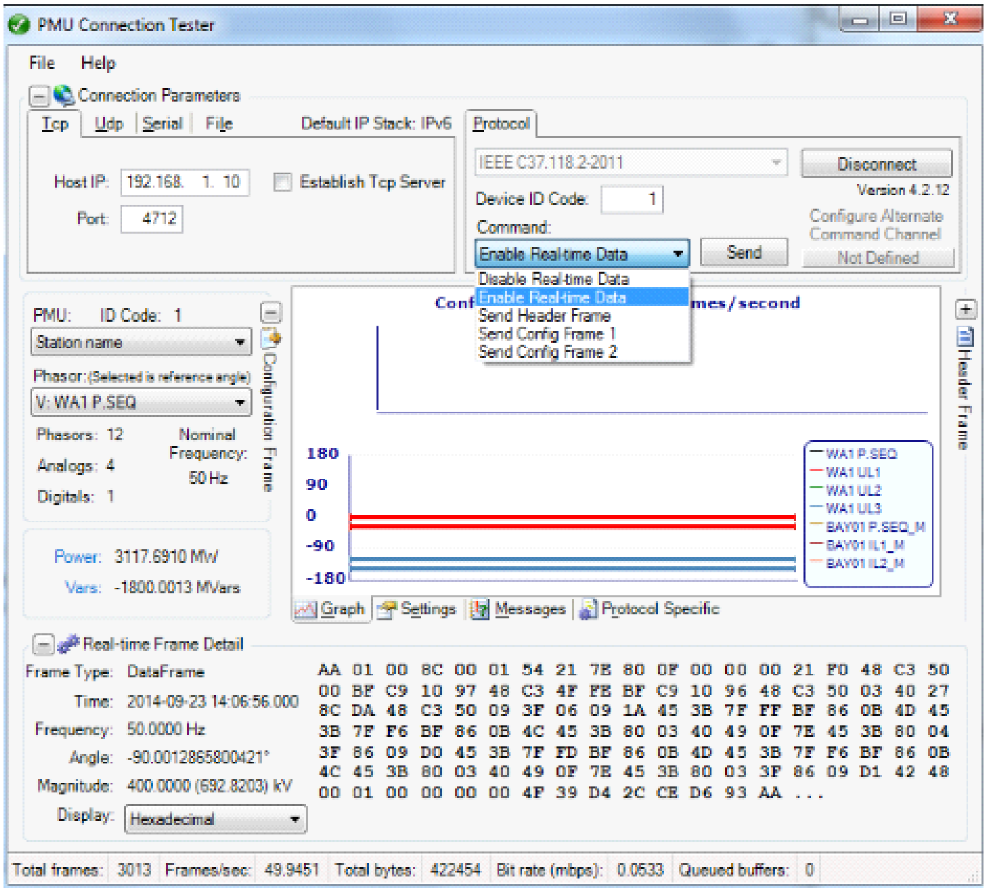

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Figure 12: Drop-down menu with commands for testing the PMU

- Switch to the **Protocol Specific** tab. Here, all the IEEE C37.118 message types can be seen. If the **HeaderFrame** is not included, ask the PMU to send the header frame via the *Send Header Frame* command (Previous stage). Open each message type and observe the content of each message.

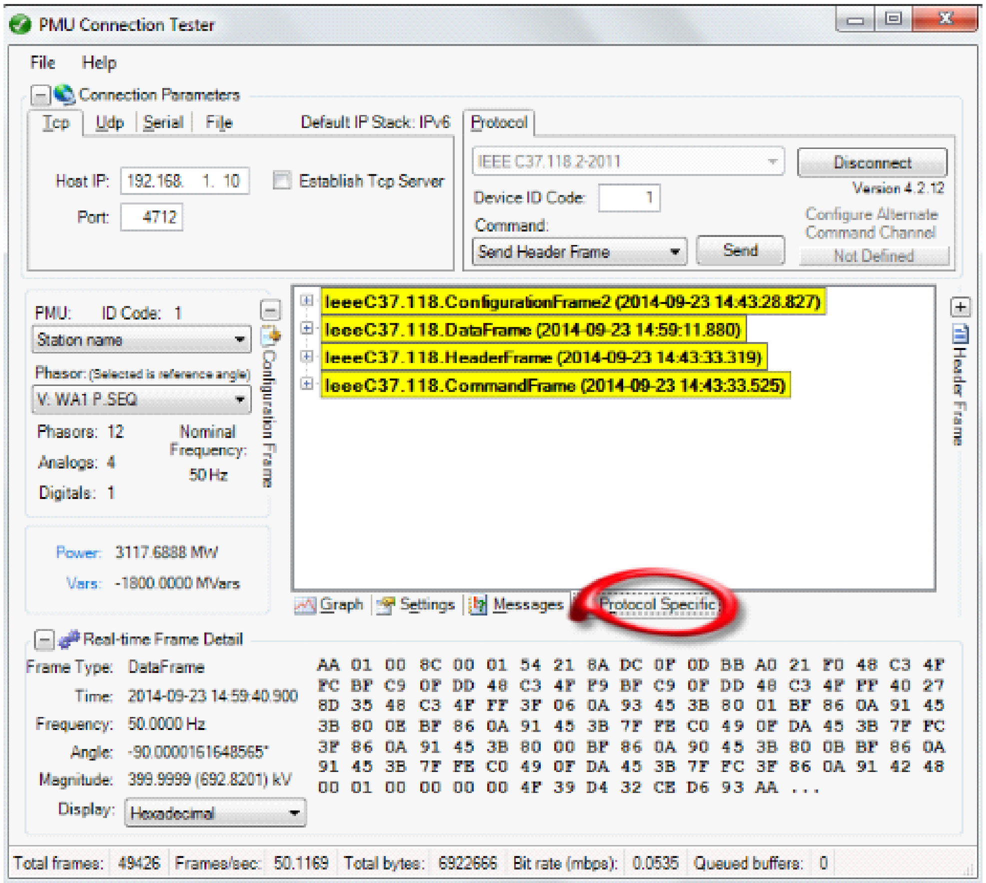

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Figure 13: All the IEEE C37.118 message types

- It is also possible to capture the IEEE C37.118 synchrophasor data in an Excel file. This is done by navigating to **File /Capture /Start Stream Debug Capture...** The tool will ask to **Set Stream Debug Capture File Name** and path to save the capture file.

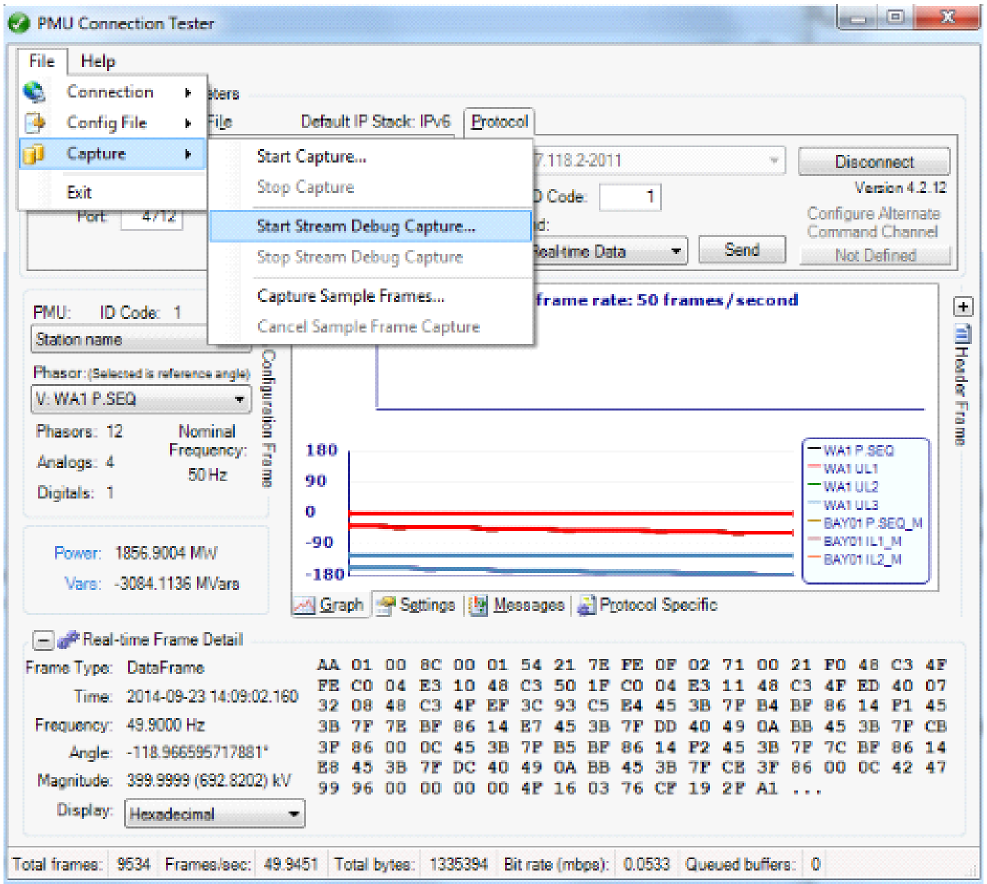

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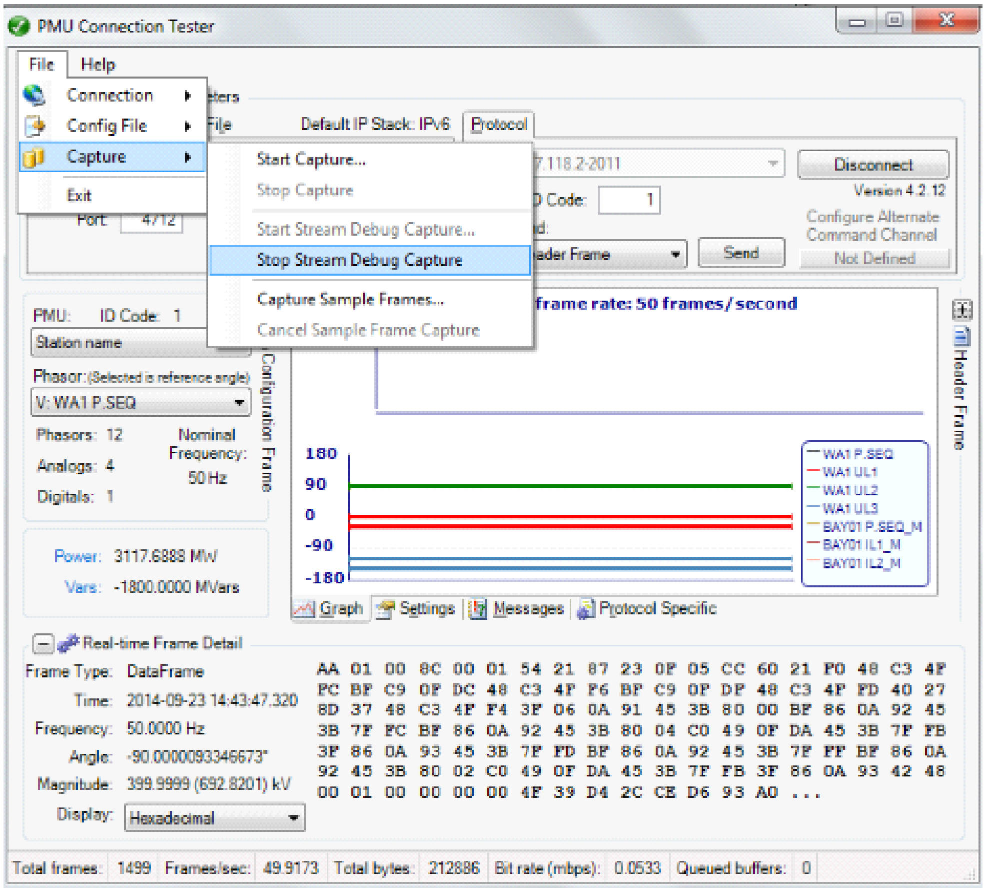
Figure 14: Start capturing the IEEE C37.118 synchrophasor data

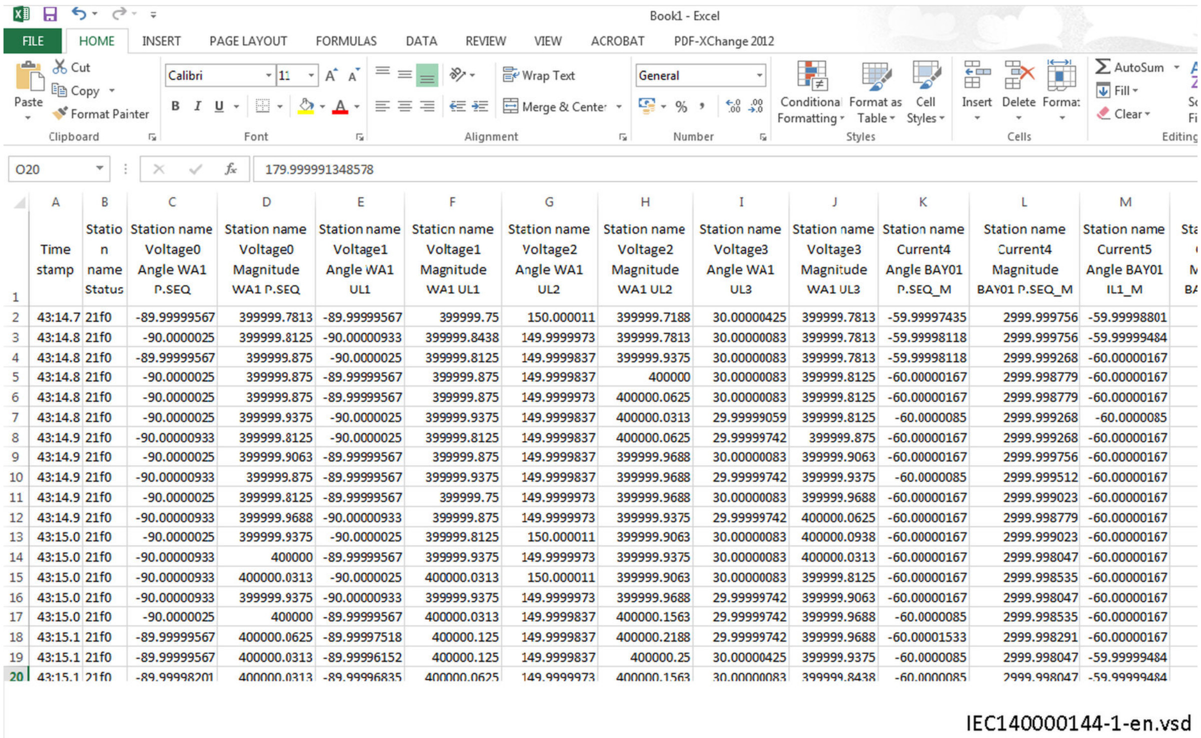
- The synchrophasor data capturing process can be stopped at any point of time by navigating to **File /Capture /Stop Stream Debug Capture...**



IEC140000143-1-en.vsd

Figure 15: Stop capturing the IEEE C37.118 synchrophasor data

- Open the capture file and observe the captured synchrophasor data. In order to get the Phasor names on top of each column (See figure 16), the capture process should start before connecting the PMU Connection Tester to the PMU, i.e. first start the capturing and then click *Connect*.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Time stamp	Station name Status	Station name Voltage0 Angle WA1 P.SEQ	Station name Voltage0 Magnitude WA1 P.SEQ	Station name Voltage1 Angle WA1 UL1	Station name Voltage1 Magnitude WA1 UL1	Station name Voltage2 Angle WA1 UL2	Station name Voltage2 Magnitude WA1 UL2	Station name Voltage3 Angle WA1 UL3	Station name Voltage3 Magnitude WA1 UL3	Station name Current4 Angle BAY01 P.SEQ_M	Station name Current4 Magnitude BAY01 P.SEQ_M	Station name Current5 Angle BAY01 IL1_M
2	43:14.7	21f0	-89.99999567	399999.7813	-89.99999567	399999.75	150.000011	399999.7188	30.00000425	399999.7813	-59.99997435	2999.999756	-59.99998801
3	43:14.8	21f0	-90.0000025	399999.8125	-90.00000933	399999.8438	149.9999973	399999.7813	30.00000083	399999.7813	-59.99998118	2999.999756	-59.99999484
4	43:14.8	21f0	-89.99999567	399999.875	-90.0000025	399999.8125	149.9999837	399999.9375	30.00000083	399999.7813	-59.99998118	2999.999268	-60.00000167
5	43:14.8	21f0	-90.0000025	399999.875	-89.99999567	399999.875	149.9999837	400000	30.00000083	399999.8125	-60.00000167	2999.998779	-60.00000167
6	43:14.8	21f0	-90.0000025	399999.875	-89.99999567	399999.875	149.9999973	400000.0625	30.00000083	399999.8125	-60.00000167	2999.998779	-60.00000167
7	43:14.8	21f0	-90.0000025	399999.9375	-90.0000025	399999.9375	149.9999837	400000.0313	29.99999059	399999.8125	-60.0000085	2999.999268	-60.0000085
8	43:14.9	21f0	-90.00000933	399999.8125	-90.0000025	399999.8125	149.9999837	400000.0625	29.99999742	399999.875	-60.00000167	2999.999268	-60.00000167
9	43:14.9	21f0	-90.0000025	399999.9063	-89.99999567	399999.875	149.9999837	399999.9688	30.00000083	399999.9063	-60.00000167	2999.999756	-60.00000167
10	43:14.9	21f0	-90.00000933	399999.875	-89.99999567	399999.9375	149.9999837	399999.9688	29.99999742	399999.9375	-60.0000085	2999.999512	-60.00000167
11	43:14.9	21f0	-90.0000025	399999.8125	-89.99999567	399999.75	149.9999973	399999.9688	30.00000083	399999.9688	-60.00000167	2999.999023	-60.00000167
12	43:14.9	21f0	-90.00000933	399999.9688	-90.00000933	399999.875	149.9999973	399999.9375	29.99999742	400000.0625	-60.00000167	2999.998779	-60.00000167
13	43:15.0	21f0	-90.0000025	399999.9375	-90.0000025	399999.8125	150.000011	399999.9063	30.00000083	400000.0938	-60.00000167	2999.999023	-60.00000167
14	43:15.0	21f0	-90.00000933	400000	-89.99999567	399999.9375	149.9999973	399999.9375	30.00000083	400000.0313	-60.00000167	2999.998047	-60.00000167
15	43:15.0	21f0	-90.00000933	400000.0313	-90.0000025	400000.0313	150.000011	399999.9063	30.00000083	399999.8125	-60.00000167	2999.998535	-60.00000167
16	43:15.0	21f0	-90.00000933	399999.9375	-90.00000933	399999.9375	149.9999973	399999.9688	29.99999742	399999.9063	-60.00000167	2999.998047	-60.00000167
17	43:15.0	21f0	-90.0000025	400000	-89.99999567	400000.0313	149.9999837	400000.1563	29.99999742	399999.9688	-60.0000085	2999.998535	-60.00000167
18	43:15.1	21f0	-89.99999567	400000.0625	-89.99997518	400000.125	149.9999837	400000.2188	29.99999742	399999.9688	-60.00001533	2999.998291	-60.00000167
19	43:15.1	21f0	-89.99999567	400000.0313	-89.99996152	400000.125	149.9999837	400000.25	30.00000425	399999.9375	-60.0000085	2999.998047	-59.99999484
20	43:15.1	21f0	-89.99998201	400000.0313	-89.99996835	400000.0625	149.9999973	400000.1563	30.00000083	399999.8438	-60.0000085	2999.998047	-59.99999484

IEC140000144-1-en.vsd

Figure 16: Captured synchrophasor data

9.5.2 Verifying the IEEE C37.118/1344 UDP communication

After setting both PMU configuration and the UDP client configuration (As explained in sections Setting the PMU station communication (PMU Report), Setting the PMU station communication (PMU configuration) and Setting the TCP/UDP client communication) and making sure that the Ethernet communication is set up, click *Connect* on the PMU Connection Tester tool.

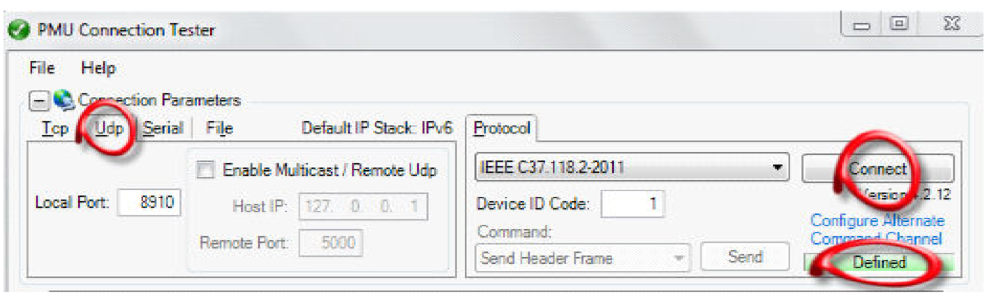


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Figure 17: Verifying the UDP communication using PMU Connection Tester

- Now it should be possible to see the streaming synchrophasor data.
- Verify the communication by following the same steps as in section Verifying the IEEE C37.118/1344 TCP communication.

9.6 Optical budget calculation for PMU - PDC communication

Most of the times, the PMU IEDs are located in the substations. A local PDC might be located in the substation. For communications within the substation or between the IED and the WAN/LAN access point, it is important to know what is the optical budget available. The graph in Figure 18 shows the dynamic range available for a PMU – PDC configuration using typical OEMs.

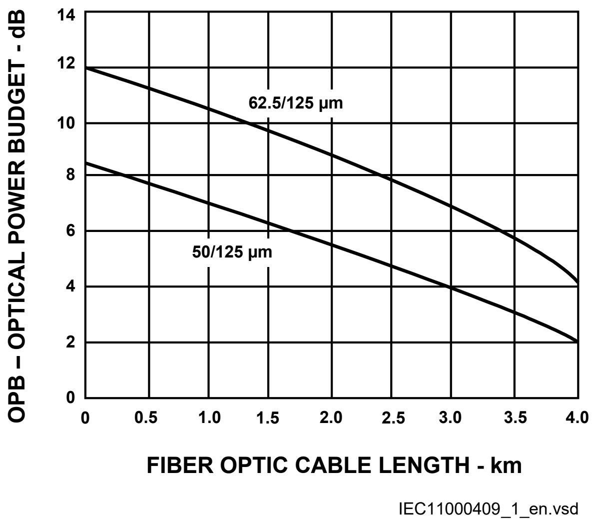

Figure 18: Optical power budget for fiber optic cable lengths

As shown in the graph, if one uses a 62.5/125 µm fiber, the value under the 62.5/125 µm curve represents the remaining optical budget at any link length, which is available for overcoming non-fiber cable related losses.

Losses in the connectors and splices are typically 0.3dB/connection. The user must reserve 3dB spare for the uncertainty of the measurements.

Section 10 Testing IED operation

10.1 Preparing for test

10.1.1 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 *Enabled*) 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 trip 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”.

If the IED is used together with a merging unit and no time synchronization is available, for example, in the laboratory test, the IED will synchronize to the SV data stream. During the re-synchronization, the protection functions will be blocked once a second for about 45 ms, and this will continue for up to 10 minutes. To avoid this, configure PTP (IEEE 1588) to *On* for the access point where the merging unit is configured.

10.1.2 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 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 pickup 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.

10.2 Activating the test mode

Put the IED into the test mode before testing. The test mode blocks almost all the protection functions (except busbar differential protections) and some of the control functions in the IED. 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 Pickup LED 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 *Enabled* 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 pickup LED above the LCD will start flashing when the IED is in test mode.

10.3 Preparing the connection to the test equipment

The IED can be equipped with a test switch of type RTXP8, RTXP18 or RTXP24 or FT. The test switch and its associated test plug handles are a part of the COMBITEST or FT systemof Hitachi Energy, 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. When FT switch is used for testing, care shall be exercised to open the tripping circuit, ahead of manipulating the CT fingers.

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.

10.4 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 19.

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 grounded before testing.

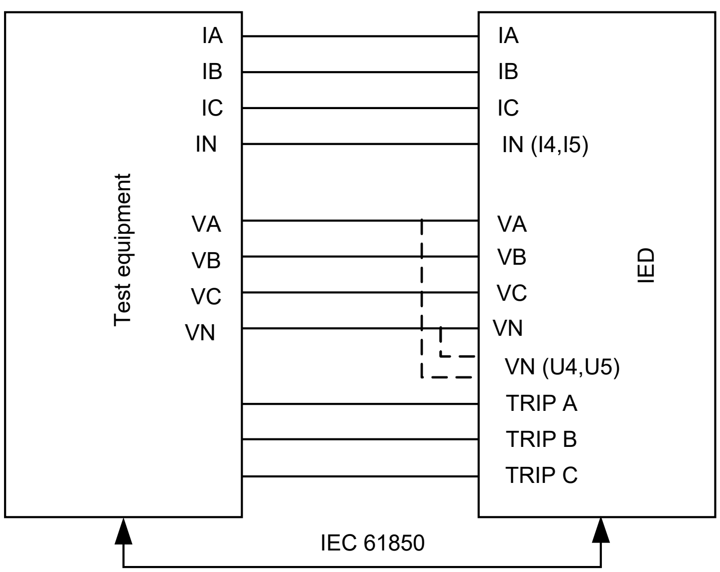

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Figure 19: Connection example of the test equipment to the IED when test equipment is connected to the transformer input module

10.5 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 *Enabled*, 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 *Enabled*, 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*.

10.6 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.

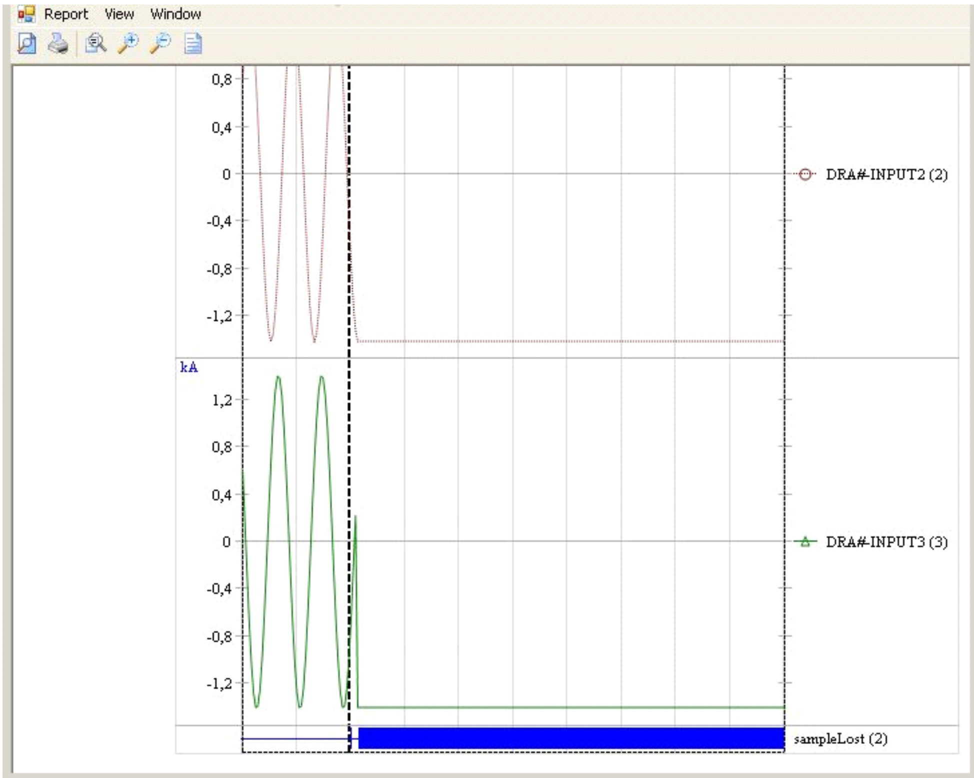
Apply input signals as needed according to the actual hardware and the application configuration.

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 disturbance report tool in PCM600 will display the current that was injected before the interruption.



IEC10000032-1-en.vsd

Figure 20: PCM600 disturbance report tool display after communication interruption

10.7 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.

10.8 Forcing of binary input/output signals for testing

10.8.1 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.

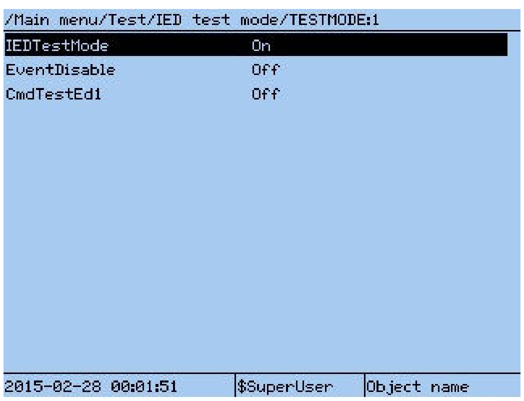
Be observant that forcing of binary inputs and outputs on an IED, with inappropriate setup, can result in potential danger.

10.8.2 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.

10.8.2.1 Enable forcing by using LHMI

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



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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.

10.8.2.2 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.

10.8.3 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.

10.8.3.1 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 21.
  2. Press the Enter key to edit the value.

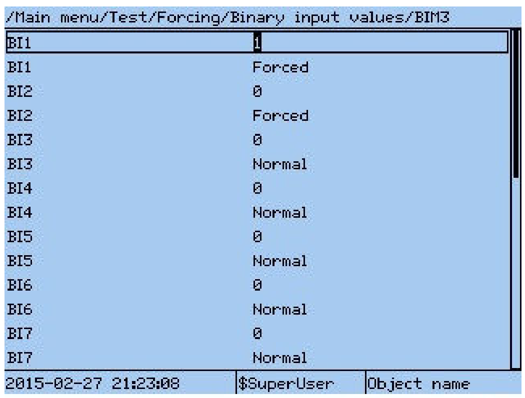

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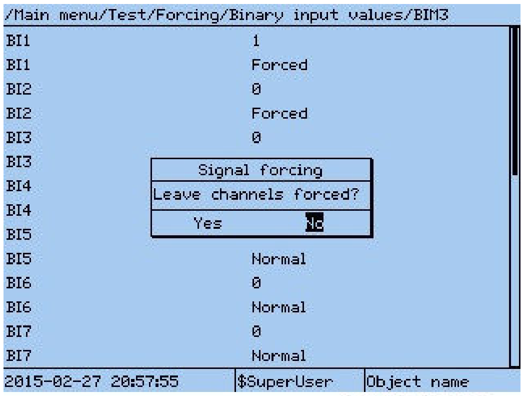
Figure 21: Value line of the desired signal

  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 22

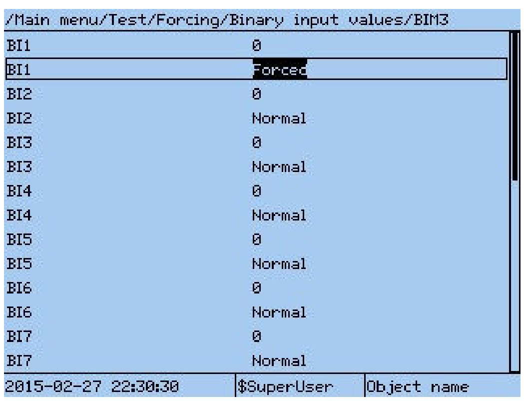


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Figure 22: Example of LHMI menu using BIM3

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.

10.8.3.2 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.

10.8.4 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.

10.8.4.1 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.

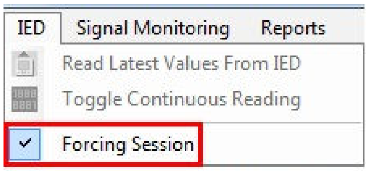
10.8.4.2 Undo forcing by using LHMI

- 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.

10.8.4.3 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 11 Testing functionality by secondary injection

11.1 Testing disturbance report

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

11.1.2 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**.

11.1.3 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*.

11.1.4 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.

11.2 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.

11.3 Impedance protection

11.3.1 Power swing detection, blocking and unblocking ZMBURPSB

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

Values of the logical signals for ZMBURPSB are available on the local HMI under **Main menu /Test/ Function status /Impedance protection/PowerSwingDetection(68,Zpsb) /ZMBURPSB(68;Zpsb):1**

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

11.3.1.1 Function revision history

Document revision	Product revision	History
A	2.2.1	-
B	2.2.1	-
C	2.2.2	-
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	Power swing unblocking feature is made available to have phase selection and thereby, releasing distance measuring loops for faults during power swing. Added new outputs FLTL1, FLTL2, FLTL3, FLT1PH, FLT2PH, FLT3PH, STCND, and RELCND. IEC 61850 LN is renamed as ZMBURPSB.
H	2.2.5	-
L	2.2.6	-
M	2.2.6	-

11.3.1.2 Verifying the signal 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.

The test is mainly divided into two parts, one aim is to verify that the settings are in accordance with the selectivity plan and another aim is to verify the operation of ZMBURPSB.

Before starting this testing process, all impedance measuring zones shall be set and in operation. Ensure that the inner zone of ZMBURPSB must cover all impedance measuring zones that are set for operation.

Test of the interactions or combinations that are not configured are not considered in this instruction.

Always set *Operation* to *On* to check the performance of power swing detection, blocking and unblocking during testing.

Testing the operating characteristics

Preconditions

The following output signals shall be configured to binary output available: *ZOUT*, measured impedance within outer impedance boundary and *ZIN*, measured impedance within inner impedance boundary.

1. Set *X1InFw*, *R1LIn*, *X1InRv*, *R1FInFw*, *R1FInRv*, *ArgLd*, *RLdOutFw*, *RLdOutRv*, *kLdRFw* and *kLdRRv* to values that are in accordance with the selectivity plan and the corresponding operating characteristic is as shown in Figure 23.
2. Set *OperationLdCh* to *On*.
3. The test points that are to be considered for the measurement accuracy of set resistive and reactive reaches for outer and inner boundaries are shown in Figure 23, Table 13 and Table 14.

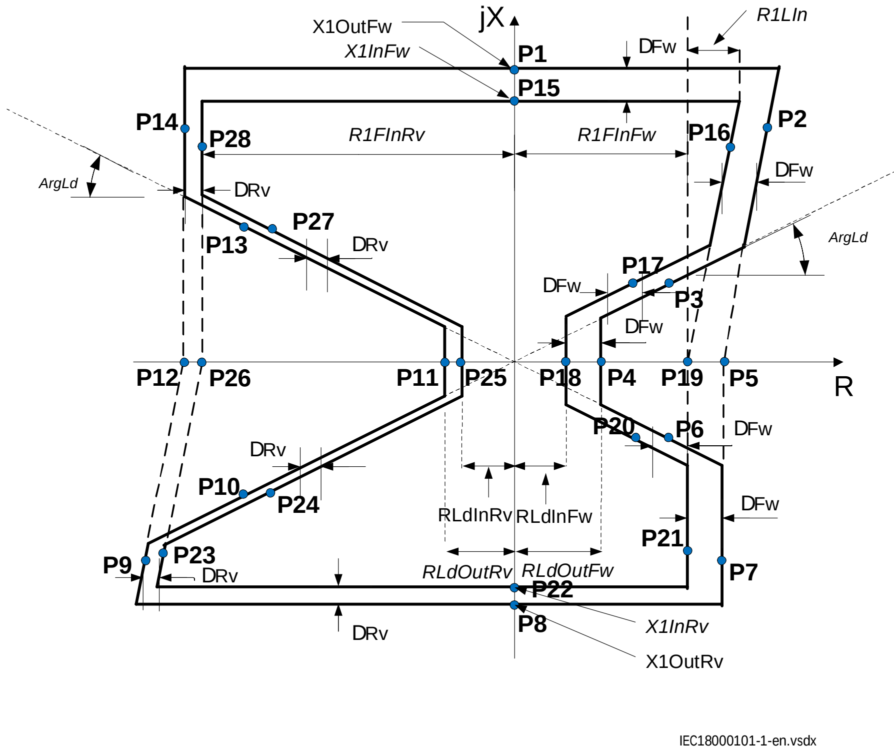


Figure 23: Proposed test points to measure the outer and inner boundaries of operating characteristics

Where,

ΔFw =	*RLdOutFw* – (*kLdRFw* **RLdOutFw*)
ΔRv =	*RLdOutRv* – (*kLdRRv* **RLdOutRv*)
RLdInFw =	*kLdRFw* * *RLdOutFw*
RLdInRv =	*kLdRFw* * *RLdOutFw*
X1OutFw =	*X1InFw* + ΔFw
X1OutRv =	*X1InRv* + ΔRv

Table 13: Testing points to measure the outer boundary

Test point	R	X	Comment
P1	0.0	*X1OutFw*	
P2	0.8 * *R1LIn* + *R1FInFw* + ΔFw	0.8 * *X1OutFw*	
P3	0.8 * (*R1FInFw* + ΔFw)	0.8 * (*R1FInFw* + ΔFw) * tan (*ArgLd*)	
P4	*RLdOutFw*	0.0	
P5	*R1FInFw* + ΔFw	0.0	If *OperationLdCh* = *Off*
Table continues on next page			

Test point	R	X	Comment
P6	0.8 * (*R1FInFw* + ∆Fw)	-0.8 * (*R1FInFw* + ∆Fw) * tan (*ArgLd*)	
P7	*R1FInFw* + ∆Fw	-0.8 * *X1OutRv*	
P8	0.0	*-X1OutRv*	
P9	-(0.8 * *R1LIn* + *R1FInRv* + ∆Rv)	-0.8 * *X1OutRv*	
P10	-0.8 * (*R1FInRv* + ∆Rv)	-0.8 * (*R1FInRv* + ∆Rv) * tan (*ArgLd*)	
P11	*-RLdOutRv*	0.0	
P12	*-R1FInRv* + ∆Rv	0.0	If *OperationLdCh = Off*
P13	-0.8 * (*R1FInRv* + ∆Rv)	0.8 * (*R1FInRv* + ∆Rv) * tan (*ArgLd*)	
P14	-(*R1FInRv* + ∆Rv)	0.8 * *X1OutFw*	

Table 14: Testing points to measure the inner boundary

Test point	R	X	Comment
P15	0.0	*X1InFw*	
P16	0.8 * *R1LIn* + *R1FInFw*	0.8 * *X1InFw*	
P17	0.8 * *R1FInFw*	(0.8 * *R1FInFw* + ∆Fw) * tan (*ArgLd*)	
P18	*RLdInFw*	0.0	
P19	*R1FInFw*	0.0	If *OperationLdCh = Off*
P20	0.8 * *R1FInFw*	-(0.8 * *R1FInFw* + ∆Fw) * tan (*ArgLd*)	
P21	*R1FInFw*	-0.8 * *X1InRv*	
P22	0.0	*-X1InRv*	
P23	-0.8 * *R1LIn* + *R1FInRv*	-0.8 * *X1InRv*	
P24	-0.8 * *R1FInRv*	-(0.8 * *-R1FInRv* + ∆Rv) * tan (*ArgLd*)	
P25	*-RLdInRv*	0.0	
P26	*-R1FInRv*	0.0	If *OperationLdCh = Off*
P27	-0.8 * *R1FInRv*	(0.8 * *-R1FInRv* + ∆Rv) * tan (*ArgLd*)	
P28	*-R1FInRv*	0.8 * *X1InFw*	

4. Change the magnitude and angle of three phase voltages to achieve the impedances at test points P1, P2,…., P28.
5. For test points P1 to P14, observe the operation value for the signal ZOUT and compare the operation value with the set value.
6. For test points P15 to P28, observe the operation value for the signal ZIN and compare the operation value with the set value.

Testing the power swing detection logic ZMBURPSB (68)

Preconditions

The following output signals shall be configured to binary outputs: ZOUT, measured impedance within outer impedance boundary and ZIN, measured impedance within inner impedance boundary and PICKUP, power swing detection.

1. Set *X1InFw*, *R1LIn*, *X1InRv*, *R1FInFw*, *R1FInRv*, *ArgLd*, *RLdOutFw*, *RLdOutRv*, *kLdRFw* and *kLdRRv* to values that are in accordance with the selectivity plan and the corresponding operating characteristic is shown in Figure 24.
2. Set *OperationLdCh* to On and set timers *tP1*, *tP2*, *tW* and *tH* to their default values.
3. Enable the input signal REL1PH to detect the power swing in one of the three phases.
4. The test points that are to be considered for the power swing detection are shown in Figure 24.

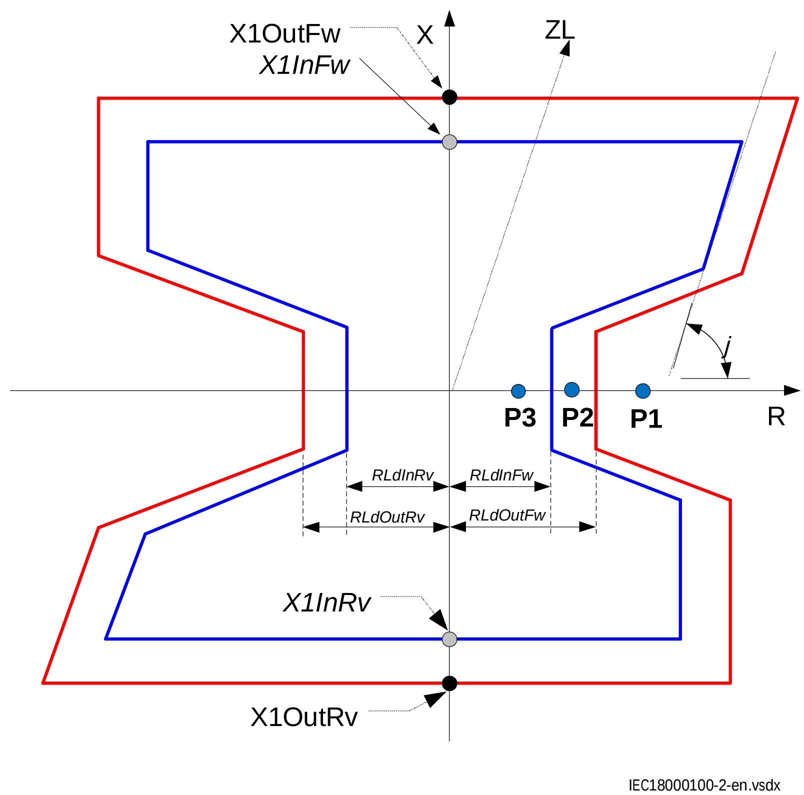


Figure 24: Proposed test points to detect power swing conditions

Where,

φ = tan^{-1} (*X1InFw*/*R1LIn*)

5. Inject voltage in one of the three phases in accordance with the test point P1 by keeping constant current in three phases throughout testing and maintaining rated voltage for the other two phases.
6. Vary the faulty phase voltage to achieve the impedance at the test point P2. At this point, observe that the output ZOUT is activated and then continue to inject for a duration greater than *tP1*.
7. Inject the faulty phase voltage to achieve the impedance at the test point P3. At this point, observe that the outputs ZIN and START are activated. It indicates that power swing has been detected.
8. Inject the faulty phase voltage in accordance with the test point P1.
9. At this condition, the outputs ZIN and ZOUT get deactivated and START signal will be maintained for a set duration of *tH*.

10. To detect consecutive power swings, repeat steps 5, 6, 7 and 8. With this condition, the output START will be activated.
11. Repeat step 6 and inject before the expiration of timer *tW*. The output ZOUT will be activated.
12. Repeat step 7 after a set duration of *tP2*. The output ZIN will be activated.
13. At this condition, it will be detected as consecutive power swing and the output signal START will be maintained.
14. Repeat step 8 and the outputs ZOUT and ZIN get deactivated. The output signal START will disappear after set duration of *tH* from the instance of step 13.
15. Repeat the above steps to test and detect power swing condition in at least two phases by enabling input REL2PH.
16. By enabling the input BLK1PH, operation mode for power swing detection in any phase will be blocked.
17. Similarly, operation mode for power swing detection in at least two phases will be blocked by enabling the input BLK2PH.
18. Repeat steps 5, 6 and 7, and enable the input signal BLOCK. At this condition, the outputs START, ZOUT and ZIN will be deactivated.
19. Output signal START will also get activated instantaneously by enabling input EXTERNAL and this input signal can be configured in ACT to the output derived from some external logics used to detect power swings. By enabling the input signal BLOCK, the output signal START will be deactivated.

Testing the inhibit logic of power swing detection function

The following output signals shall be configured to binary output available: ZOUT, measured impedance within outer impedance boundary and ZIN, measured impedance within inner impedance boundary and START, power swing detection.

1. Set *X1InFw*, *R1LIn*, *X1InRv*, *R1FInFw*, *R1FInRv*, *ArgLd*, *RLdOutFw*, *RLdOutRv*, *kLdRFw* and *kLdRRv* to values that are in accordance with the selectivity plan and the corresponding operating characteristic is shown in Figure 24.
2. Set *OperationLdCh* to On and set timers *tP1*, *tP2*, *tW*, *tH*, *tR1*, *tR2* and *tEF* to their default values.
3. Enable the input signal REL1PH to detect the power swing in one of the three phases.

Inhibit START output by the presence of residual current

Preconditions

The input signal I0CHECK, residual current (3I0) detection used to inhibit the start output, must be configured to the output signal STPE on the FDPSPDIS, FRPSPDIS, ZMFPDIS or ZMFCPDIS function.

The input signal BLKI02, block inhibit of the start output for subsequent residual current detection, is connected to FALSE.

1. Create a test sequence such that power swing has been detected, which can be done by referring to steps 5, 6 and 7 described in section Testing the power swing detection logic ZMBURPSB and

inject voltage in one of the phases accordingly by keeping constant current in all three phases. With this condition, the output signal START will be activated.

2. Create a condition such that residual current is measured (that is, earth fault occurs in the power system) and its value should be above the value seen during unbalanced loading condition. It can be done by increasing current in one of the phases without disturbing healthy phase currents.
3. With this condition, I0CHECK connected to STPE output of FDPSPDIS, FRPSPDIS, ZMFPDIS or ZMFCPDIS function, will be activated and I0CHECK should be activated before the expiration of timer tR1.
4. By doing this, the output START will be disappeared after a set time delay of *tR1*.
5. If required to block inhibit of start output by the presence of residual current, BLKI02 must be configured to TRUE and thereby, the output signal START will be maintained as long as the power swing condition exists.

Inhibit START output by the presence of slow power swings

Preconditions

The input signal BLKI01, block inhibit of the start output for slow power swings is connected to FALSE.

1. Create a test sequence such that the power swing should be detected . This can be done by referring to steps 5, 6, and 7 described in section Testing the power swing detection logic ZMBURPSB and inject voltage in one of the phases accordingly by keeping constant current in all three phases. With this condition, the output signal START will be activated.
2. After expiration of the set time delay by a timer *tR2*, the output START will disappear.
3. If required to block inhibit of start output by the presence of slow power swings, BLKI01 must be configured to TRUE. Thereby, the output signal START will be maintained as long as the power swing condition exists.

Inhibit START output by the single pole reclosing

Preconditions

The input signal I0CHECK, residual current (3I0) detection used to inhibit the start output, must be configured to the output signal STPE on the FDPSPDIS, FRPSPDIS, ZMFPDIS or ZMFCPDIS function.

The input signal BLKI02, block inhibit of the start output for subsequent residual current detection and BLKI01, block inhibit of the start output for slow power swings must be connected to TRUE.

1. Create a phase-to-earth fault such that the input signal I0CHECK will be activated and a trip signal from any impedance protection function will be generated.
2. With this condition, the input signal TRSP connected to a tripping function is activated.
3. Clear the fault by injecting zero current magnitude in the fault phase and maintain healthy conditions in other phases. With this, I0CHECK and TRSP will be deactivated.
4. Make a test sequence to create power swing condition in healthy phases in accordance with steps 5, 6, and 7 described in section Testing the power swing detection logic ZMBURPSB (68). With this condition, the output signal START will be activated.
5. Repeat step 1 to create phase-to-earth fault and thereby, I0CHECK will be activated again.
6. Steps 4 and 5 must be performed before the expiration of set time delay of *tEF*. There may exist a two phase power swing during single pole autoreclosing time and then switched-on-to the persistent phase-to-earth fault after single pole autoreclosing time.
7. By doing this, the output signal START will be inhibited.
8. If I0CHECK appears the expiration of a timer *tEF*, the condition will be seen as power swing and thereby, the output signal START will be maintained as long as the power swing exists in the power system.

Testing the power swing unblocking logic
Preconditions

The following output signals shall be configured to binary outputs: FLTL1, FLTL2, FLTL3, FLT1PH, FLT2PH, FLT3PH and START.

Ensure that the setting *OpModePSU* is set to *On*.

1. Inject rated currents and voltages in all three phases. The service values IL1, IL2, IL3 and UL1, UL2, UL3 can be monitored in the local HMI.
2. Create a test sequence such that power swing has been detected, which can be done by referring to steps 5, 6 and 7 described in section Testing the power swing detection logic ZMBURPSB and inject voltage in one of the phases accordingly by keeping constant current in all three phases. With this condition, the output signal START will be activated.
3. Create a phase-earth fault condition by simultaneously reducing the voltage and increasing the current in phase L1. Ensure that the residual current (3I0) is above 20% IB and the negative sequence current (I2) is above 12% IB. At this condition, the outputs FLTL1 and FLT1PH will be activated. The service values STCND and RELCND will show the value as 1.
4. Repeat the above steps by creating fault in L2 and L3 phases. The outputs FLTL2, FLT1PH and FLTL3, FLT1PH will be activated for L2 and L3 faults respectively. The service values STCND and RELCND will show the values 2 and 4 for L2 and L3 faults respectively.
5. Create a power swing condition by repeating Step 2 and create a phase-phase fault condition by simultaneously reducing the voltages and increasing the currents in phases L1 and L2. Ensure that the negative sequence current (I2) is above 12% IB. At this condition, the outputs FLTL1, FLTL2 and FLT2PH will be activated. The service values STCND and RELCND will show the value as 8.
6. Repeat Step 5 by creating faults between phases L2 and L3 and between L3 and L1. The outputs FLTL2, FLTL3, FLT2PH and FLTL3, FLTL1, FLT2PH will be activated for L2L3 and L3L1 faults respectively. The service values STCND and RELCND will show the values 16 and 32 for L2L3 and L3L1 faults respectively.
7. Create a power swing condition by repeating Step 2 and create a 3-Phase fault condition by simultaneously reducing the voltages and increasing the currents in all three phases. At this condition, the outputs FLTL1, FLTL2, FLTL3 and FLT3PH will be activated. The service values STCND and RELCND will show the value as 56.

11.3.1.3 Completing the test

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

11.3.2 Out-of-step protection OOSPPAM

The out-of-step protection (OOSPPAM (78)) function in the IED can be used for both generator protection and as well for line protection applications.

The main purpose of the OOSPPAM (78) function is to detect, evaluate, and take the required action during pole slipping occurrences in the power system.

The OOSPPAM (78) function detects pole slip conditions and trips the generator as fast as possible, after the first pole-slip if the center of oscillation is found to be in zone 1, which normally includes the generator and its step-up power transformer. If the center of oscillation is found to be further out in the power system, in zone 2, more than one pole-slip is usually allowed before the generator-transformer unit is disconnected. A parameter setting is available to take into account the circuit breaker opening time. If there are several out-of-step relays in the power system, then the one which finds the center of oscillation in its zone 1 should operate first.

Two current channels I3P1 and I3P2 are available in OOSPPAM function to allow the direct connection of two groups of three-phase currents; that may be needed for very powerful generators, with stator windings split into two groups per phase, when each group is equipped with current transformers. The protection function performs a simple summation of the currents of the two channels I3P1 and I3P2.

11.3.2.1 Verifying the settings

The test of the out-of-step protection function is made to verify that the trip is issued if the following events happen.

- the impedance, seen by the function, enters the lens characteristic from one side and leaves it from the opposite side
- the trip is issued according to the settings *TripAngle* and *tBreaker*

The tripping zone needs to be detected and confirmed. The test may be performed by taking into account the following key points that are shown in Figure 25:

- the point RE (RE = Receiving End)
- the intersection between the line segment SE-RE and the X-line, which is defined through the setting *ReachZ1*
- the point SE (SE = Sending End)

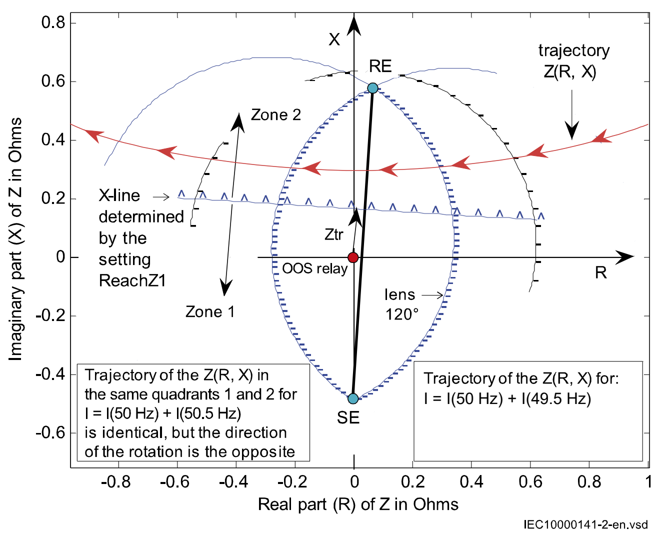


Figure 25: Trajectory of the impedance Z(R, X) for the injected current with two components: a 50 Hz component and a 49.5 Hz current component

The test of the out-of-step protection function requires the injection of the analog quantities for a quite long time. The rating of the analogue channels must be considered in order to avoid any hardware damage. The test current is lower than the continuous permissive overload current I_{ovrl} of the protection current channels of the transformer module.

If the rated secondary current I_{rs} of the analog channel is 1 A, then the maximum current test I_{ts} is

$$I_{ts} \leq I_{ovrl} = 4 \times I_{rs} = 4A$$

(Equation 1)

If the CT of the generator has ratio 9000/1 A, then in primary values

$$I_t \leq I_{ovrl,p} = I_{ovrl} \times \frac{I_{rp}}{I_{rs}} = 4 \times \frac{9000}{1} = 36000A$$

(Equation 2)

Reference is made to the numerical values of the example, explained in the “Setting guidelines” of the *Application Manual*. A test current equal to 2.5 time the base current of the generator is chosen; this choice is related to the selected test voltage that is applied while testing the point SE and RE.

$$I_t = 2.5 \times I_{Base} = 2.5 \times 8367 = 20918A$$

(Equation 3)

The parameter *ReachZ1* defines the boundary between zone 1 and zone 2; it is expressed in percent of the parameter *ForwardX*. If the setting of *ReachZ1 = 12%*, then corresponding primary value of the reactance is

$$X_{RZ1} = \frac{ReachZ1}{100} \times \frac{ForwardX}{100} \times ZBase = \frac{12}{100} \times \frac{59.33}{100} \times 0.9522 = 0.068\Omega$$

(Equation 4)

The calculation of the test voltage, that is related to *ReachZ1*, is based on the impedance Z_{RZ1} that has imaginary part X_{RZ1} and real part R_{RZ1} :

$$RRZ1 = \frac{ReachZ1}{100} \times \frac{ForwardR}{100} \times ZBase = \frac{12}{100} \times \frac{8.19}{100} \times 0.9522 = 0.009\Omega$$

(Equation 5)

The magnitude of the impedance Z_{RZ1} is:

$$Z_{RZ1} = \sqrt{R_{RZ1}^2 + X_{RZ1}^2} = \sqrt{0.009^2 + 0.068^2} = 0.069\ \Omega$$

(Equation 6)

Hence the reference voltage of the test of the boundary between zone 1 and zone 2 is

$$V_{t,RZ1} = Z_{RZ1} \times I_t = 0.069 \times 20918 = 1435V$$

(Equation 7)

If the test voltage is lower than $V_{t,RZ1}$ (or in opposition), then the test is related to the zone 1; if the test voltage is higher than $V_{t,RZ1}$, then the test is related to the zone 2.

Considering the resistances and reactances which are related to the settings (*ForwardR*, *ForwardX*) and (*ReverseR*, *ReverseX*):

$$R_{FwdR} = \frac{ForwardR}{100} \times ZBase = \frac{8.19}{100} \times 0.9522 = 0.078\Omega$$

(Equation 8)

$$X_{FwdX} = \frac{ForwardX}{100} \times ZBase = \frac{59.33}{100} \times 0.9522 = 0.565\Omega$$

(Equation 9)

$$R_{RvsR} = \frac{ReverseR}{100} \times ZBase = \frac{0.29}{100} \times 0.9522 = 0.003\Omega$$

(Equation 10)

$$X_{RvsX} = \frac{ReverseR}{100} \times ZBase = \frac{29.6}{100} \times 0.9522 = 0.282\,\Omega$$

(Equation 11)

and the voltages that are related to them:

$$V_{t,FwdZ} = Z_{FwdZ} \times I_t = \sqrt{R^2{}_{FwdR} + X^2{}_{FwdX}} \times I_t = \sqrt{0.078^2 + 0.565^2} \times 20918 = 0.570 \times 20918 = 11931V$$

(Equation 12)

$$V_{t,RvsZ} = Z_{RvsZ} \times I_t = \sqrt{R^2{}_{RvsR} + X^2{}_{RvsX}} \times I_t = \sqrt{0.003^2 + 0.282^2} \times 20918 = 0.282 \times 20918 = 5899V$$

(Equation 13)

The previous calculations are in primary values. They are transferred to secondary values to perform injections by a test set. Primary values are transferred to secondary values by taking into account the CT ratio and the VT ratio (respectively 9000/1 A and 13.8/0.1 kV in the example).

The magnitude of the secondary voltages, that are related to the points RE and SE of the R-X plane, needs to be checked.

RE (R_{FwdR}, X_{FwdX}):

$$V_{t,FwdZs} = V_{t,FwdZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 11931 \times \frac{0.1}{13.8} = 86.45V$$

(Equation 14)

SE (R_{RvsR}, X_{RvsX}):

$$V_{t,RvsZs} = V_{t,RvsZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 5899 \times \frac{0.1}{13.8} = 42.75V$$

(Equation 15)

The tests, which are described in this section, may require voltages that have magnitude equal to 110% of the previous values. The continuous permissive overload voltage of the protection voltage channels of the TRM module is 420 V; so the previous voltages may be applied to the analog channels of the IED continuously. Limitations may be related to the available test set; the current I_t was calculated by using a factor 2.5 (instead of the maximum value 4) in order to reduce the magnitude of the test voltage for the points RE and SE.

Test sets usually do not have a feature to simulate a real network during a power swing and apply the related analog quantities at the terminal of the generator. The scope of the present test is not a simulation of a real network. Voltages and currents are supplied in order to measure an impedance that changes in the time and traverses the plane R-X and, in particular, the area inside the lens characteristic. The test may be performed by applying:

- Symmetric three-phase voltage at 50 Hz. The magnitude depends on the point of the characteristic that needs to be verified. The following three main points of the line segment SE-RE need to be checked:
  - the point RE (R_{FwdR}, X_{FwdX})
  - a point which is related to the parameter *ReachZ1* (boundary between zone 1 and zone 2)
  - the point SE (R_{RvsR}, X_{RvsX})

The phase angle of the test voltages is equal to:

- arctan (*ForwardX*/*ForwardR*) for tests in the quadrant 1 and 2 of the R-X plane
- arctan (*ReverseX*/*ReverseR*) -180° for tests in the quadrant 3 and 4 of the R-X plane

- Symmetric three-phase current, where the current is the summation of two currents that have the same magnitude, but different frequencies.

$$I_{50} = I_{tf} = \frac{I_t}{2} = \frac{20918}{2} = 10459A$$

(Equation 16)

The first current I_{50} has frequency 50 Hz, magnitude 10459 A (that is, 1.162 A secondary) and phase angle 0º.
The second current I_{tf} has magnitude 10459 A (that is, 1.162 A secondary), phase angle 180º (at the starting time of the test) and frequency:

- 49.5 Hz for the test as generator in the quadrant 1 and 2 of the R-X plane
- 50.5 Hz for the test as generator in the quadrant 3 and 4 of the R-X plane

When the trajectory of the impedance, that is seen by the protection function, traverses the lens characteristic then a pole slipping is detected. The present procedure avoids tests of points of the line SE-RE that are too close to the R-axis because in that case the voltage is close to zero and, therefore, the impedance may approach a non-defined quantity 0/0.

The accuracy of the impedance reach is ±2% of the base impedance; that is considered while evaluating the test results.

For the test as motor the frequency current may have 50.5 Hz in the quadrant 1 and 2 of the R-X plane and 49.5 Hz in the quadrant 3 and 4.

Verifying the settings by secondary injection

It is advised to connect the analog output channels of the function block OOSPPAM to the internal disturbance recorder (and in particular to the function block A4RADR) in order to perform a better analysis of the tests.

If the device is in test mode, the recording of the disturbances are enabled by the setting in **Main menu / Settings /IED Settings /Monitoring /Disturbance report /DisturbanceReport /DRPRDRE:1:** set the parameter *OpModeTest* to *On*.

1. Check the Application Configuration: verify that hardware voltage and current channels of the IED are properly connected to SMAI function blocks, and that the proper analog outputs of SMAI's are connected to the analog inputs of the function block OOSPPAM.
2. Connect three-phase voltage channels of the test set to the appropriate IED terminals.
3. Connect in parallel two groups of three-phase currents of the test set to the appropriate IED terminals.
4. Connect the appropriate trip output of the IED to the input channel of the test set that monitors the trip.
5. Go to **Main menu /Settings /IED Settings /Impedance protection /OutOfStep(78,Ucos) / OOSPPAM(78,Ucos):1** , and make sure that the function is enabled, that is, *Operation* is set to *On*.

11.3.2.2 Test of point RE (R_{FwdR}, X_{FwdX})

The trajectory of the impedance does not enter the lens characteristic.

Preliminary steady state test at 50 Hz

- Go to **Main menu /Test /Function status /Impedance protection /OutOfStep(78,Ucos) / OOSPPAM(78,Ucos):1 /Outputs** to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 1.1 \times V_{t,FwdZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1V$$

(Equation 17)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 18)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 19)

$\angle I_{50s}$=0°
frequency of I_{50s} = 50 Hz

$$It_{fs} = Itf \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 20)

$\angle I_{tfs}$=0°
frequency of I_{tfs} = 50 Hz

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to 0 rad.
  For this particular injection the service values are:
  - VOLTAGE = 13.12 kV
  - CURRENT = 20918 A
  - R = 9.01%
  - X = 65.27%
  - ROTORANG = 0.04 rad

Note that these values identify a point outside the lens characteristic, even if it is close to the point RE. Neither START nor TRIP is issued.

Execution of the dynamic test
The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.
  Steady voltage and current are applied in order to get a steady high impedance. This is a point in the plane R-X that is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 1.1 \times V_{t,FwdZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1V$$

(Equation 21)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 22)

frequency of V_{ts} = 50 Hz
I_{50s}=0 A
I_{tfs}=0 A

- State 2: main test step.
  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 1.1 \times V_{t,FwdZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1V$$

(Equation 23)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 24)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 25)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = Itf \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 26)

$\angle I_{tfs}$ = 180º
frequency of I_{tfs} = 49.5 Hz

Expected result: the protection function does not issue either start or trip.

The trajectory of the impedance traverses the lens characteristic in zone 2

Preliminary steady state test at 50 Hz

- Go to **Main menu /Test /Function status /Impedance protection /OutOfStep(78,Ucos) / OOSPPAM(78,Ucos):1 /Outputs** to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 0.9 \times V_{t,FwdZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81V$$

(Equation 27)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 28)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 29)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = It_f \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 30)

$\angle I_{tfs}$ = 0º
frequency of I_{tf} = 50 Hz

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to 3.14 rad. For this particular injection the service values are:
  - VOLTAGE = 10.74 kV
  - CURRENT = 20918 A
  - R = 7.37%
  - X = 53.40%
  - ROTORANG = -3.09 rad

  Note that these values identify a point inside the lens characteristic, in the zone 2, that is close to the point RE. The START is issued, but no TRIP is performed.

Execution of the dynamic test
The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.
  Steady voltage and current are applied in order to get a steady high impedance, that is, a point in the plane R-X which is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 0.9 \times V_{t,FwdZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81V$$

(Equation 31)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 32)

frequency of V_{ts} = 50 Hz
I_{50s} = 0 A
I_{tfs} = 0 A

- State 2: main test step.
  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 0.9 \times V_{t,FwdZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81V$$

(Equation 33)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 34)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 35)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = Itf \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 36)

$\angle I_{tfs}$ = 180º
frequency of I_{tfs} = 49.5 Hz

Expected result: start of the protection function and trip in zone 2, when trip conditions are fulfilled.

11.3.2.3 Test of the boundary between zone 1 and zone 2, which is defined by the parameter *ReachZ1*

The trajectory of the impedance traverses the lens characteristic in zone 2

Preliminary steady state test at 50 Hz

- Go to **Main menu /Test /Function status /Impedance protection /OutOfStep(78,Ucos) / OOSPPAM(78,Ucos):1 /Outputs** to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 1.1 \times V_{t,RZ1} \times \frac{V_{VT,s}}{V_{VT,p}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44V$$

(Equation 37)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 38)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 39)

$\angle I_{50s}$ = 0º

frequency of I_{50s} = 50 Hz

$$It_{fs} = Itf \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 40)

$\angle I_{tfs}$ = 0º
frequency of I_{tfs} = 50 Hz

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to 3.14 rad. For this particular injection the service values are:
  - VOLTAGE = 1.58 kV
  - CURRENT = 20918 A
  - R = 1.08%
  - X = 7.85%
  - ROTORANG = -3.04 rad

Note that these values identify a point inside the lens characteristic, in the Zone 2, that is close to the boundary between zone 1 and zone 2. The START is issued, but no TRIP is performed.

Execution of the dynamic test
The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.
  Steady voltage and current are applied in order to get a steady high impedance, that is a point in the plane R-X that is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 1.1 \times V_{t,RZ1} \times \frac{V_{VT,s}}{V_{VT,p}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44V$$

(Equation 41)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 42)

frequency of V_t= 50 Hz.
I_{50s} = 0 A
I_{tfs} = 0 A

- State 2: main test step.
  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 1.1 \times V_{t,RZ1} \times \frac{V_{VT,s}}{V_{VT,p}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44V$$

(Equation 43)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 44)

frequency of V_t = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 45)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = Itf \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 46)

$\angle I_{tfs}$ = 180º
frequency of I_{tfs} = 49.5 Hz

Expected result: start of the protection function and trip in zone 2 when trip conditions are fulfilled.

The trajectory of the impedance traverses the lens characteristic in zone 1

Preliminary steady state test at 50 Hz

- Go to **Main menu /Test /Function status /Impedance protection /OutOfStep(78,Ucos) / OOSPPAM(78,Ucos):1 /Outputs** to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 0.9 \times V_{t,RZ1} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36V$$

(Equation 47)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 48)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 49)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = Itf \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 50)

$\angle I_{tfs}$ = 0º
frequency of I_{tf} = 50 Hz

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to 3.14 rad. For this particular injection the service values are:

- VOLTAGE = 1.29 kV
- CURRENT = 20918 A
- R = 0.89%
- X=6.42%
- ROTORANG = -3.04 rad

Note that these values identify a point inside the lens characteristic in zone 1, that is close to the boundary between zone 1 and zone 2. The START is issued, but no TRIP is performed.

Execution of the dynamic test

The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.
  Steady voltage and current are applied in order to get a steady high impedance, that is a point in the plane R-X which is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 0.9 \times V_{t,RZ1} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36V$$

(Equation 51)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 52)

frequency of V_{ts} = 50 Hz
I_{50s} = 0 A
I_{tfs} = 0 A

- State 2: main test step.
  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 0.9 \times V_{t,RZ1} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36V$$

(Equation 53)

$$\angle V_{ts} = \arctan\left(\frac{ForwardX}{ForwardR}\right) = \arctan\left(\frac{59.33}{8.19}\right) = 82.14°$$

(Equation 54)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 55)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = It\!f \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 56)

$\angle I_{tfs}$ = 180º
frequency of I_{tfs} = 49.5 Hz

Expected result: start of the protection function and trip in zone 1 when trip conditions are fulfilled.

11.3.2.4 Test of the point SE (R_{RvsR}, X_{RvsX})

The trajectory of the impedance traverses the lens characteristic in zone 1

Preliminary steady state test at 50 Hz

- Go to **Main menu /Test /Function status /Impedance protection /OutOfStep(78,Ucos) / OOSPPAM(78,Ucos):1 /Outputs** to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 0.9 \times V_{t,RvsZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V$$

(Equation 57)

$$\angle V_{ts} = \arctan\left(\frac{ReverseX}{ReverseR}\right) - 180° = \arctan\left(\frac{29.60}{0.29}\right) - 180° = -90.56°$$

(Equation 58)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 59)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = Itf \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 60)

$\angle I_{tfs}$ = 0º
frequency of I_{tf} = 50 Hz

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to 3.14 rad. For this particular injection the service values are:
  - VOLTAGE = 5.31 kV
  - CURRENT = 20918 A
  - R = -0.26%
  - X = -26.65%
  - ROTORANG = -3.06 rad

  Note that these values identify a point inside the lens characteristic in zone 1 that is close to the point SE. The START is issued, but no TRIP is performed.

Execution of the dynamic test
The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.

Steady voltage and current are applied in order to get a steady high impedance, that is a point in the plane R-X which is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 0.9 \times V_{t,RvsZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V$$

(Equation 61)

$$\angle V_{ts} = \arctan\left(\frac{ReverseX}{ReverseR}\right) - 180° = \arctan\left(\frac{29.60}{0.29}\right) - 180° = -90.56°$$

(Equation 62)

frequency of V_{ts} = 50 Hz
I_{50s} = 0 A
I_{tfs} = 0 A

- State 2: main test step.
  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 0.9 \times V_{t,RvsZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V$$

(Equation 63)

$$\angle V_{ts} = \arctan\left(\frac{ReverseX}{ReverseR}\right) - 180° = \arctan\left(\frac{29.60}{0.29}\right) - 180° = -90.56°$$

(Equation 64)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 65)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = Itf \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 66)

$\angle I_{tfs}$ = 180º
frequency of I_{tfs} = 50.5 Hz

Expected result: start of the protection function and trip in zone 1 when trip conditions are fulfilled.

The trajectory of the impedance does not enter the lens characteristic

Preliminary steady state test at 50 Hz

- Go to **Main menu /Test /Function status /Impedance protection /OutOfStep(78,Ucos) / OOSPPAM(78,Ucos):1 /Outputs** to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 1.1 \times V_{t,RvsZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02V$$

(Equation 67)

$$\angle V_{ts} = \arctan\left(\frac{ReverseX}{ReverseR}\right) - 180° = \arctan\left(\frac{29.60}{0.29}\right) - 180° = -90.56°$$

(Equation 68)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 69)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = It\!f \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 70)

$\angle I_{tfs}$ = 0º
frequency of I_{tf} = 50 Hz

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to 0 rad. For this particular injection the service values are:
  - VOLTAGE= 6.49 kV
  - CURRENT= 20918 A
  - R= –0.32%
  - X=–32.57%
  - ROTORANG= 0.08 rad

  Note that these values identify a point outside the lens characteristic, even if it is close to the point SE. Neither START nor TRIP is issued.

Execution of the dynamic test
The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.
  Steady voltage and current are applied in order to get a steady high impedance, that is, a point in the plane R-X which is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 1.1 \times V_{t,RvsZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02V$$

(Equation 71)

$$\angle V_{ts} = \arctan\left(\frac{ReverseX}{ReverseR}\right) - 180° = \arctan\left(\frac{29.60}{0.29}\right) - 180° = -90.56°$$

(Equation 72)

frequency of V_{ts} = 50 Hz
I_{50s} = 0 A

I_{tfs} = 0 A

- State 2: main test step.
  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

$$V_{ts} = 1.1 \times V_{t,RvsZ} \times \frac{V_{VT,s}}{V_{VT,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02V$$

(Equation 73)

$$\angle V_{ts} = \arctan\left(\frac{ReverseX}{ReverseR}\right) - 180° = \arctan\left(\frac{29.60}{0.29}\right) - 180° = -90.56°$$

(Equation 74)

frequency of V_{ts} = 50 Hz

$$I_{50s} = I_{50} \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162\,A$$

(Equation 75)

$\angle I_{50s}$ = 0º
frequency of I_{50s} = 50 Hz

$$It_{fs} = Itf \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162A$$

(Equation 76)

$\angle I_{tfs}$ = 180º
frequency of I_{tfs} = 50.5 Hz

Expected result: the protection function does not issue either start or trip.

After each test it is possible to download and study the related disturbance recording.

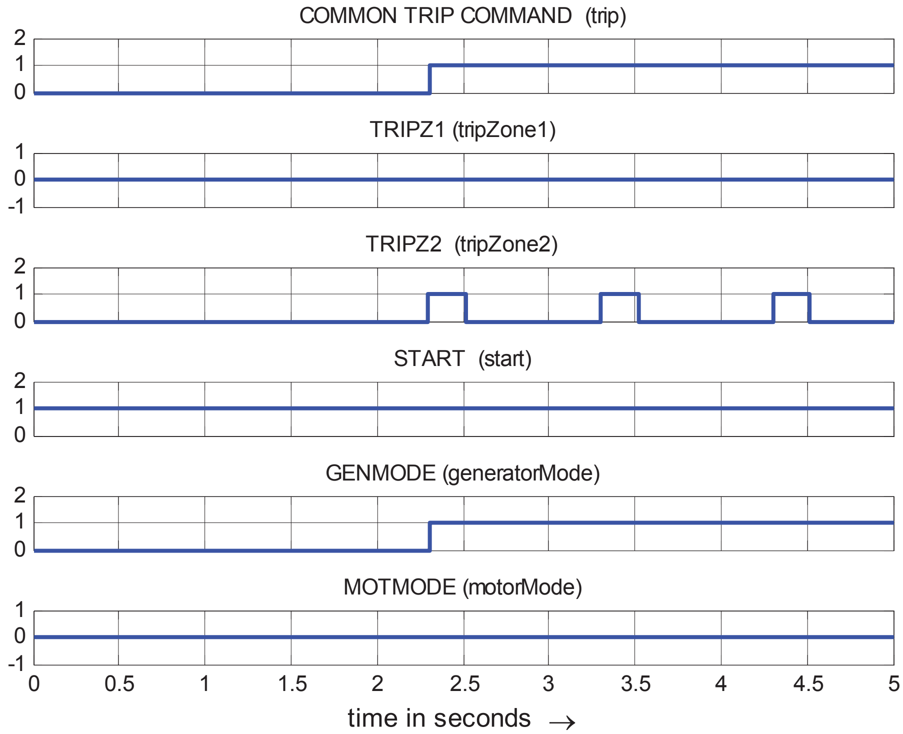


Figure 26: Boolean output signals for the injected current with two components: a 50 Hz current component and a 49.5 Hz current component

11.4 Current protection

11.4.1 Directional phase overcurrent protection, four steps OC4PTOC (51_67)

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

Values of the logical signals for OC4PTOC are available on the local HMI under **Main menu/Tests/ Function status/Current protection/PhaseOverCurrent4Step(51_67,4(3I>)) / OC4PTOC(51_67;4(3I>)):x**, where x = instance number.

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

11.4.1.1 Function revision history

Document revision	Product revision	History
A	2.2.1	-
B	2.2.1	-
C	2.2.2	-
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	-
H	2.2.4	-
J	2.2.5	• The harmonic restraint function changed to freeze the definite and IDMT timers. • The maximum value of the settings *IMin1*, *IMin2*, *IMin3* and *IMin4* has been decreased to 1000.0 % of IBase.
L	2.2.6	-
M	2.2.6	Minimum value changed to 0.01 for k1,k2,k3 and k4 settings

11.4.1.2 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 four available overcurrent steps, make sure that the step under test is enabled (for example, end fault protection).
   If *1 out of 3* currents are chosen for operation: Connect the injection current to phases A and neutral.
   If *2 out of 3* currents are chosen for operation: Connect the injection current into phase A and out from phase B.
   If *3 out of 3* currents are chosen for operation: Connect the symmetrical three-phase injection current into phases A, B and C.
2. Connect the test set for the appropriate three-phase voltage injection to the IED phases A, B and C. The protection shall be fed with a symmetrical three-phase voltage.
3. Block higher set stages when testing lower set stages by following the procedure described below:
   3.1. Set the injected polarizing voltage larger than the set minimum polarizing voltage (default is 5% of *VBase*) and set the injection current to lag the appropriate voltage by an angle of about 80° if forward directional function is selected.
   If *1 out of 3* currents are chosen for operation: The voltage angle of phase A is the reference.
   If *2 out of 3* currents are chosen for operation: The phase angle of the phase-to-phase voltage AB is the reference for APhase.
   If *3 out of 3* currents are chosen for operation: The voltage angle of phase A is the reference.
   If reverse directional function is selected, set the injection current to lag the polarizing voltage by an angle equal to 260° (equal to 80° + 180°).
   3.2. Increase the injected current, note the trip 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. If the test has been performed by injection of current in phase A, repeat the test, injecting current into phases B and C with polarizing voltage connected to phases B, respectively C (*1 out of 3* currents for operation).
5. If the test has been performed by injection of current in phases AB, repeat the test, injecting current into phases BC and CA with the appropriate phase angle of injected currents.
6. Connect a trip output contact to a timer.
7. Set the injected current to 200% of the trip level of the tested stage, switch on the current and check the time delay.
   For inverse time curves, check the trip time at a current equal to 110% of the trip current for *txMin*.
8. Check that all trip and pickup contacts trip according to the configuration (signal matrixes).
9. Reverse the direction of the injected current and check that the protection does not trip.
10. If *2 out of 3* or *3 out of 3* currents are chosen for operation: Check that the function will not trip with current in one phase only.
11. Repeat the above described tests for the higher set stages.
12. Check that pickup and trip information is stored in the event menu .

11.4.1.3 Completing the test

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

11.4.2 Four step residual overcurrent protection, (Zero sequence or negative sequence directionality) EF4PTOC (51N/67N)

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/Test/ Function status /Current protection/ResidualOverCurr4Step(51N_67N,4(IN>)) / EF4PTOC(51N_67N;4(IN>)):x**, where x = instance number.

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

11.4.2.1 Function revision history

Document revision	Product revision	History
A	2.2.1	-
B	2.2.1	-
C	2.2.2	Technical data table updated with note “Operate time and reset time are only valid if harmonic blocking is turned off for a step”.
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	-
H	2.2.4	The phase selection logic is added to allow phase segregated trip. The new phase selections outputs added to this release are PHSELL1, PHSELL2 and PHSELL3. The setting *EnPhaseSel* is added to enable or disable phase selection. The maximum value changed to 2000.0 % of IBase for *IMin1, IMin2, IMin3* and *IMin4* settings.
Table continues on next page		

Document revision	Product revision	History
J	2.2.5	The harmonic restrain function changed to freeze the definite and IDMT timers.
L	2.2.6	-
M	2.2.6	Minimum value changed to 0.01 for k1,k2,k3 and k4 settings

11.4.2.2 Four step directional ground fault protection

1. Connect the test set for single current injection to the appropriate IED terminals.
   Connect the injection current to terminals A and neutral.
2. Set the injected polarizing voltage slightly larger than the set minimum polarizing voltage (5% of Vn) and set the injection current to lag the voltage by an angle equal to the set reference characteristic angle (*AngleRCA*), if the 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 RCA+ 180°.
3. Increase the injected current and note the value at which the studied step of the function trips.
4. Decrease the current slowly and note the reset value.
5. If the test has been performed by injection of current in phase A, repeat the test, injecting current into terminals B and C with a polarizing voltage connected to terminals B, respectively C.
6. Block lower set steps when testing higher set steps according to the instructions that follow.
7. Connect a trip output contact to a timer.
8. Set the injected current to 200% of the trip level of the tested step, switch on the current and check the time delay.
   For inverse time curves, check the trip time at a current equal to 110% of the trip current for *txMin*.
9. Check that all trip and pickup contacts trip according to the configuration (signal matrixes).
10. Reverse the direction of the injected current and check that the step does not trip.
11. Check that the protection does not trip when the polarizing voltage is zero.
12. Repeat the above described tests for the higher set steps.
13. Finally, check that pickup and trip information is stored in the event menu.

11.4.2.3 Four step non-directional ground fault protection

1. Do as described in Section 11.4.2.2, but without applying any polarizing voltage.

11.4.2.4 Completing the test

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

11.4.3 Four step negative sequence overcurrent protection NS4PTOC (46I2)

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

11.4.3.1 Function revision history

Document revision	Product revision	History
A	2.2.1	-
B	2.2.1	-
C	2.2.2	-
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	Maximum value changed to 2000.0 % of IBase for *IMin1*, *IMin2*, *IMin3* and *IMin4* settings.
H	2.2.5	-
L	2.2.6	-
M	2.2.6	Minimum value changed to 0.01 for k1,k2,k3 and k4 settings

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

Procedure

1. Connect the test set for injection of three-phase currents and voltages to the appropriate CT and VT inputs of the IED.
2. Inject pure negative sequence current, that is, phase currents with exactly same magnitude, reversed sequence and exactly 120° phase displaced into the IED with an initial value below negative sequence current pickup level. No output signals should be activated. Check under NS4PTOC function Service Values that correct I2 magnitude is measured by the function.
3. Set the injected negative sequence polarizing voltage slightly larger than the set minimum polarizing voltage (default 5 % of Vn) and set the injection current to lag the voltage by an angle equal to the set reference characteristic angle (*180° - AngleRCA*) if the 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 RCA.
4. Increase the injected current and note the value at which the studied step of the function trip.
5. Decrease the current slowly and note the reset value.
6. Block lower set steps when testing higher set steps according to the instructions that follow.
7. Connect a trip output contact to a timer.
8. Set the injected current to 200% of the trip level of the tested step, switch on the current and check the time delay.
   For inverse time curves, check the trip time at a current equal to 110% of the trip current in order to test parameter *txmin*.
9. Check that all trip and pickup contacts trip according to the configuration (signal matrixes)
10. Reverse the direction of the injected current and check that the step does not trip.
11. Check that the protection does not trip when the polarizing voltage is zero.
12. Repeat the above-described tests for the higher set steps.
13. Finally, check that pickup and trip information is stored in the event menu.

11.4.3.2 Completing the test

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

11.4.4 Sensitive directional residual overcurrent and power protection SDEPSDE (67N)

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

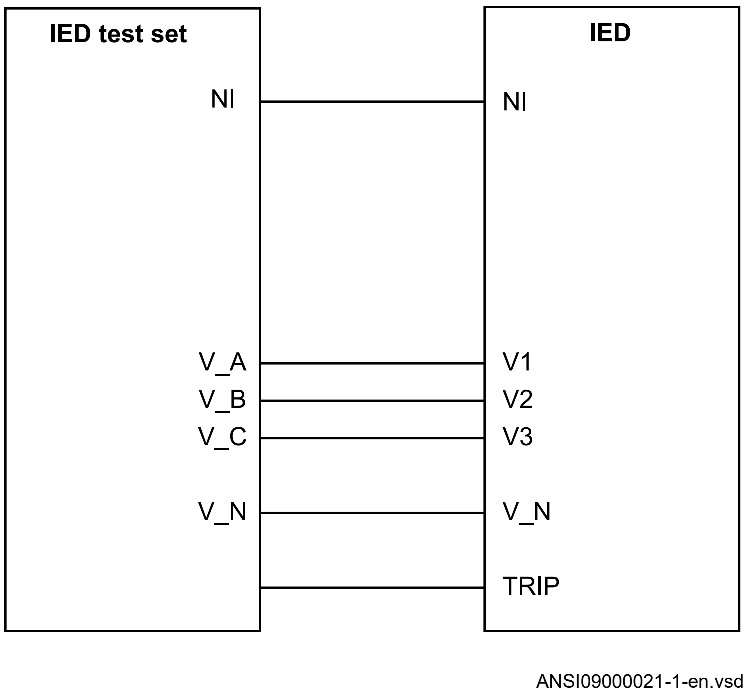


Figure 27: Principle connection of the test set

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**

11.4.4.1 Measuring the trip and time limit for set values

Operation mode $3I_0 \cdot \cos\varphi$

Procedure

1. Set the polarizing voltage to 1.2 · *VNRelPU* and set the phase angle between voltage and current to the set characteristic angle (*RCADir*). Note that the the current lagging 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 trip current of the set directional element is equal to the *INcosPhiPU* setting.

The I Dir ($3I_0 \cdot \cos\varphi$) function activates the PICKUP and PUNDIN output.

3. Assume that φ´ is the phase angle between injected voltage ($3V_0$) and current ($3I_0$) i.e. φ´ = *RCADir*-φ. Change φ´ to for example 45 degrees. Increase the injected current until the function trips.
4. Compare the result with the set value and make sure that the new injected $3I_0 \cdot \cos\varphi$ is equal to the setting *INcosPhiPU*..
   Take the set characteristic into consideration, see Figure 28 and Figure 29.
5. Measure the trip time of the timer by injecting a current two times the set *INcosPhiPU* value and the polarizing voltage 1.2 · *VNRelPU*.

$$Tinv = \frac{\mathrm{TDSN} \cdot \mathrm{SRef}}{3I_0 \cdot 3V_{0test} \cdot \cos(\varphi)}$$

(Equation 77)

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. Compare the voltage with the set value *VNRelPU* .
8. Continue to test another function or complete the test by setting the test mode to *Disabled*.

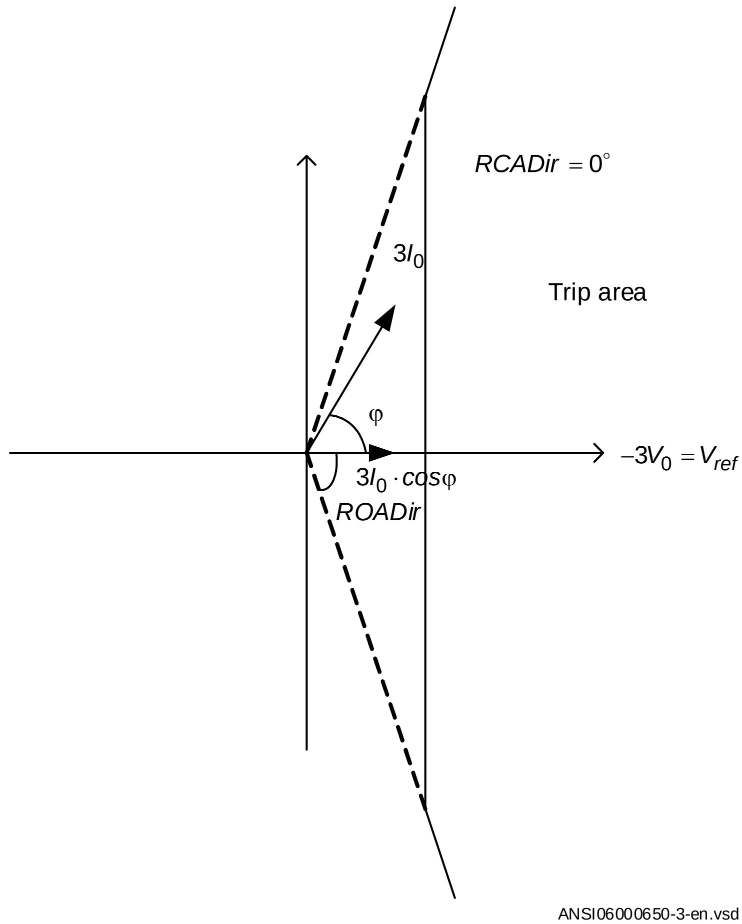


Figure 28: Characteristic with ROADir restriction

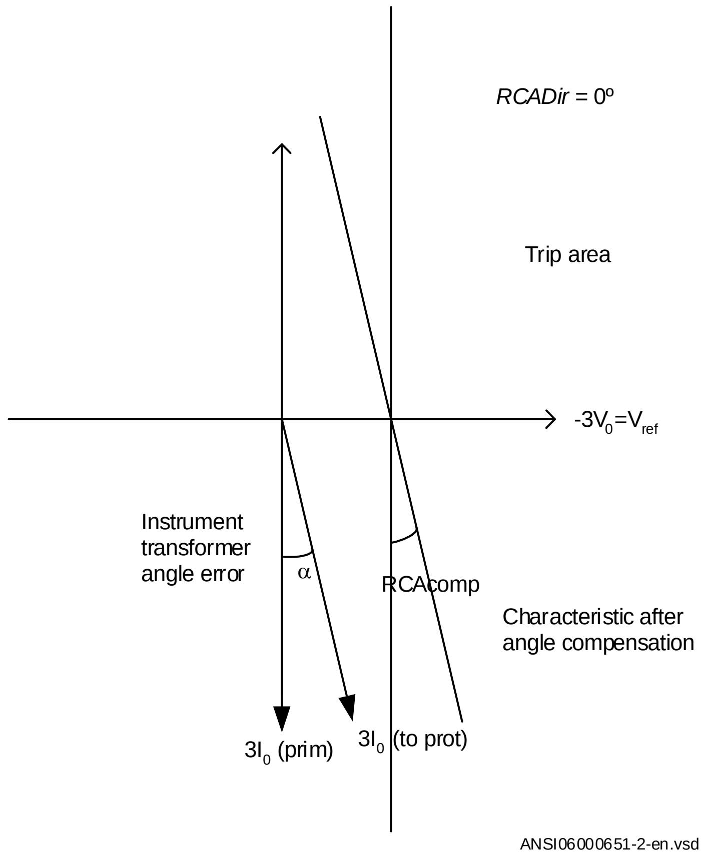


Figure 29: Explanation of RCAcomp

Operation mode $3I_0 \cdot 3V_0 \cdot \cos\varphi$

1. Set the polarizing voltage to 1.2 · *VNRelPU* and set the phase angle between voltage and current to the set characteristic angle (*RCADir*). Note that the current lagging the voltage.
2. Inject current until the function picks up, and make sure that the trip power is equal to the *SN_PU* setting for the set directional element.
   Note that for pick-up, both the injected current and voltage must be greater than the set values *INRelPU* and *VNRelPU* respectively.
   The function activates the PICKUP and PUDIRIN outputs.
3. Assume that φ´ is the phase angle between injected voltage ($3V_0$) and current ($3I_0$) i.e. φ´ = *RCADir*-φ. Change φ´ to for example 45 degrees. Increase the injected current until the function trips.
4. Compare the result with the set value and make sure that the new injected $3I_0 \cdot 3V_0 \cdot \cos\varphi$ is equal to the setting *SN_PU*. Take the set characteristic into consideration, see figure 28 and figure 29.
5. Measure the trip time of the timer by injecting 1.2 · *VNRelPU* and a current to get two times the set *SN_PU* trip value.

$$Tinv = \text{TDSN} \cdot \text{SRef} / 3I_{0test} \cdot 3V_{0test} \cdot \cos(\varphi)$$

(Equation 78)

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 *Disabled*.

Operation mode $3I_0$ and φ

1. Set the polarizing voltage to 1.2 · *VNRelPU* and set the phase angle between voltage and current to the set characteristic angle (*RCADir*). Note that the current lagging the voltage.
2. Inject current until the function picks up, and make sure that the trip current is equal to the *INRelPU* setting for the set directional element.

   Note that for pickup, both the injected current and voltage must be greater than the set values *INRelPU* and *VNRelPU* respectively.

   The function activates the PICKUPand PUDIRIN output.
3. Measure with angles φ around *RCADir +/- ROADir.*
4. Compare the result with the set values, refer to figure 30 for example characteristic.
5. Measure the trip time of the timer by injecting a current to get two times the set *SN_PU* trip value.

$$Tinv = \text{TDSN} \cdot \text{SRef} / 3I_{0test} \cdot 3V_{0test} \cdot \cos(\varphi)$$

(Equation 79)

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 *Disabled*.

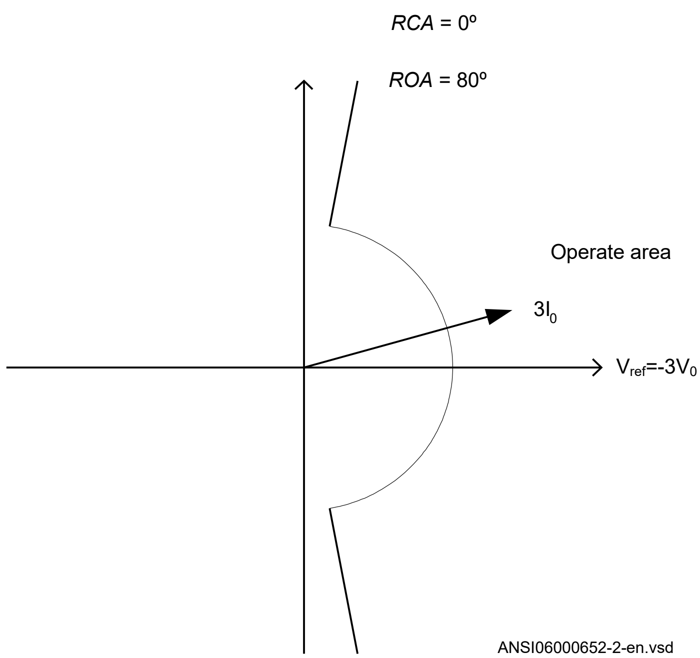


Figure 30: Example characteristic

Non-directional ground fault current protection
Procedure

1. Measure that the trip current is equal to the *INNonDirPU* setting.
   The function activates the PICKUP and PUDIRIN output.
2. Measure the trip time of the timer by injecting a current of 200% of the trip value.
3. Compare the result with the expected value.
   The expected value depends on whether definite time *tINNonDir* or inverse time was selected.
4. Continue to test another function or complete the test by setting the test mode to *Disabled*.

Residual overvoltage release and protection
Procedure

1. Measure that the trip voltage is equal to the *VN_PU* setting.
   The function activates the PICKUP and PUVN signals.
2. Measure the trip time by injecting a voltage 1.2 times set *VN_PU* trip value.
3. Compare the result with the set *tVN* trip value.
4. Inject a voltage 0.8 · *VNRelPU* and a current high enough to trip 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 *VNRelPU* trip value.

11.4.4.2 Completing the test

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

11.4.5 Thermal overload protection, one time constant, Fahrenheit/ Celsius LFPTTR/LCPTTR (26)

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

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

11.4.5.1 Measuring the trip and time limit of set values

Testing the protection without external temperature compensation (NonComp)

1. Quickly set the measured current (fault current) in one phase to about 300% of *IRef* (to minimise the trip time), and switch the current off.
2. Reset the thermal memory on the local HMI under **Main menu /Reset /Reset temperature / ThermalOverload1TimeConst(PTTR,26) /LFPTTR:x** , **Main menu /Reset /Reset temperature / ThermalOverload1TimeConst(PTTR,26) /LCPTTR:x** ,
3. 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) / LFPTTR:x /TEMP** , **Main menu /Test /Function status /Current protection / ThermOverLoad1TimeConst(PTTR,26) /LCPTTR:x /TEMP** ,

4. 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.
5. Measure the LFPTTR/LCPTTR (26)protection trip time.
   Use the TRIP signal from the configured binary output to stop the timer.
6. Take the TEMP readings.
   Compare with the setting of *TripTemp*.
7. Activate the BLOCK binary input.
   The signals ALARM, PICKUP and TRIP should disappear.
8. Reset the BLOCK binary input.
9. Check the reset limit (TdReset).
   Monitor the signal PICKUP until it disappears on the corresponding binary output or on the local HMI, take the TEMP readings and compare with the setting of *ReclTemp*.
10. Compare the measured trip time with the setting according to the formula.
11. Reset the thermal memory.
12. Continue to test another function or end the test by changing the test mode setting to *Disabled*.

11.4.5.2 Completing the test

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

11.4.6 Directional underpower protection GUPPDUP (37)

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

11.4.6.1 Verifying the settings

The underpower protection shall be set to values according to the real set values to be used.

The test is made by means of injection of voltage and current where the amplitude of both current and voltage and the phase angle between the voltage and current can be controlled. During the test, the analog outputs of active and reactive power shall be monitored.

1. Connect the test set for injection of voltage and current corresponding to the mode to be used in the application. If a three-phase test set is available this could be used for all the modes. If a single-phase current/voltage test set is available the test set should be connected to a selected input for one-phase current and voltage.

Table 15: Calculation modes

Set value: ***Mode***	**Formula used for complex power calculation**
A, B, C	$$\bar{S} = \bar{V}_A \cdot \bar{I}_A^* + \bar{V}_B \cdot \bar{I}_B^* + \bar{V}_C \cdot \bar{I}_C^*$$ (Equation 80)
Arone	$$\bar{S} = \bar{V}_{AB} \cdot \bar{I}_A^* - \bar{V}_{BC} \cdot \bar{I}_C^*$$ (Equation 81)
PosSeq	$$\bar{S} = 3 \cdot \bar{V}_{PosSeq} \cdot \bar{I}_{PosSeq}^*$$ (Equation 82)
AB	$$\bar{S} = \bar{V}_{AB} \cdot (\bar{I}_A^* - \bar{I}_B^*)$$ (Equation 83)
BC	$$\bar{S} = \bar{V}_{BC} \cdot (\bar{I}_B^* - \bar{I}_C^*)$$ (Equation 84)
CA	$$\bar{S} = \bar{V}_{CA} \cdot (\bar{I}_C^* - \bar{I}_A^*)$$ (Equation 85)
A	$$\bar{S} = 3 \cdot \bar{V}_A \cdot \bar{I}_A^*$$ (Equation 86)
B	$$\bar{S} = 3 \cdot \bar{V}_B \cdot \bar{I}_B^*$$ (Equation 87)
C	$$\bar{S} = 3 \cdot \bar{V}_C \cdot \bar{I}_C^*$$ (Equation 88)

2. Adjust the injected current and voltage to the set values in % of *IBase* and *VBase* (converted to secondary current and voltage). The angle between the injected current and voltage shall be set equal to the set direction *Angle1*, angle for stage 1 (equal to 0° for low forward power protection and equal to 180° for reverse power protection). Check that the monitored active power is equal to 100% of rated power and that the reactive power is equal to 0% of rated power.
3. Change the angle between the injected current and voltage to *Angle1* + 90°. Check that the monitored active power is equal to 0% of rated power and that the reactive power is equal to 100% of rated power.

4. Change the angle between the injected current and voltage back to 0°. Decrease the current slowly until the PICKUP1 signal, pickup of stage 1, is activated.
5. Increase the current to 100% of *IBase*.
6. Switch the current off and measure the time for activation of TRIP1, trip of stage 1.
7. If a second stage is used, repeat steps 2 to 6 for the second stage.

11.4.6.2 Completing the test

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

11.4.7 Directional overpower protection GOPPDOP (32)

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

11.4.7.1 Verifying the settings

The overpower protection shall be set to values according to the real set values to be used. The test is made by means of injection of voltage and current where the amplitude of both current and voltage and the phase angle between the voltage and current can be controlled. During the test the analog outputs of active and reactive power shall be monitored.

1. Connect the test set for injection of voltage and current corresponding to the mode to be used in the application. If a three phase test set is available this could be used for all the modes. If a single phase current/voltage test set is available the test set should be connected to a selected input for one phase current and voltage.
2. Adjust the injected current and voltage to the set rated values in % of *IBase* and *VBase* (converted to secondary current and voltage). The angle between the injected current and voltage shall be set equal to the set direction *Angle1*, angle for stage 1 (equal to 0° for low forward power protection and equal to 180° for reverse power protection). Check that the monitored active power is equal to 100% of rated power and that the reactive power is equal to 0% of rated power.
3. Change the angle between the injected current and voltage to *Angle1* + 90°. Check that the monitored active power is equal to 0% of rated power and that the reactive power is equal to 100% of rated power.
4. Change the angle between the injected current and voltage back to *Angle1* value. Increase the current slowly from 0 until the PICKUP1 signal, pickup of stage 1, is activated. Check the injected power and compare it to the set value *Power1*, power setting for stage 1 in % of *Sbase*.
5. Increase the current to 100% of *IBase* and switch the current off.
6. Switch the current on and measure the time for activation of TRIP1, trip of stage 1.
7. If a second stage is used, repeat steps 2 to 6 for the second stage.

11.4.7.2 Completing the test

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

11.5 Voltage protection

11.5.1 Two step undervoltage protection UV2PTUV (27)

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

11.5.1.1 Verifying the settings

Verification of pickup value and time delay to trip for Step 1

1. Check that the IED settings are appropriate, especially the PICKUP value, the definite time delay and the *1 out of 3* operation mode.
2. Supply the IED with three-phase voltages at their rated values.
3. Slowly decrease the voltage in one of the phases, until the PICKUP signal appears.
4. Note the trip value and compare it with the set value.

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

For phase-to-ground measurement:

$$\frac{Vpickup<}{100} \times \frac{VBase}{\sqrt{3}} \times \frac{VT\sec}{VTprim}$$

(Equation 89)

For phase-to-phase measurement:

$$\frac{Vpickup<}{100} \times VBase \times \frac{VT\sec}{VTprim}$$

(Equation 90)

5. Increase the measured voltage to rated load conditions.
6. Check that the PICKUP signal resets.
7. Instantaneously decrease the voltage in one phase to a value about 20% lower than the measured trip value.
8. Measure the time delay for the TRIP signal, and compare it with the set value.
9. Check the inverse time delay by injecting a voltage corresponding to 0.8 × Vpickup<.

For example, if the inverse time curve A is selected, the trip signals TRST1 and TRIP trip after a time corresponding to the equation:

$$t(s) = \frac{TD1}{\left(1 - \frac{V}{Vpickup<}\right)}$$

(Equation 91)

where:

t(s)	Trip time in seconds

TD1	Settable time multiplier of the function for step 1
V	Measured voltage
Vpickup<	Set pickup voltage for step 1

For example, if the measured voltage jumps from the rated value to 0.8 times the set pickup voltage level and time multiplier TD1 is set to 0.05 s (default value), then the TRST1 and TRIP signals trip at a time equal to 0.250 s ± tolerance.

10. The test above can be repeated to check the inverse time characteristic at different voltage levels.
11. Repeat the above described steps for Step 2 of the function.

Extended testing

The tests above can be repeated for *2 out of 3* and for *3 out of 3* operation mode.

11.5.1.2 Completing the test

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

11.5.2 Two step overvoltage protection OV2PTOV (59)

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

11.5.2.1 Verifying the settings

Verification of single-phase voltage and time delay to trip for Step 1

1. Apply single-phase voltage below the set value *Pickup1*.
2. Slowly increase the voltage until the PU_ST1 signal appears.
3. Note the trip value and compare it with the set value *Pickup1*.

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

For phase-to-ground measurement:

$$\frac{Vpickup>}{100} \times \frac{VBase}{\sqrt{3}} \times \frac{VT\sec}{VTprim}$$

(Equation 92)

For phase-to-phase measurement:

$$\frac{Vpickup>}{100} \times VBase \times \frac{VT\sec}{VTprim}$$

(Equation 93)

4. Decrease the voltage slowly and note the reset value.
5. Set and apply about 20% higher voltage than the measured trip value for one phase.
6. Measure the time delay for the TRST1 signal and compare it with the set value.
7. Check the inverse time delay by injecting a voltage corresponding to 1.2 × Vpickup>.
8. Repeat the test to check the inverse time characteristic at different over-voltage levels.
9. Repeat the above described steps for Step 2 of the function.

11.5.2.2 Extended testing

1. The tests above can be repeated for *2 out of 3* and for *3 out of 3* operation mode.

11.5.2.3 Completing the test

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

11.6 Frequency protection

11.6.1 Underfrequency protection SAPTUF (81)

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

11.6.1.1 Verifying the settings

Verification of PICKUP value and time delay to trip

1. Check that the IED settings are appropriate, for example the pickup value and the time delay.
2. Supply the IED with three-phase voltages at their rated values and initial frequency.
   The initial frequency is calculated using Equation 94.

$$StartFrequency + 0.02 + floor\left[\left|f_r - StartFrequency\right| / 0.04\right] \times 0.04$$

(Equation 94)

3. Slowly decrease the voltage frequency bysteps of 40 mHz until the TRIP 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. Note the frequency value at which the TRIP signal appears and compare it with the set value *StartFrequency*.
6. Increase the frequency until its rated value is reached.
7. Check that the PICKUP signal resets.
8. Supply the IED with three-phase voltages at their rated values and frequency 20 mHz over the set value *StartFrequency*.
9. Decrease the frequency with a 40 mHz step, applying it for a time that is at least 10% longer than (*tDelay*+100ms).
10. 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 of the time delay plus the minimum trip time of the pickup start function (80 - 90 ms).

Extended testing

1. The test above can be repeated to check the time to reset.
2. The tests above can be repeated to test the frequency dependent inverse time characteristic.

Verification of the low voltage magnitude blocking

1. Check that the IED settings are appropriate, for example the *PUFrequency*, *VMin*, and the *tDelay*.
2. Supply the IED with three-phase voltages at rated values.
3. Slowly decrease the magnitude of the applied voltage, until the BLKDMAGN signal appears.
4. Note the voltage magnitude value and compare it with the set value *VMin*.
5. Slowly decrease the frequency of the applied voltage, to a value below *PUFrequency*.
6. Check that the PICKUP signal does not appear.
7. Wait for a time corresponding to *tDelay*, make sure that the TRIP signal does not appear.

11.6.1.2 Completing the test

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

11.6.2 Overfrequency protection SAPTOF (81)

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

11.6.2.1 Verifying the settings

Verification of PICKUP value and time delay to trip

1. Check that the IED settings are appropriate, for example the pickup value and the time delay.
2. Supply the IED with three-phase voltages at their rated values and initial frequency.
3. Slowly increase the frequency of the applied voltage with a 40 mHz step, applying it for a period that is 10% longer than *tDelay*.
4. Note the trip value and compare it with the set value.
5. Decrease the frequency to rated operating conditions.
6. Check that the PICKUP signal resets.
7. Set the frequency to 20 mHz under the trip value.
8. Increase the frequency with a 40 mHz step, applying it for a period that is 10% longer than *tDelay*.
9. Measure the time delay for the TRIP signal, and compare it with the set value. Note that the measured time consists of the set value for time delay plus minimum trip time of the pickup function (80 - 90 ms).

Extended testing

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

Verification of the low voltage magnitude blocking

1. Check that the settings in the IED are appropriate, for example the *PUFrequency* and the *tDelay*.
2. Supply the IED with three-phase voltages at their rated values.
3. Slowly decrease the magnitude of the applied voltage, until the BLKDMAGN signal appears.
4. Note the voltage magnitude value and compare it with the set value.
5. Slowly increase the frequency of the applied voltage, to a value above *PUFrequency*.
6. Check that the PICKUP signal does not appear.
7. Wait for a time corresponding to *tDelay*, make sure that the TRIP signal does not appear.

11.6.2.2 Completing the test

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

11.6.3 Rate-of-change frequency protection SAPFRC (81)

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

11.6.3.1 Verifying the settings

PICKUP value and time delay to trip

1. Check that the settings in the IED are appropriate, especially the PICKUP value and the definite time delay. Set *PickupFreqgrad*, to a rather small negative value.
2. Supply the IED with three-phase voltages at their rated values.
3. Slowly decrease the frequency of the applied voltage, with an increasing rate-of-change that finally exceeds the setting of *PickupFreqgrad*, and check that the PICKUP signal appears.
4. Note the trip value and compare it with the set value.
5. Increase the frequency to rated operating conditions, and zero rate-of-change.
6. Check that the PICKUP signal resets.
7. Instantaneously decrease the frequency of the applied voltage to a value about 20% lower than the nominal value.
8. Measure the time delay for the TRIP signal, and compare it with the set value.

Extended testing

1. The test above can be repeated to check a positive setting of *PickupFreqGrad*.
2. The tests above can be repeated to check the time to reset.
3. The tests above can be repeated to test the RESTORE signal, when the frequency recovers from a low value.

11.6.3.2 Completing the test

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

11.6.4 Frequency time accumulation protection function FTAQFVR (81A)

Prepare the IED for verification of settings as outlined in section “Overview” and section “Preparing for test” in this chapter.

11.6.4.1 Verifying the settings

Time measurement and the injection of current and voltage can be done using a common test equipment.

Verification of the PICKUP value and time delay to trip

1. Connect the test set for the injection of three-phase currents and three-phase voltages to the appropriate current and voltage terminals of the IED.
2. Ensure that the settings in the IED are appropriate, especially the *PickupCurrentLevel*, *FreqHighLimit*, *FreqLowLimit*, *VHighLimit* and *VLowLimit* setting.
3. Supply the IED with three-phase currents and voltages at their rated value.
4. Slowly decrease the frequency of the applied voltage until it crosses the frequency high limit and the `BFI_3P` signal appears.
5. Check that the `FREQOK` signal appears.
6. Compare the trip value to the set frequency high limit value.
7. Decrease the frequency of the applied voltage until it crosses the frequency low limit and the `BFI_3P` signal disappears.
8. Check that the `FREQOK` signal disappears.
9. Compare the reset value to the set frequency low limit value.
10. Readjust the frequency of the applied voltage (with steps of 0.001 Hz/s) to a value within the set frequency band limit.
11. Ensure that the `BFI_3P` signal reappears.
12. Wait for a time corresponding to *tCont* and ensure that the `TRIP` and `TRIPCONT` signals are generated.
13. Measure the time delay for the `TRIP` signal and compare it to the set value.

Verification of the ACCALARM value and time delay to trip

1. Connect the test set for the injection of three-phase currents and three-phase voltages to the appropriate current and voltage terminals of the IED.
2. Ensure that the settings in the IED are appropriate for the default settings, especially the *PickupCurrentLevel*, *FreqHighLimit*, *FreqLowLimit*, *VHighLimit* and *VLowLimit* setting.
3. Supply the IED with three-phase currents and voltages at their rated value.
4. Slowly decrease the frequency of the applied voltage until it crosses the frequency high limit and the `BFI_3P` signal appears.
5. Continuously change the frequency of the applied voltage, so that for a certain time the frequency is outside the set band limit and falls gradually within the band limit.
6. Count only the time when the frequency lies within the set frequency band limit. Wait for a time corresponding to *tAccLimit* and ensure that the `ACCALARM` signal appears.
7. Measure the time delay for the `ACCALARM` signal and compare it to the set value.

Extended testing

1. To check the value of `TRIPACC`, repeat the above test case in such a way that the frequency of the applied voltage is within the set frequency band when time approaches the *tAccLimit* setting value.

Verification of generator start and stop logic

1. Ensure that the settings in the IED are appropriate to the default settings, especially the *PickupCurrentLevel*, *FreqHighLimit*, *FreqLowLimit*, *VHighLimit* and *VLowLimit*.
2. Ensure that the setting *CBCheck* is enabled.
3. Supply the IED with three-phase currents and voltages at their rated values.
4. Slowly decrease the frequency of the applied voltage until the `BFI_3P` signal appears.
5. Activate the `CBOPEN` input signal.
6. Slowly decrease the injected current below the *PickupCurrentLevel* value until the `BFI_3P` signal disappears.
7. Compare the current magnitude value to the set value.

Verification of voltage band limit check logic

1. Ensure that the settings in the IED are appropriate to the default settings, especially the *PickupCurrentLevel*, *FreqHighLimit*, *FreqLowLimit*, *VHighLimit* and *VLowLimit* settings.
2. Ensure that the *EnaVoltCheck* is enabled.
3. Supply the IED with three-phase currents and voltages at their rated values.
4. Check that the `VOLTOK` signal appears.
5. Slowly decrease the frequency of the applied voltage until the `BFI_3P` signal appears.
6. Slowly decrease the positive-sequence voltage of the injected voltage below the *VLowLimit* value until the `BFI_3P` signal disappears.
7. Check that the `VOLTOK` signal disappears.
8. Compare the reset value to the set voltage low limit value.
9. Readjust the positive-sequence voltage of the applied voltage to a value within the set voltage band limits.
10. Check that the `BFI_3P` signal reappears.
11. Slowly increase the positive-sequence voltage of the injected voltage above the *VUHighLimit* value until the `BFI_3P` signal disappears.
12. Compare the reset value to the set voltage high limit value.

11.6.4.2 Completing the test

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

11.7 Multipurpose protection

11.7.1 Function revision history

Document revision	Product revision	History
A	2.2.1	-
B	2.2.1	-
C	2.2.2	-
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	-
H	2.2.4	-
J	2.2.5	• The harmonic restraint function changed to freeze the definite and IDMT timers. • The maximum value of the settings *IMin1* and *IMin2* has been decreased to 1000.0 % of IBase. • Setting *BlkLevel2nd* was removed from the function. • Previously called stepwise settings *t_DefOCx* and *tResetDef_OCx* had their names changed to *t_OCx* and *tReset_OCx* for more clear understanding.
L	2.2.6	-
M	2.2.6	Minimum value changed to 0.01 for k_OC1 and k_OC2 settings

11.7.2 General current and voltage protection CVGAPC

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

One of the facilities within the general current and voltage protection function CVGAPC is that the value, which is processed and used for evaluation in the function, can be chosen in many different ways by the setting parameters *CurrentInput* and *VoltageInput*.

These setting parameters decide what kind of preprocessing the connected three-phase CT and VT inputs shall be subjected to. That is, for example, single-phase quantities, phase-to-phase quantities, positive sequence quantities, negative sequence quantities, maximum quantity from the three-phase group, minimum quantity from the three-phase group, difference between maximum and minimum quantities (unbalance) can be derived and then used in the function.

Due to the versatile possibilities of CVGAPC itself, but also the possibilities of logic combinations in the application configuration of outputs from more than one CVGAPC function block, it is hardly possible to define a fully covering general commissioning test.

11.7.2.1 Built-in overcurrent feature (non-directional)

Procedure

1. Go to **Main menu /Test /Function test modes /Multipurpose protection / GeneralCurrentVoltage(GAPC) /CVGAPC:x** and make sure that CVGAPC to be tested is unblocked and other functions that might disturb the evaluation of the test are blocked.
2. Connect the test set for injection of three-phase currents to the appropriate current terminals of the IED.
3. Inject current(s) in a way that relevant measured current (according to setting parameter *CurrentInput*) is created from the test set. Increase the current(s) until the low set stage trips and check against the set trip value.
4. Decrease the current slowly and check the reset value.
5. Block high set stage if the injection current will activate the high set stage when testing the low set stage according to below.
6. Connect a TRIP output contact to the timer.
7. Set the current to 200% of the trip value of low set stage, switch on the current and check the time delay.
   For inverse time curves, check the trip time at a current equal to 110% of the trip current at *t_MinTripDelay*.
8. Check that TRIP and PICKUP contacts trip according to the configuration logic.
9. Release the blocking of the high set stage and check the trip and reset value and the time delay for the high set stage in the same way as for the low set stage.
10. Finally check that PICKUP and TRIP information is stored in the event menu.

Information on how to use the event menu is found in the operator's manual.

11.7.2.2 Overcurrent feature with current restraint

The current restraining value has also to be measured or calculated and the influence on the operation has to be calculated when the testing of the trip value is done.

Procedure

1. Trip value measurement
   The current restraining value has also to be measured or calculated and the influence on the operation has to be calculated when the testing of the trip value is done.

11.7.2.3 Overcurrent feature with voltage restraint

Procedure

1. Connect the test set for injection of three-phase currents and three-phase voltages to the appropriate current and voltage terminals of the IED.
2. Inject current(s) and voltage(s) in a way that relevant measured (according to setting parameter *CurrentInput* and *VoltageInput*) currents and voltages are created from the test set.
   Overall check in principal as above (non-directional overcurrent feature)
3. Trip value measurement
   The relevant voltage restraining value (according to setting parameter *VoltageInput*) has also to be injected from the test set and the influence on the trip value has to be calculated when testing of the trip value is done.
4. Trip time measurement
   Definite times may be tested as above (non-directional overcurrent feature). For inverse time characteristics the PICKUP value (to which the overcurrent ratio has to be calculated) is the actual pickup value as got with actual restraining from the voltage restraining quantity.

11.7.2.4 Overcurrent feature with directionality

Please note that the directional characteristic can be set in two different ways either just dependent on the angle between current and polarizing voltage (setting parameter *DirPrinc_OC1* or *DirPrinc_OC2* set to or in a way that the trip value also is dependent on the angle between current and polarizing voltage according to the I · cos(Φ) law (setting parameter *DirPrinc_OC1* or *DirPrinc_OC2* set to I · cos(Φ). This has to be known if a more detailed measurement of the directional characteristic is made, than the one described below.

Procedure

1. Connect the test set for injection of three-phase currents and three-phase voltages to the appropriate current and voltage terminals of the IED.
2. Inject current(s) and voltage(s) in a way that relevant measured (according to setting parameter *CurrentInput* and *VoltageInput*) currents and voltages are created from the test set.
3. Set the relevant measuring quantity current to lag or lead (lag for negative RCA angle and lead for positive RCA angle) the relevant polarizing quantity voltage by an angle equal to the set IED characteristic angle (rca-dir) when forward directional feature is selected and the *CTWYEpoint* configuration parameter is set to *ToObject*.
   If reverse directional feature is selected or *CTWYEpoint* configuration parameter is set to *FromObject*, the angle between current and polarizing voltage shall be set equal to rca-dir+180°.
4. Overall check in principal as above (non-directional overcurrent feature)
5. Reverse the direction of the injection current and check that the protection does not trip.
6. Check with low polarization voltage that the feature becomes non-directional, blocked or with memory according to the setting.

11.7.2.5 Over/Undervoltage feature

Procedure

1. Connect the test set for injection three-phase voltages to the appropriate voltage terminals of the IED.
2. Inject voltage(s) in a way that relevant measured (according to setting parameter *VoltageInput*) voltages are created from the test set.
3. Overall check in principal as above (non-directional overcurrent feature) and correspondingly for the undervoltage feature.

11.7.2.6 Completing the test

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

11.8 Secondary system supervision

11.8.1 Current circuit supervision CCSSPVC (87)

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

The Current circuit supervision function CCSSPVC (87) is conveniently tested with the same three-phase test set as used when testing the measuring functions in the IED.

The condition for this procedure is that the setting of *IMinOp* is lower than the setting of *Pickup_Block*.

11.8.1.1 Verifying the settings

1. Check the input circuits and the trip value of the *IMinOp* current level detector by injecting current, one phase at a time.
2. Check the phase current blocking function for all three phases by injecting current, one phase at a time. The output signals shall reset with a delay of 1 second when the current exceeds 1.5 · *IBase*.
3. Inject a current 0.1 · *IBase* to the reference current input Analogue channel ID current input 5.
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*.

11.8.1.2 Completing the test

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

11.8.2 Fuse failure supervision FUFSPVC

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

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 trip as expected according to actual configuration. In the second part the relevant set trip values are measured.

11.8.2.1 Checking that the binary inputs and outputs trip as expected

1. Simulate normal operating conditions with the three-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 89bS binary input.
   - The signal BLKV should appear with almost no time delay.
   - The signals BLKZ and 3PH should not appear on the IED.
   - Only the distance protection function can trip.
   - Undervoltage-dependent functions must not trip.
3. Disconnect the dc voltage from the 89b binary input terminal.
4. Connect the nominal dc voltage to the MCBOP binary input.
   - The BLKVand 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.
   BLKV and BLKZ signals should appear simultaneously wether the BLKV and BLKZ reset depends on the setting *SealIn* “on” or “off”. If “on” no reset, if “off” reset.
7. After more than 5 seconds disconnect the remaining two-phase voltages and all three currents.
   - There should be no change in the high status of the output signals BLKV and BLKZ.
   - The signal 3PH will appear.
8. Establish normal voltage and current operating conditions simultaneously and observe the corresponding output signals.
   They should change to logical 0 as follows:
   - Signal 3PH after about 25ms
   - Signal BLKV after about 50ms
   - Signal BLKZ after about 200ms

11.8.2.2 Measuring the trip value for the negative sequence function

Measure the trip value for the negative sequence function, if included in the IED.

1. Simulate normal operating conditions with the three-phase currents in phase with their corresponding phase voltages and with all of them equal to their rated values.
2. Slowly decrease the measured voltage in one phase until the BLKV signal appears.
3. Record the measured voltage and calculate the corresponding negative-sequence voltage according to the equation (observe that the voltages in the equation are phasors):

$$3 \cdot \overline{V_2} = \overline{V_A} + a^2 \cdot \overline{V_B} + a \cdot \overline{V_C}$$

(Equation 95)

Where:

$\overline{V_A} \overline{V_B} and \overline{V_C}$	are the measured phase voltages

$$a = 1 \cdot e^{j\frac{2 \cdot \pi}{3}} = -0.5 + j\frac{\sqrt{3}}{2}$$

4. Compare the result with the set value of the negative-sequence operating voltage (consider that the set value *3V2PU* is in percentage of the base voltage *VBase*).

5. Repeat steps 1 and 2. Then slowly increase the measured current in one phase until the BLKV signal disappears.
6. Record the measured current and calculate the corresponding negative-sequence current according to the equation (observe that the currents in the equation are phasors):

$$3 \cdot \overline{I_2} = \overline{I_A} + a^2 \cdot \overline{I_B} + a \cdot \overline{I_C}$$

(Equation 96)

Where:

$\overline{I_A}, \overline{I_B}$ and $\overline{I_C}$ are the measured phase currents

$$a = 1 \cdot e^{j\frac{2 \cdot \pi}{3}} = -0.5 + j\frac{\sqrt{3}}{2}$$

7. Compare the result with the set value of the negative-sequence operating current. Consider that the set value *3I2<* is in percentage of the base current *IBase*.

11.8.2.3 Measuring the trip value for the zero-sequence function

Measure the trip value for the zero-sequence function, if included in the IED.

1. Simulate normal operating conditions with the three-phase currents in phase with their corresponding phase voltages and with all of them equal to their rated values.
2. Slowly decrease the measured voltage in one phase until the BLKV signal appears.
3. Record the measured voltage and calculate the corresponding zero-sequence voltage according to the equation (observe that the voltages in the equation are phasors):

$$3 \cdot \overline{V_0} = \overline{V_A} + \overline{V_B} + \overline{V_C}$$

(Equation 97)

Where:

$\overline{V_A} \overline{V_B} and \overline{V_C}$ are the measured phase voltages

4. Compare the result with the set value of the zero-sequence tripping voltage (consider that the set value *3V0Pickup* is in percentage of the base voltage.)
5. Repeat steps 1 and 2. Then slowly increase the measured current in one phase until the BLKV signal disappears.
6. Record the measured current and calculate the corresponding zero-sequence current according to the equation (observe that the currents in the equation are phasors):

$$3 \cdot \overline{I_0} = \overline{I_\mathrm{A}} + \overline{I_\mathrm{B}} + \overline{I_\mathrm{C}}$$

(Equation 98)

Where:

$\overline{I_A}, \overline{I_B}$ *and* $\overline{I_C}$ are the measured phase currents

7. Compare the result with the set value of the zero-sequence trip current. Consider that the set value *3I0<* is in percentage of the base current *IBase*.

11.8.2.4 Measuring the *trip* value for the dead line detection function

1. Apply three-phase voltages with their rated value and zero currents.
2. Decrease the measured voltage in one phase until the DLD1PH 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 VDLDPU (VDLDPU is in percentage of the base voltage *VBase*).
4. Apply three-phase currents with their rated value and zero voltages.
5. Decrease the measured current in one phase until the DLD1PH 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 IDLDPU (IDLDPU is in percentage of the base current *IBase*).

11.8.2.5 Checking the operation of the dv/dt and di/dt based function

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

1. Simulate normal operating conditions with the three-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 three phases simultaneously.
   The voltage change must be higher than the set value *DVPU* and the current change must be lower than the set value *DIPU*.
   - The BLKV and BLKZ signals appear without any time delay. The BLKZ signal will be activated only if the internal deadline detection is not activated at the same time.
   - 3PH should appear after 5 seconds, if the remaining voltage levels are lower than the set *VDLDPU* of the dead line detection function.
3. Apply normal conditions as in step 1.
   The BLKV, BLKZ and 3PH signals should reset, if activated, see step 1 and 2.
4. Change the voltages and currents in all three phases simultaneously.
   The voltage change must be higher than the set value *DVPU* and the current change must be higher than the set value *DIPU*.
   The BLKV, BLKZ and 3PH signals should not appear.
5. Repeat step 2.
6. Connect the nominal voltages in all three phases and feed a current below the trip level in all three phases.
7. Keep the current constant. Disconnect the voltage in all three phases simultaneously.
   The BLKV, BLKZ and 3PH signals should not appear.
8. Change the magnitude of the voltage and current for phase 1 to a value higher than the set value *DVPU* and *DIPU*.
9. Check that the pickup output signals PU_DV_A and PU_DI_A and the general pickup signals PU_DV or PU_DI are activated.
10. Check that the pickup output signals for the current and voltage phases 2 and 3 are activated by changing the magnitude of the voltage and current for phases 2 and 3.

11.8.2.6 Completing the test

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

11.8.3 Voltage based delta supervision DELVSPVC

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

11.8.3.1 Verifying the signals and settings

Make sure that the function is connected to SMAI function with V3P 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* = Enabled
   - *MeasMode* = Phase-to-ground
   - *Umin* = 10% of *VBase*
   - *DelU>* = 50% of *VBase*
   - *DelUang>* = 10°
   - *DeltaT* = 2
   - *tHold* = 100
2. Set the constant voltage input of UL1 = 63.5V at 0° and UL2 = 63.5V at 120° and UL3 at 63.5 -120° secondary at rated frequency.
3. Based on the mode of operation, carry out the following changes on input condition of Step 2 to detect pickup 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, BFI_3P signal should be TRUE for 100 ms
3-b	Instantaneous 1 cycle or Instantaneous 2 cycle	Change UL1 back to 63.5V	STL1 , STRISE, BFI_3P signal should be TRUE for 100 ms
3-a	RMS or DFT Mag	Change UL1 to 20V	STL1, STLOW, BFI_3P signal should be TRUE for 100 ms
3-b	RMS or DFT Mag	Change UL1 back to 63.5V	STL1 , STRISE, BFI_3P signal should be TRUE for 100 ms
3-a	DFT Angle (vector shift)	Change UL1 to 63.5V at 15° without changing frequency	STL1, BFI_3P signal will be TRUE for 100 ms.
3-b	DFT Angle (Vector shift)	Change UL1 to 63.5V at 0° without changing frequency	STL1, BFI_3P signal will be TRUE for 100 ms

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

11.8.3.2 Completing the test

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

11.8.4 Current based delta supervision DELISPVC(7I)

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

11.8.4.1 Verifying the signals and settings

Make sure that the function is connected to SMAI function with I3P 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 120° and IL3 at -120° secondary at rated frequency.
3. Based on the mode of operation, carry out the following changes on input condition of Step 2 to detect pickup 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, BFI_3P signal should be TRUE for 100 ms
3-b	Instantaneous 1 cycle or Instantaneous 2 cycle	Change IL1 back to 1A	STL1 , STLOW, BFI_3P signal should be TRUE for 100 ms
3-a	RMS or DFT Mag	Change IL1 to 2 A	STL1, STRISE, BFI_3P signal should be TRUE for 100 ms
3-b	RMS or DFT Mag	Change IL1 back to 1A	STL1 , STLOW, BFI_3P signal should be TRUE for 100 ms

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

11.8.4.2 Completing the test

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

11.8.5 Delta supervision of real input DELSPVC

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

11.8.5.1 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.

11.8.5.2 Completing the test

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

11.9 Control

11.9.1 Single command, 16 inputs 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.

11.10 Logic

11.10.1 Tripping logic, common 3-phase output SMPPTRC (94)

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

This function is functionality tested together with other protection functions (line differential protection, ground-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.

11.10.1.1 Function revision history

Document revision	Product revision	History
A	2.2.1	STN (Start neutral) output added. IEC 61850 mapping is made for the added output.
B	2.2.1	-
C	2.2.2	-
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	Added TRINN (Trip neutral) input and TRN (trip neutral) outputs. TRINALL (Trip all phases) input is changed from TRIN. IEC 61850 mapping is made for the added output. The block logic is corrected for the lockout functionality.
H	2.2.5	-
L	2.2.6	-
M	2.2.6	Fault current and voltage reporting is added

11.10.1.2 Three-phase operating mode

1. Check that *AutoLock* and *TripLockout* are both set to *Disabled* .
2. Initiate a three-phase fault.
   An adequate time interval between the faults should be considered, to overcome a reset time caused by the possible activation of the autorecloser function SMBRREC (79). The function must issue a three-pole trip in all cases when trip is initiated by any protection or some other built-in or external function. The following functional output signals must always appear simultaneously: TRIP, TR_A, TR_B, TR_C and TR3P.

11.10.1.3 1p/3p operating mode

In addition to various other tests, the following tests should be performed. They depend on the complete configuration of an IED:

Procedure

1. Make sure that *TripLockout* and *AutoLock* are both set to *Disabled*.
2. Initiate different single-phase-to-ground faults one at a time.
3. Initiate different phase-to-phase and three-phase faults.
   Consider using an adequate time interval between faults, to overcome a reset time, which is activated by SMBRREC (79). A three-pole trip should occur for each separate fault and all of the trips. Functional outputs TRIP, all TR_A, TR_B, TR_C and TR3P should be active at each fault.

   No other outputs should be active.
4. Initiate a single phase-to-ground fault and switch it off immediately when the trip signal is issued for the corresponding phase. Initiate the same fault once again within the reset time of the used SMBRREC (79).
5. Initiate a single phase-to-ground fault and switch it off immediately when the trip signal is issued for the corresponding phase. Initiate the second single phase-to-ground fault in one of the remaining

phases within the time interval, shorter than *tEvolvingFault* (default setting 2.0s) and shorter than the dead-time of SMBRREC (79), when included in the protection scheme.
Check that the second trip is a three-pole trip and that a three-phase autoreclosing attempt is given after the three-phase dead time. Functional outputs TRIP, TR_A, TR_B, TR_C and TR1P should be active during the first fault. No other outputs should be active. Functional outputs TRIP, all TR_A, TR_B, TR_C and TR3P should be active during second fault.

11.10.1.4 1p/2p/3p operating mode

In addition to other tests, the following tests, which depend on the complete configuration of an IED, should be carried out.

Procedure

1. Make sure that *AutoLock* and *TripLockout* are both set to *Disabled*.
2. Initiate different single-phase-to-ground faults one at a time.
   Take an adequate time interval between faults into consideration, to overcome a reset time, which is activated by the autorecloser function SMBRREC (79). Only a single-pole trip should occur for each separate fault and only one of the trip outputs (TR_A, TR_B, TR_C) should be activated at a time. Functional outputs TRIP and TR1P should be active at each fault. No other outputs should be active.
3. Initiate different phase-to-phase faults one at a time.
   Take an adequate time interval between faults into consideration, to overcome a reset time which is activated by SMBRREC (79). Only a two-phase trip should occur for each separate fault and only corresponding two trip outputs (TR_A, TR_B, TR_C) should be activated at a time. Functional outputs TRIP and TR2P should be active at each fault. No other outputs should be active.
4. Initiate a three-phase fault.
5. Initiate a single phase-to-ground fault and switch it off immediately when the trip signal is issued for the corresponding phase. Initiate the same fault once again within the reset time of the used SMBRREC (79).
   A single-phase fault shall be given at the first fault. A three-pole trip must be initiated for the second fault. Check that the corresponding trip signals appear after both faults. Functional outputs TRIP, TR_A, TR_B, TR_C and TR1P should be active during first fault. No other outputs should be active. Functional outputs TRIP, all TR_A, TR_B, TR_C and TR3P should be active during second fault.
6. Initiate a single phase-to-ground fault and switch it off immediately when the trip signal is generated for the corresponding phase. Initiate the second single-phase-to-ground fault in one of the remaining phases within the time interval, shorter than *tEvolvingFault* (default setting 2.0s) and shorter than the dead-time of SMBRREC (79), when included in the protection scheme.
7. Check, that the output signals, issued for the first fault, correspond to a two-phase trip for included phases. The output signals generated by the second fault must correspond to the three-phase tripping action.

11.10.1.5 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 *Disabled*.
2. Activate shortly the set lockout (SETLKOUT) signal in the IED.
3. Check that the circuit breaker lockout (CLLKOUT) signal is set.
4. Activate shortly thereafter, the reset lockout (RSTLKOUT) signal in the IED.
5. Check that the circuit breaker lockout (CLLKOUT) signal is reset.
6. Initiate a three-phase fault.

A three- trip should occur and all trip outputs TR_A, TR_B, TR_C should be activated. Functional outputs TRIP and TR3P should be active at each fault. The output CLLKOUT should not be set.

7. Activate the automatic lockout function, set *AutoLock* = *Enabled* and repeat.
   Besides the TRIP outputs, CLLKOUT should be set.
8. Reset the lockout signal by activating the reset lockout (RSTLKOUT) signal.
9. Activate the trip signal lockout function, set *TripLockout* = *Enabled* and repeat.
   All trip outputs (TR_A, TR_B, TR_C) and functional outputs TRIP and TR3P must be active and stay active after each fault, CLLKOUT should be set.
10. Reset the lockout.
    All functional outputs should reset.
11. Deactivate the trip signal lockout function, set *TripLockout* = *Disabled* and the automatic lockout function, set *AutoLock* = *Disabled*.

11.10.1.6 Completing the test

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

11.11 Monitoring

11.11.1 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 /Test / 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.

11.11.1.1 Function revision history

Document revision	Product revision	History
A	2.2.1	-
B	2.2.1	-
C	2.2.2	-
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	Binary quality inputs SENPRESQ and SENTEMPQ have been added for pressure and temperature sensor signals in order to control alarm and lockout signals. Whenever there is no sensor, the quality of the binary input will be low. If sensor quality is low, then lockout and alarm signals will get reset.

Table continues on next page

Document revision	Product revision	History
H	2.2.5	-
L	2.2.6	-
M	2.2.6	-

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

1. Connect the binary inputs to consider gas pressure and gas density to initiate the alarms.
2. Activate the binary input SENPRESQ.
3. 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* .
4. Gas pressure lockout input SETPLO can be used to set PRESLO.
5. Ensure that binary input SENPRESQ is activated and 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* .
6. Activate BLOCK binary input and check that the outputs PRESALM, PRESLO, ALARM and LOCKOUT disappears.
7. Reset the BLOCK binary input.
8. Ensure that pressure lockout condition exists and then activate the reset lockout input RESETLO and check that the outputs PRESLO and LOCKOUT reset.

11.11.1.3 Testing the gas medium supervision for temperature alarm and temperature lockout conditions

1. Activate the binary input SENTEMPQ.
2. 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* .
3. Temperature lockout input SETTLO can be used to set TEMPLO signal.
4. Ensure that binary input SENTEMPQ is activated and increase further the temperature input above *TempLOLimit* , check that the outputs TEMPLO and LOCKOUT appear after a set time delay of *tTempLockOut* .
5. Activate BLOCK binary input and check that the outputs TEMPALM, TEMPLO, ALARM and LOCKOUT disappear.
6. Reset the BLOCK binary input.
7. Ensure that temperature lockout condition exists and then activate the reset lockout input RESETLO and check that the outputs TEMPLO and LOCKOUT reset.

11.11.1.4 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.

11.11.2 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 SSIML protection are available on the local HMI under **Main menu /Test / 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.

11.11.2.1 Function revision history

Document revision	Product revision	History
A	2.2.1	-
B	2.2.1	-
C	2.2.2	-
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	Binary quality inputs SENLVLQ and SENTEMPQ have been added for pressure and temperature sensor signals in order to control alarm and lockout signals. Whenever there is no sensor, the quality of the binary input will be low. If sensor quality is low, then lockout and alarm signals will get reset.
H	2.2.5	-
L	2.2.6	-

11.11.2.2 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. Activate the binary input SENLEVELQ.
3. 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*.
4. Liquid level lockout input SENLVLLO can be used to set LVLLO.
5. Ensure that binary input SENLEVELQ is activated and 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*.
6. Activate BLOCK binary input and check that the outputs LVLALM, LVLLO, ALARM and LOCKOUT disappears.
7. Reset the BLOCK binary input.
8. Ensure that level lockout condition exists and then activate the reset lockout input RESETLO and check that the outputs PRESLO and LOCKOUT reset.

11.11.2.3 Testing the gas medium supervision for temperature alarm and temperature lockout conditions

1. Activate the binary input SENTEMPQ.
2. 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*.
3. Temperature lockout input SETTLO can be used to set TEMPLO signal.
4. Ensure that binary input SENTEMPQ is activated and increase further the temperature input above *TempLOLimit*, check that the outputs TEMPLO and LOCKOUT appear after a set time delay of *tTempLockOut*.
5. Activate BLOCK binary input and check that the outputs TEMPALM, TEMPLO, ALARM and LOCKOUT disappear.
6. Reset the BLOCK binary input.
7. Ensure that temperature lockout condition exists and then activate the reset lockout input RESETLO and check that the outputs TEMPLO and LOCKOUT reset.

11.11.2.4 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.

11.11.3 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**

11.11.3.1 Verifying the settings

1. Connect the test set for the injection of a three-phase current to the appropriate current terminals of the IED.
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:

POSCLS	0	1	0
POSOPN	0	0	1

4. Test of CB contact operation time
   4.1. Test the set timing defined by *OpTmOpnCor*, *OpTmClsCor*, *OpTmOpnAlmLev* and *OpTmClsAlmLev*.
   4.2. Change the status of the auxiliary contacts such that operation time to open `OPTMOPN` and operation time to close `OPTMCLS` exceed the respective set values (*OpTmOpnAlmLev* and

OpTmClsAlmLev). The measured operation time for opening and closing is shown on OPTMOPN and OPTMCLS respectively.

4.3. Check that OPTMOPNALM and OPTMCLSALM are activated.

5. Test of CB status
   5.1. Test the set current level defined by *AccmAbrStopCur*.
   5.2. Check the CLSPOS output by changing the POSOPN to *0* and POSCLS to *1*.
   5.3. Check the OPNPOS output by changing the POSOPN to *1* and POSCLS to *0* and also inject the current in the selected phase slightly lower and higher than *AccmAbrStopCur* set value. Only for a current lower than set *AccmAbrStopCur* should activate the output POSOPN.
   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 *AccmAbrStopCur* set value.
6. Test of remaining life of CB
   6.1. Test the set timing defined by *RatedOpCur*, *RatedFltCur*, *OpNumRatedCur*, OpNumFltCur, *DirCff*, *RmnLifeAlmLev*.
   6.2. Vary the phase current in the selected phase from below rated operated current, *RatedOpCur* to above rated fault current, *RatedFltCur* of a breaker.
   6.3. The remaining life of CB output RMNLIFE is estimated when the CB is changed from closed to open position. Check that the output RMNLIFE is decreased with a value that corresponds to the injected current.
   6.4. RMNLIFEALM is activated as soon as RMNLIFE is below the set *RmnLifeAlmLev* value.
7. Test of accumulated contact abrasion
   7.1. Test the actual set values defined by *AccmAbrClcMod* to *Aux Contact*, *OpnTmTrvlCor* and *AccmAbrWrnLev*.
   7.2. Inject phase current in the selected phase such that its value is greater than set *AccmAbrStopCur* value.
   7.3. When the breaker goes to open position, accumulated contact abrasion ACCMABR is calculated. The calculated value can be seen on the output ACCMABR.
   7.4. Warning signal ACCMABRWRN appears when ACCMABR is greater than set *AccmAbrWrnLev* value.
   7.5. Alarm signal ACCMABRALM appears if ACCMABR exceeds further to the threshold value *AccmAbrAlmLev*.
   7.6. Calculation of accumulated contact abrasion ACCMABR is stopped when injected current is lower than set *AccmAbrStopCur* value.
8. Test of CB operation cycles
   8.1. Test the actual set values defined by *OpNumWrnLev* and *OpNumAlmLev*.
   8.2. The operation counter, OPNUM is updated for every close-open sequence of the breaker by changing the position of auxiliary contacts POSCLS and POSOPN.
   8.3. OPCNTWRN is activated when OPNUM value exceeds the set *OpNumWrnLev* value. The actual value can be read on the output OPNUM.
   8.4. OPCNTALM is activated when OPNUM value exceeds the set *OpNumAlmLev* value.
9. Test of CB spring charge monitoring
   9.1. Test the actual set value defined by *SpcTmAlmLev*.
   9.2. Enable SPC input. Also activate SPD after a time greater than set time *SpcTmAlmLev*.
   9.3. At this condition, SPCALM is activated.
10. Test of CB gas pressure indication

10.1. Test the actual set value defined by *tGasPresAlm* and *tGasPresLO*.
10.2. The output GPRESALM is activated after a time greater than set time of *tGasPresAlm* value if the input PRESALM is enabled.
10.3. The output GPRESLO is activated after a set time of *tGasPresLO* value if the input PRESLO is enabled.

11. Test of CB coil open indication
    11.1. Enable the binary inputs EXEOPNXCBR and EXEOPNCSWI.
    11.2. At this condition, COLOPN is activated.

11.11.3.2 Completing the test

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

11.11.4 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.

11.11.5 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.

11.11.5.1 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.

11.11.6 Current harmonic monitoring CHMMHAI(ITHD)

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

11.11.6.1 Function revision history

Document revision	Product revision	History
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	-
H	2.2.4	-
J	2.2.5	Updated monitoring till 9th order current harmonics. Refer to document revision H for monitoring till 5th order current harmonics.
L	2.2.6	-
M	2.2.6	-

11.11.6.2 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 # = 2nd, 3rd, 4th…9th)

1. Supply the IED with current at rated value.
2. Apply 2nd 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 9th order.

11.11.6.3 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.

11.11.7 Voltage harmonic monitoring VHMMHAI(VTHD)

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

11.11.7.1 Function revision history

Document revision	Product revision	History
D	2.2.3	-
E	2.2.3	-
F	2.2.4	-
G	2.2.4	-
H	2.2.4	-
J	2.2.5	Updated monitoring till 9th order voltage harmonics. Refer to document revision H for monitoring till 5th order voltage harmonics.
L	2.2.6	-
M	2.2.6	-

11.11.7.2 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 # = 2nd, 3rd, 4th…9th)

1. Supply the IED with voltage at rated value.
2. Apply 2nd 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 9th order.

11.11.7.3 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.

11.12 Metering

11.12.1 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* = *Enable* or *Operation* = *Disable* and the function blocked or unblocked. The pulse counter value is then checked in PCM600 or on the local HMI.

11.12.2 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.

11.12.2.1 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 three-phase currents and three-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 three-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 three-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 three-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 three-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.

11.12.2.2 Completing the test

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

11.13 Station communication

11.13.1 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.

11.14 Remote communication

11.14.1 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 31. 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.

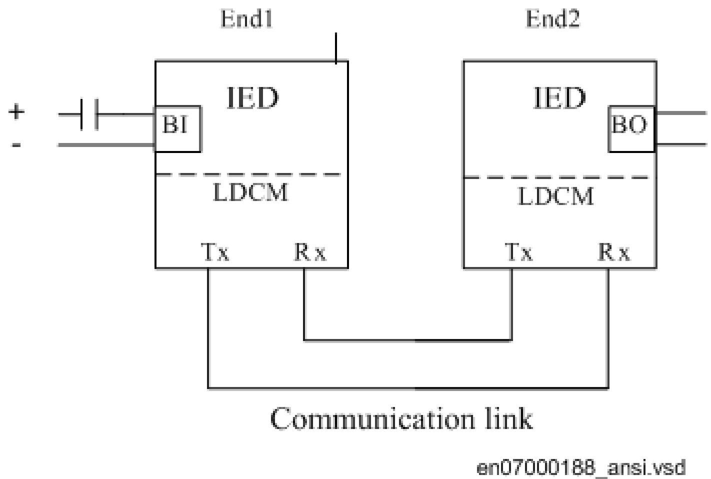


Figure 31: Test of RTC with I/O

11.15 Basic IED functions

11.15.1 Parameter setting group handling SETGRPS

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

11.15.1.1 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.

11.15.1.2 Completing the test

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

11.16 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 *Enable* setting to *Disable*. Press the 'E' key and the left arrow key.
3. Answer *YES*, press the 'E' key and exit the menus.

Section 12 Commissioning and maintenance of the fault clearing system

12.1 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 highlighting 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 magnitudes 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.

12.2 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 practices of the user should be followed. However, Hitachi Energy'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.

12.2.1 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.

12.2.2 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.

Hitachi Energy protection IEDs are preferably tested by aid of components from the COMBITEST testing system or FT test systems 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.

Important components of FT test system are FT1, FTx, FT19, FT19RS, FR19RX switches and assemblies as well as FT-1 test plug.

12.2.2.1 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

12.2.2.2 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.

12.2.2.3 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.

12.2.2.4 Alarm test

When inserting the test handle of RTXP or using FT plugs, the alarm and event signalling is normally blocked. This is done in the IED by setting the event reporting to *Disabled* 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.

12.2.2.5 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.

12.2.2.6 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.

12.2.2.7 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 ground-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 ground-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.

12.2.2.8 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 13 Troubleshooting

13.1 Checking the self supervision signals

13.1.1 Checking the self supervision function

13.1.1.1 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.

13.1.2 Self supervision HMI data

13.1.2.1 General IED status

The following table shows the general IED status signals.

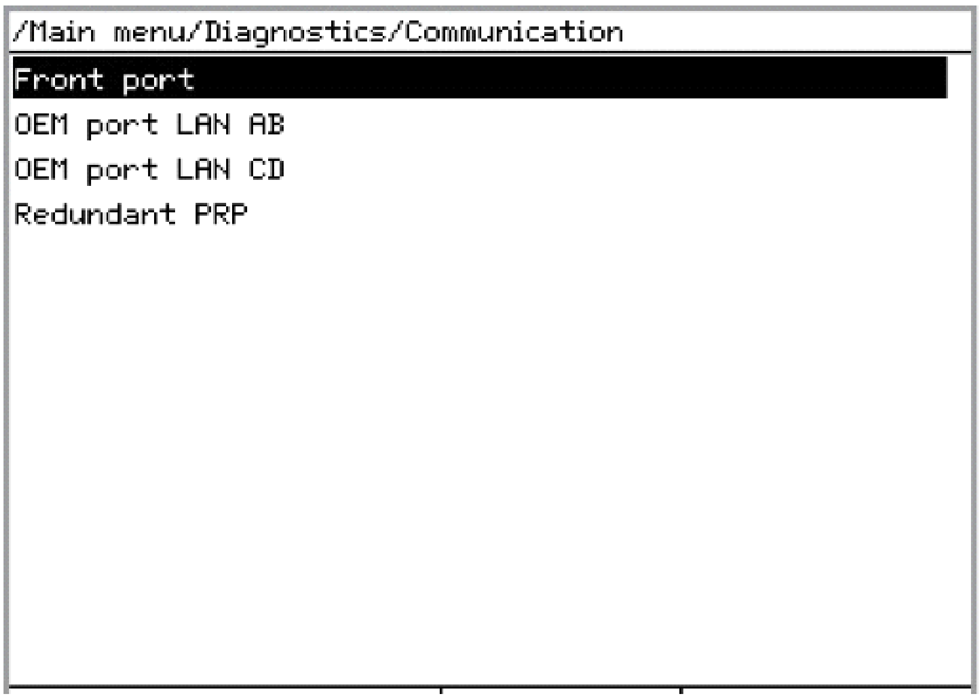
Table 16: Signals from the General menu in the diagnostics tree.

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 Hitachi Energy representative for service. None.
Real time clock Fail	The real time clock has been reset.	Set the clock.
ADC-module OK	No problem detected.	None.
ADC-module Fail	The AD conversion module has failed.	Contact your Hitachi Energy representative for service.
(Protocol name) Ready	No problem detected.	None.
Table continues on next page		

Indicated result	Possible reason	Proposed action
(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 Hitachi Energy representative for service.

13.1.2.2 Communication Diagnostics

All the communications in the IED (Front port and rear LAN AB/CD ports) can be supervised via the local HMI under **Main menu/Diagnostics/Communication** .



IEC140000115-2-en.vsd

Figure 32: The PMU communication diagnostic menu

Denial of Service on Communication Ports

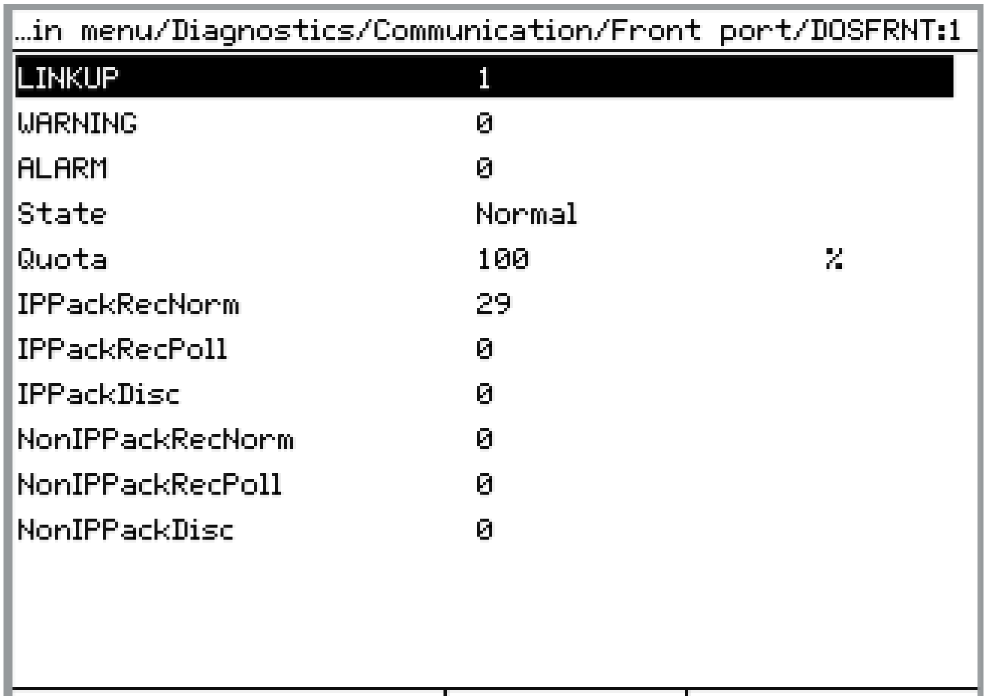
The denial of service functions (DOSFRNT, DOSOEMAB and DOSOEMCD) are designed to limit the CPU load that can be produced by Ethernet network traffic on the IED. The communication facilities must not be allowed to compromise the primary functionality of the device. All inbound network traffic will be quota controlled so that too heavy network loads can be controlled. Heavy network load might for instance be the result of malfunctioning equipment connected to the network.

DOSFRNT, DOSOEMAB and DOSOEMCD measures the IED load from communication and, if necessary, limit it for not jeopardizing the IEDs control and protection functionality due to high CPU load. The following outputs are available in ACT via PCM600 for each DOS function block:

- LINKUP indicates the Ethernet link status
- WARNING indicates that communication (frame rate) is higher than normal
- ALARM indicates the IED limits communication

In addition, it is possible to monitor the status of the communication ports via the Local HMI under **Main menu/Diagnostics/Communication** .

As an example, IED front communication port can be monitored via LHMI under **Main menu/Diagnostics/Communication/Front port/DOSFRNT:1** .



IEC140000116-2-en.vsd

Figure 33: The PMU communication front port diagnostic

PMU Diagnostics

The PMU diagnostics presents the status of the PMU client connections for the user and also any errors that are encountered by a client during the connection. The status of this component is only shown on the Local HMI under **Main menu /Diagnostics /Communication /PMU diagnostics /PMUSTATUS:1** .

All these outputs are reset to defaults after the IED reboots or if the user clears the diagnostics from the LHMI clear menu. Following table shows the PMUSTATUS output signals and their possible output states.

Table 17: PMUSTATUS output signals available only via Local HMI

Name	Status Values	Description
PMUInst1	Off Ready Data Invalid Config Error	PMU instance 1 status
PMUInst2	Off Ready Data Invalid Config Error	PMU instance 2 status
TCPConnStatus1	Off Active	TCP connection 1 status
TCPConnStatus2	Off Active	TCP connection 2 status
TCPConnStatus3	Off Active	TCP connection 3 status
TCPConnStatus4	Off Active	TCP connection 4 status
TCPConnStatus5	Off Active	TCP connection 5 status
TCPConnStatus6	Off Active	TCP connection 6 status
TCPConnStatus7	Off Active	TCP connection 7 status
TCPConnStatus8	Off Active	TCP connection 8 status
TCPCtrlDataErrCnt	0 to 4294967295	Number of times IED has failed to respond for a command requested on C37.118 or IEEE1344 on TCP
TCPCtrlCfgErrCnt	0 to 4294967295	Number of errors that have occurred due to incorrect configuration request by the client on TCP
UDPStreamStat1	Off Active Config Error Off by client Client unreachable	UDP data stream status for UDP Group1
UDPCtrlConnCnt1	0 to 4	Number of UDP control client connected on Group1
UDPStreamStat2	Off Active Config Error Off by client Client unreachable	UDP data stream status for UDP Group2
UDPCtrlConnCnt2	UDPCtrlConnCnt2 0 to 4	Number of UDP control client connected on UDP Group2
UDPStreamStat3	Off Active Config Error Off by client Client unreachable	UDP data stream status for UDP Group3
UDPCtrlConnCnt3	0 to 4	Number of UDP control client connected on UDP Group3
Table continues on next page		

UDPStreamStat4	Off Active Config Error Off by client Client unreachable	UDP data stream status for UDP Group4
UDPCtrlConnCnt4	0 to 4	Number of UDP control client connected on UDP Group4
UDPStreamStat5	Off Active Config Error Off by client Client unreachable	UDP data stream status for UDP Group5
UDPCtrlConnCnt5	0 to 4	Number of UDP control client connected on UDP Group5
UDPStreamStat6	Off Active Config Error Off by client Client unreachable	UDP data stream status for UDP Group6
UDPCtrlConnCnt6	0 to 4	Number of UDP control client connected on UDP Group6
UDPCtrlDataErrCnt	0 to 4294967295	Number of times IED has failed to respond for a command requested on C37.118 or IEEE1344 over TCP control for UDP
UDPCtrlCfgErrCnt	0 to 4294967295	Number of errors that have occurred due to incorrect configuration request by the client over TCP control for UDP

The following describes the various output states:

- *PMUInst1, PMUInst2* – The outputs on these channels show the status of the two available PMUREPORT instances.
  Each status output has the following states:
  - Off – When the component is not in operation.
  - Ready – when it is sending data based on the configuration.
  - ConfigError – if same PMU Id is used for both the instances.
  - Data Invalid – when the PMU is producing an invalid data stream and the data from it cannot be trusted.
- *TCPConnStatus1-8* – The 8 TCP connection status outputs show if there is an active TCP connection or not. Each status output has the following states:
  - Off - No active connection.
  - Active - A client is connected and receiving data.
- *TCPCtrlDataErrCnt* - The output shows the number of times the PMU has failed to send the configuration frame, header frames or data frame on C37.118 or IEEE1344.
- *TCPCtrlCfgErrCnt* - The outputs show the number of errors that have occurred due to incorrect configuration request by the client. These errors can be due to client trying to send a wrong PMUId on this link than the one that is configured, or trying to request an IEEE1344 configuration on C37.118 channel.
- *UDPStreamStat1-6* - The six UDP stream status outputs have the following states:

    - Off - UDP data stream is turned off.
    - Active – UDP data stream is on.
    - ConfigError – When the stream is set to send a stream from PMU instance not instantiated in ACT.
    - Off by client – UDP data stream is turned off by an external client.
    - Client Unreachable – Unable to send data to configured client, or host unreachable.
- *UDPCtrlConnStatus1-6* – The 6 UDP stream control connection status output, shows the number of concurrent clients connected to control the UDP data stream. A maximum of 4 clients can be connected concurrently.
- *UDPCtrlDataErrCnt* - The output shows the number of times IED has failed to respond for a command requested on C37.118 or IEEE1344.
- *UDPCtrlCfgErrCnt* - The output shows the number of errors that have occurred due to incorrect configuration request by the client. These errors can be due to client trying to send a wrong PMUId on this link than the one configured, or trying to request an IEEE1344 configuration on C37.118 channel.

The PMUSTATUS output signals can also be mapped on DNP3.0 protocol. Table 18 shows the different numbers corresponding to different output statuses.

Table 18: The PMUSTATUS output signals mapped on DNP3.0 protocol

PMU Diagnostic Output	Status	DNP3.0 Mapping
PMUInst1	Off Ready Config Error Data Invalid	0 1 2 3
PMUInst2	Off Ready Config Error Data Invalid	0 1 2 3
TCPConnStatus1	Off Active	0 1
TCPConnStatus2	Off Active	0 1
TCPConnStatus3	Off Active	0 1
TCPConnStatus4	Off Active	0 1
TCPConnStatus5	Off Active	0 1
TCPConnStatus6	Off Active	0 1
TCPConnStatus7	Off Active	0 1
TCPConnStatus8	Off Active	0 1
UDPStreamStat1	Off Active Config Error Off by client Client unreachable	0 1 2 3 4

Table continues on next page

UDPStreamStat2	Off Active Config Error Off by client Client unreachable	0 1 2 3 4
UDPStreamStat3	Off Active Config Error Off by client Client unreachable	0 1 2 3 4
UDPStreamStat4	Off Active Config Error Off by client Client unreachable	0 1 2 3 4
UDPStreamStat5	Off Active Config Error Off by client Client unreachable	0 1 2 3 4
UDPStreamStat6	Off Active Config Error Off by client Client unreachable	0 1 2 3 4

13.2 Fault tracing

13.2.1 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 19.

Table 19: 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.
BIMnn	READY / FAIL	BIM error. Binary input module Error status. Affected applications are blocked.
Table continues on next page		

HMI Signal Name:	Status	Description
BOMn	READY / FAIL	BOM error. Binary output module Error status.Affected applications are blocked.
IOMn	READY / FAIL	IOM-error. Input/Output Module Error status. Affected applications are blocked.
MIMn	READY / FAIL	mA input module MIM1 failed.Affected applications are blocked.
RTC	READY / FAIL	This signal will be active when there is a hardware error with the real time clock and the affected applications are blocked. In case of RTC error, the time will be reset to 2004-01-01.
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.Affected applications are blocked.
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 19. 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.

13.2.2 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 20: 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.

13.2.3 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 22: 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: <Hitachi Energy _MU0101>
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: <Hitachi Energy _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: <Hitachi Energy _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 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 3PHSUM.
Invalid value set for PMU Parameters	There are two possible error conditions: Check if the following parameters are set correctly on PMUREPORT:1 *ReportRate* or *SvcClass* or parameter PRIMVAL:1.*FrequencySel* is not set as 50Hz / 60Hz.
	Check if the following parameters are set correctly on PMUREPORT:1 *ReportRate* or *SvcClass* or *RptTimetag* or parameter PRIMVAL:1.*FrequencySel* is not set as 50Hz / 60Hz.
Table continues on next page	

Headline	Explanation
Invalid phase angle reference	The selected *PhaseAngleRef* corresponds to an analog channel that is not configured. 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. Enable GOOSE on access points: <Access Points>, can be any of these: AP_FRONT, AP_1, AP_2, AP_3, AP_4, AP_5, AP_6,AP_7, AP_8
LDCM not running the application image	LDCM in <slot number> is running the factory image instead of the application image. The factory image is older than the required FW version and does not contain the latest updates and fixes. Reboot the IED. If the problem persists, update the LDCM firmware or replace the board.
LDCM rate (2M) is not supported	The <firmware version> does not support 2M mode. Set the LDCM to 64k bit mode.
LDCM version is not accepted	<device name> firmware version <version string> is not accepted. The minimum accepted version is <version string>. Update the LDCM firmware or replace the board.
OEM not running the application image	OEM in pos <slot number> is running the factory image instead of the application image. The factory image is older than the required FW version and does not contain the latest updates and fixes. Reboot the IED. If the problem persists, update the OEM firmware or replace the board.
SFP unplugged from the slot	SFP has been unplugged from the slot. 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. Restart IED and consider reconfigure of HW modules in LHMI path: **\Main menu\Configuration\Reconfigure HW modules** to get the updated hardware list.
Non Hitachi Energy vendor SFP detected	Non Hitachi Energy vendor SFP detected. Corresponding hardware(s) is set to fail. Use Hitachi Energy approved SFP's.
Merging unit has no access point	Merging unit has no access point. Check AP configuration.
FPGA version is not accepted	FPGA version is not accepted. If OEM or NUM FPGA code is of too low version, then update.
Duplicate IP address detected	Duplicate IP address detected. Duplicate IP: <xxxx> Access Point: <xxxx> Access Point MAC: <xxxx> IP duplicator's MAC: <xxxx>

Table continues on next page

Headline	Explanation
High CPU Load	Total: 81.3% Core0: 64.2 % Core1: 98.4% Tips to reduce the CPU load: • Configure minimum number of functional blocks • Switch off functional blocks not in use • Switch off protocols not in use • Remove IEC 61850 data sets not in use • Configure minimum communication data points
Invaild parameter set for MIM	The IED prevented from applying the user settings for *IMinChx*, *IMaxChx*, *ValueMinch*, *ValueMaxCh* as they result in incorrect zero point calculation. Settings are reverted to default values. MIM:pX Channels:Channel_numbers
Mismatching data batch size to DistRep	Check cycle time for SMAI and 3PHSUM blocks connected to Disturbance Report blocks. SMAI and 3PHSUM blocks shall have the same cycle time.
LDCM missing connections	LDCM transmitter is missing connections. Check the LDCMTRN block.
LDCM system frequency	System frequency is different in local and remote end of LDCM link. Check the parameter FrequencySel at both ends.
LDCM AnalogLatency	LDCM analog latency is different in local and remote. Check the LDCM parameters AnalogLatency and remAinLatency at both ends.
HW Configuration missing	HW configuration necessary to configure RSTP on <Access Point> is missing. Please contact the SA - T Supportline to fix this error. Access points can be any of these : AP_1, AP_3
SMAI incorrect calculated phase-earth	Calculated phase-earth values are used from one or more SMAIs configured for phase-phase inputs, without connected N input. However, this configuration, combined with unbalanced three-phase input, will result in incorrectly calculated phase-earth values. This in turn may result in maloperation of functions connected to SMAIs configured this way, if the function uses phase-earth based values. Further, if SUM3PH is connected to such a SMAI, then its output values will be incorrect, and connected functions may maloperate. To remedy the situation, please revise the configuration from this perspective.

13.2.4 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.

13.3 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 Hitachi Energy for repair. When a printed circuit board is sent to Hitachi Energy , 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 ground.

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.

13.4 Repair support

If an IED needs to be repaired, the whole IED must be removed and sent to an Hitachi Energy Logistic Center. Please contact the local Hitachi Energy representative to get more details.

e-mail: *sa-t-order@hitachienergy.com*

13.5 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 14 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
AP	Access Point
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
CAM	Central Account Management
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
FIPS	Federal Information Processing Standards
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 IP20- Protected against solid foreign objects of 12.5mm diameter and greater.
IP 40	Ingression protection, according to IEC 60529, level IP40-Protected against solid foreign objects of 1mm diameter and greater.
IP 54	Ingression protection, according to IEC 60529, level IP54-Dust-protected, protected against splashing water.
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
LDAPS	Lightweight Directory Access Protocol
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/Wye 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 gound-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 ground-fault current

$3V_O$	Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage

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