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This product includes cryptographic software written/developed by: Eric Young (eay@cryptsoft.com) and Tim Hudson (tjh@cryptsoft.com).

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Section 14 Glossary
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

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

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 application and functionality descriptions and lists function blocks, logic diagrams, input and output signals, setting parameters and technical data, sorted per function. The manual can be used as a technical reference during the engineering phase, installation and commissioning phase, and during normal service.

The communication protocol 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

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1.3.3 Related documents

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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.

![Electrical Warning Icon]

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

![Warning Icon]

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

![Caution Hot Surface Icon]
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/output signal name indicates that the signal
    must be connected to another function block in the application configuration
    to achieve a valid application configuration.
- Logic diagrams describe the signal logic inside the function block and are
  bordered by dashed lines.
• Signals in frames with a shaded area on their right hand side represent setting parameter signals that are only settable via the PST or LHMI.
• If an internal signal path cannot be drawn with a continuous line, the suffix -int is added to the signal name to indicate where the signal starts and continues.
• Signal paths that extend beyond the logic diagram and continue in another diagram have the suffix “-cont.”
• Dimensions are provided both in inches and mm. If it is not specifically mentioned then the dimension is in mm.

1.4.3 IEC61850 edition 1 / edition 2 mapping

Table 1: IEC61850 edition 1 / edition 2 mapping

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Section 2 Safety information

2.1 Symbols on the product

All warnings must be observed.

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

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.
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 IEDs operation. Be careful and check regulations before making the change.

2.3 Note signs

Observe the maximum allowed continuous current for the different current transformer inputs of the IED. See technical data.
## Section 3 Available functions

### 3.1 Main protection functions

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#### Impedance protection

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<td>High speed distance protection</td>
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<tr>
<td>ZMFCPDIS</td>
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<td>High speed distance protection for series compensated lines</td>
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<td>ZMRPSB</td>
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<td>Power swing detection</td>
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<td>Power swing logic</td>
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<td>Pole slip/out-of-step protection</td>
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<td>OOSPPAM</td>
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<td>Out-of-step protection</td>
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<td>ZCVPSOF</td>
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<td>Automatic switch onto fault logic, voltage and current based</td>
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<td>PPLPHIZ</td>
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<td>Phase preference logic</td>
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### 3.2 Back-up protection functions

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<td>PHPIOC</td>
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<td>Instantaneous phase overcurrent protection</td>
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<td>OC4PTOC</td>
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<td>Four step phase overcurrent protection</td>
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<td>EFPIOC</td>
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<td>Instantaneous residual overcurrent protection</td>
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<td>EF4PTOC</td>
<td>51N</td>
<td>Four step residual overcurrent protection</td>
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<td>NS4PTOC</td>
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<td>Four step directional negative phase sequence overcurrent protection</td>
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<td>SDEPSDE</td>
<td>67N</td>
<td>Sensitive directional residual overcurrent and power protection</td>
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<td>LCPTTR</td>
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<td>Thermal overload protection, one time constant, Celsius</td>
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<td>LFPTTR</td>
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<td>Thermal overload protection, one time constant, Fahrenheit</td>
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<td>CCRBRF</td>
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<td>Breaker failure protection</td>
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<td>STBPTOC</td>
<td>50STB</td>
<td>Stub protection</td>
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<td>CCPDSC</td>
<td>52PD</td>
<td>Pole discordance protection</td>
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<td>GUPPDUP</td>
<td>37</td>
<td>Directional underpower protection</td>
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<td>GOPPDOP</td>
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<td>Directional overpower protection</td>
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<td>BRCPPTOC</td>
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<td>Broken conductor check</td>
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<td>VRPVOC</td>
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<td>Voltage restrained overcurrent protection</td>
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#### Voltage protection

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<td>Two step overvoltage protection</td>
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<td>Two step residual overvoltage protection</td>
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<td>Overexcitation protection</td>
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<td>VDCPTOV</td>
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<td>Voltage differential protection</td>
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<td>LOVPTUV</td>
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<td>Loss of voltage check</td>
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<td>PAPGAPC</td>
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<td>Radial feeder protection</td>
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<td><strong>Frequency protection</strong></td>
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<td>Underfrequency protection</td>
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<td>SAPTOF</td>
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<td>Overfrequency protection</td>
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<td><strong>General calculation</strong></td>
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1) 67 requires voltage  
2) 67N requires voltage

### 3.3 Control and monitoring functions

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<td>Synchrocheck, energizing check and synchronizing</td>
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<td>SMBRREC</td>
<td>79</td>
<td>Autorecloser</td>
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<td>VSGAPC</td>
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<td>Selector mini switch</td>
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<td>Generic communication function for Double Point indication</td>
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<td>Single point generic control 8 signals</td>
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### Available functions

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<td>Function commands generic for IEC 60870-5-103</td>
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<td>I103POSCMD</td>
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<td>IED commands with position and select for IEC 60870-5-103</td>
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<td>I103USRCMD</td>
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#### Secondary system supervision

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<td>CCSSPVC</td>
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<td>FUFSPVC</td>
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#### Logic

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<td>TMAGAPC</td>
<td>Trip matrix logic</td>
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<td>ALMCALH</td>
<td>Logic for group alarm</td>
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<td>WRNICALH</td>
<td>Logic for group warning</td>
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<td>INDCALH</td>
<td>Logic for group indication</td>
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| List of configurable logic blocks                                          |       |
| AND, OR, INV, PULSETIMER, GATE, TIMERSET, XOR, LL, SRMEMORY, RSMEMORY    | 40-420|

| List of configurable logic blocks Q/T                                      |       |
| ANDQ, ORQ, INVERTERQ, XORQ, RSMEMORYQ, T, RSMEMORYQ, T, TIMERSETQ, PULSETIERQ, INVALIDQ, INDCOMBSPQ, T, INDEXTEQPQ | 0-1   |

| List of extension logic package                                             |       |
| SLGAPC, VSGAPC, AND, OR, PULSETIMER, GATE, TIMERSET, XOR, LL, SRMEMORY, INV | 0-1   |

| FXDSIGN | Fixed signal function block | 1       |

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<td>B16I</td>
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<td>Boolean 16 to Integer conversion with Logic Node representation</td>
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<td>IB16</td>
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<td>Integer to Boolean 16 conversion</td>
<td>18</td>
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<tr>
<td>ITBAPC</td>
<td></td>
<td>Integer to Boolean 16 conversion with Logic Node representation</td>
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<td>TEIGAPC</td>
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<tr>
<td>CVMMXN, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU</td>
<td>Monitoring</td>
<td>Measurements</td>
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<td>AISVBAS</td>
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<td>Event function</td>
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<td>SPGAPC</td>
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<td>SP16GAPC</td>
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<td>Generic communication function for Single Point indication 16 inputs</td>
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<td>Generic communication function for Measured Value</td>
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<td>71</td>
<td>Liquid medium supervision</td>
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<td>I103EF</td>
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<td>I103FLTROF</td>
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<td>L4UFCNT</td>
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<td>Event counter with limit supervision</td>
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<td><strong>Metering</strong></td>
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<td>Function for energy calculation and demand handling</td>
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### 3.4 Communication

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<td>ADE</td>
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<td>LON communication protocol</td>
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<td>Network variables via LON</td>
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<td>Operation selection for RS485</td>
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<td>DNP3.0 communication general protocol</td>
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<td>DNP3.0 communication general TCP protocol</td>
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<td>CH1TCP, CH2TCP, CH3TCP, CH4TCP</td>
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<td>DNP3.0 for TCP/IP communication protocol</td>
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<td>GOOSE function block to receive an integer value</td>
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<td>GOOSEMVRCV</td>
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<td>GOOSE function block to receive a measurand value</td>
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<td>Multiple command and transmit</td>
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<td>FRONT, LANAIB, LANA, LANC, LANC</td>
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<td>GATEWAY</td>
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<td>PCMACCS</td>
<td>V</td>
<td>IED Configuration Protocol</td>
<td>REL670 1</td>
</tr>
<tr>
<td>SECALARM</td>
<td>V</td>
<td>Component for mapping security events on protocols such as DNP3 and IEC103</td>
<td>REL670 1</td>
</tr>
<tr>
<td>FSTACCS</td>
<td>V</td>
<td>Field service tool access via SPA protocol over ethernet communication</td>
<td>REL670 1</td>
</tr>
<tr>
<td>ACTIVLOG</td>
<td>V</td>
<td>Activity logging parameters</td>
<td>REL670 1</td>
</tr>
<tr>
<td>ALTRK</td>
<td>V</td>
<td>Service Tracking</td>
<td>REL670 1</td>
</tr>
<tr>
<td>SINGLELCCH</td>
<td>V</td>
<td>Single ethernet port link status</td>
<td>REL670 1</td>
</tr>
<tr>
<td>PRPSTATUS</td>
<td>V</td>
<td>Dual ethernet port link status</td>
<td>REL670 1</td>
</tr>
<tr>
<td>PRP</td>
<td>V</td>
<td>Process bus communication IEC 61850-9-2 1)</td>
<td>REL670 0-1</td>
</tr>
</tbody>
</table>

Remote communication

- Binary signal transfer receive/transmit: 6/36
- Transmission of analog data from LDCM: 1
- Receive binary status from remote LDCM: 6/3/3

Scheme communication

Table continues on next page
### 3.5 Basic IED functions

#### Table 2: Basic IED functions

<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTEERRSIG</td>
<td>Self supervision with internal event list</td>
</tr>
<tr>
<td>SELFSSUPEVLST</td>
<td>Self supervision with internal event list</td>
</tr>
<tr>
<td>TIMESYNYCHGEN</td>
<td>Time synchronization module</td>
</tr>
<tr>
<td>SYNHCMPI, SYNCHCAN, SYNCHCMPPS, SYNCHCMPPS, SYNCHCMPPS</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>SYNCHCMPPS</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>TIMEOUTE</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>DSTBEGIN, DSTENABLE, DSTEND</td>
<td>GPS time synchronization module</td>
</tr>
<tr>
<td>IRIG-B</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>SETGRPS</td>
<td>Number of setting groups</td>
</tr>
<tr>
<td>ACTVGRP</td>
<td>Parameter setting groups</td>
</tr>
<tr>
<td>TESTMODE</td>
<td>Test mode functionality</td>
</tr>
<tr>
<td>CHNGLCK</td>
<td>Change lock function</td>
</tr>
</tbody>
</table>

1) Only included for 9-2LE products
<table>
<thead>
<tr>
<th>IEC 61850 function name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMBI</td>
<td>Signal matrix for binary inputs</td>
</tr>
<tr>
<td>SMBO</td>
<td>Signal matrix for binary outputs</td>
</tr>
<tr>
<td>SMMI</td>
<td>Signal matrix for mA inputs</td>
</tr>
<tr>
<td>SMAI1 - SMAI20</td>
<td>Signal matrix for analog inputs</td>
</tr>
<tr>
<td>3PHSUM</td>
<td>Summation block 3 phase</td>
</tr>
<tr>
<td>ATHSTAT</td>
<td>Authority status</td>
</tr>
<tr>
<td>ATHCHCK</td>
<td>Authority check</td>
</tr>
<tr>
<td>AUTHMAN</td>
<td>Authority management</td>
</tr>
<tr>
<td>FTPACCS</td>
<td>FTP access with password</td>
</tr>
<tr>
<td>SPACOMMMAP</td>
<td>SPA communication mapping</td>
</tr>
<tr>
<td>SPATD</td>
<td>Date and time via SPA protocol</td>
</tr>
<tr>
<td>DOSFRNT</td>
<td>Denial of service, frame rate control for front port</td>
</tr>
<tr>
<td>DOSLANAB</td>
<td>Denial of service, frame rate control for OEM port AB</td>
</tr>
<tr>
<td>DOSLANCD</td>
<td>Denial of service, frame rate control for OEM port CD</td>
</tr>
<tr>
<td>DOSSCKT</td>
<td>Denial of service, socket flow control</td>
</tr>
<tr>
<td>GBASVAL</td>
<td>Global base values for settings</td>
</tr>
<tr>
<td>PRIMVAL</td>
<td>Primary system values</td>
</tr>
<tr>
<td>ALTMS</td>
<td>Time master supervision</td>
</tr>
<tr>
<td>ALTIM</td>
<td>Time management</td>
</tr>
<tr>
<td>ALTRK</td>
<td>Service tracking</td>
</tr>
<tr>
<td>ACTIVLOG</td>
<td>Activity logging parameters</td>
</tr>
<tr>
<td>FSTACCS</td>
<td>Field service tool access via SPA protocol over ethernet communication</td>
</tr>
<tr>
<td>PCMACCS</td>
<td>IED Configuration Protocol</td>
</tr>
<tr>
<td>SECALARM</td>
<td>Component for mapping security events on protocols such as DNP3 and IEC103</td>
</tr>
<tr>
<td>DNPGEN</td>
<td>DNP3.0 communication general protocol</td>
</tr>
<tr>
<td>DNPGENTCP</td>
<td>DNP3.0 communication general TCP protocol</td>
</tr>
<tr>
<td>CHSEROPT</td>
<td>DNP3.0 for TCP/IP and EIA-485 communication protocol</td>
</tr>
<tr>
<td>MSTSER</td>
<td>DNP3.0 for serial communication protocol</td>
</tr>
<tr>
<td>OPTICAL103</td>
<td>IEC 60870-5-103 Optical serial communication</td>
</tr>
<tr>
<td>RS485103</td>
<td>IEC 60870-5-103 serial communication for RS485</td>
</tr>
<tr>
<td>IEC61850-8-1</td>
<td>Parameter setting function for IEC 61850</td>
</tr>
<tr>
<td>HORZCOMM</td>
<td>Network variables via LON</td>
</tr>
<tr>
<td>LONSPA</td>
<td>SPA communication protocol</td>
</tr>
<tr>
<td>LEDGEN</td>
<td>General LED indication part for LHMI</td>
</tr>
</tbody>
</table>
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

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.

The user could also check the software version, the IED's serial number and the installed modules and their ordering number to ensure that the IED is according to delivery and ordering specifications.

Energize the power supply of the IED to pickup. This could be done in a number of ways, from energizing a whole cubicle to energizing a single IED. The user should re-configure the IED to activate the hardware modules in order to enable the self-supervision function to detect possible hardware errors. Set the IED time if no time synchronization source is configured. Check also the self-supervision function in **Main menu/Diagnostics/Monitoring** menu in local HMI to verify that the IED operates properly.

#### 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.
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. See section "Checking the self supervision function" to investigate the fault.

4.5 Setting up communication between PCM600 and the IED

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

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

Each IED has an RJ-45 Ethernet interface connector on the front. The front Ethernet connector shall 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.
- Indirect 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

The IP address and the corresponding mask must be set via the LHMI for each available Ethernet interface in the IED. Each Ethernet interface has a default factory IP address when the IED is delivered. This is not given when an additional Ethernet interface is installed or an interface is replaced.

- 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/Ethernet configuration/FRONT:1.

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

A special cable is needed to connect two physical Ethernet interfaces together without a hub, router, bridge or switch in between. The Tx and Rx signal wires must be crossed in the cable to connect Tx with Rx on the other side and vice versa. These cables are known as cross over cables. The maximum length is 2 m. The connector type is RJ-45.

Figure 3: Point-to-point link between IED and PCM600 using a null-modem cable

The following description is an example valid for standard PCs using Microsoft Windows operating system. The example is taken from a Laptop with one Ethernet interface.

Administrator rights are required to change the PC communication setup. Some PCs have the feature to automatically detect that Tx signals from the IED are received on the Tx pin on the PC. Thus, a straight (standard) Ethernet cable can be used.
1. Select **Search programs and files** in the **Start menu** in Windows.

![Search programs and files in the Start menu](image)

*Figure 4: Select: Search programs and files*

2. Type **View network connections** and click on the **View network connections** icon.
3. Right-click and select **Properties**.

4. Select the TCP/IPv4 protocol from the list of configured components using this connection and click **Properties**.
Figure 7: 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 8**. The IP address must be different from the IP address chosen for the IED.
Section 4
Starting up

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

**Setting up the PC to access the IED via a network**

This task depends on the used LAN/WAN network.

![Diagram](image)

*Figure 8: Select: Use the following IP address*

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 the application configuration tool, 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 I/O circuits

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 requires a minimum depth 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. A new configuration is done with the application configuration tool. The binary outputs can be selected from a signal list where the signals are grouped under their function names. It is also possible to specify a user-defined name for each input and output signal.

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. A setting file can be prepared using the Parameter Setting tool, which is available in PCM600.

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.

It takes a minimum of three minutes for the IED to save the new settings, during this time the DC supply must not be turned off.

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. These mechanisms make it necessary to think about a couple of issues in order to not loose configuration data, especially at commissioning time.

After the commissioning is complete, the configuration data is always stored to FLASH, so that is not an issue. But other things, like objects states and the Local/Remote switch position is stored in a slightly different way, where the save of data to FLASH is performed more and more seldom to eliminate the risk of wearing out the
FLASH disk. In worst case, the time between saves of this kind of data is around one hour.

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/Settings/General Settings/Analog modules/AnalogInputs**

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

<table>
<thead>
<tr>
<th>Parameter description</th>
<th>Parameter name</th>
<th>Range</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated CT primary current in A</td>
<td>CT Prim Input</td>
<td>from -10000 to +10000</td>
<td>0</td>
</tr>
</tbody>
</table>

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. Negative values (that is -1000) can be used in order to reverse the direction of the CT current by software for the differential function. This might be necessary if two sets of CTs have different neutral (WYE) point locations in relation to the protected busbar. It is recommended that this parameter is set to zero, for all unused CT inputs.

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 Reconfiguring the IED

I/O modules configured as logical I/O modules (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/IEC port, the SPA/IEC port has to be set either for SPA or IEC 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:

- for plastic fibres with connector type HFBR
- for glass fibres with connectors type ST

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

Procedure

1. Set the operation of the rear optical SPA/IEC port to “SPA”.
   The operation of the rear SPA port can be found on the local HMI under Main menu/Configuration/Communication/Station communication/Port configuration/SLM optical serial port/PROTOCOL:1
   When the setting is entered the IED restarts automatically. After the restart the SPA/IEC port operates as a SPA port.

2. Set the slave number and baud rate for the rear SPA port
   The slave number and baud rate can be found on the local HMI under Main menu/Configuration/Communication/Station communication/SPA/SPA:1
   Set the same slave number and baud rate as set in the SMS system for the IED.

6.1.2   Entering IEC settings

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

Two types of interfaces can be used:
• for plastic fibres with connector type HFBR
• for glass fibres with connectors type ST

Procedure

1. Set the operation of the rear SPA/IEC port to “IEC”.
   The operation of the rear SPA/IEC port can be found on the local HMI under
   Main menu/Configuration/Communication/SLM configuration/Rear optical
   SPA-IEC-DNP port/PROTOCOL:1
   When the setting is entered the IED restarts automatically. After the restart the
   selected IEC port operates as an IEC port.

2. Set the slave number and baud rate for the rear IEC port.
   The slave number and baud rate can be found on the local HMI under Main
   menu/Configuration/Communication/SLM configuration/Rear optical SPA-
   IEC-DNP port/IEC60870–5–103
   Set the same slave number and baud rate as set in the IEC master 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 2.0...”.

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 Fibre optic loop

The SPA communication is mainly used for SMS. It can include different numerical IEDs with remote communication possibilities. The fibre 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>
<thead>
<tr>
<th>Table 4: Max distances between IEDs/nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>glass</td>
</tr>
<tr>
<td>plastic</td>
</tr>
</tbody>
</table>
## 6.4 Optical budget calculation for serial communication with SPA/IEC

### Table 5: Example

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

The communication protocol Local Optical Network (LON) is available for 670 IED series.

![Diagram](IEC05000663-1-en.vsd)

*Figure 9: 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 in the 670 series through the LON bus from the operator’s workplace, from the control center and also from other IEDs via bay-to-bay horizontal communication.

The fibre optic LON bus is implemented using either glass core or plastic core fibre optic cables.

<table>
<thead>
<tr>
<th>Table 6:</th>
<th>Specification of the fibre optic connectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Glass fibre</td>
</tr>
<tr>
<td>Cable connector</td>
<td>ST-connector</td>
</tr>
<tr>
<td>Cable diameter</td>
<td>62.5/125 m</td>
</tr>
<tr>
<td>Max. cable length</td>
<td>1000 m</td>
</tr>
<tr>
<td>Wavelength</td>
<td>820-900 nm</td>
</tr>
<tr>
<td>Transmitted power</td>
<td>-13 dBm (HFBR-1414)</td>
</tr>
<tr>
<td>Receiver sensitivity</td>
<td>-24 dBm (HFBR-2412)</td>
</tr>
</tbody>
</table>

### 7.2.1 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.

### 7.2.2 Hardware and software modules

The hardware needed for applying LON communication depends on the application, but one very central unit needed is the LON Star Coupler and optical fibres connecting the star coupler to the IEDs. To interface the IEDs from MicroSCADA, the application library LIB670 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 within MicroSCADA applications.

The HV Control 670 software module is used for control functions in IEDs in the 670 series. This module contains the process picture, dialogues and a tool to generate the process database for the control application in MicroSCADA.

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.

The setting parameters for the LON communication are set via the local HMI. Refer to the technical manual for setting parameters specifications.

The path to LON settings in the local HMI is Main menu/Configuration/Communication/SLM configuration/Rear optical LON port

If the LON communication from the IED stops, caused by setting of illegal communication parameters (outside the setting range) or by another disturbance, it is possible to reset the LON port of the IED.

Path in the local HMI under Main menu/Configuration/Communication/SLM configuration/Rear optical LON port

These parameters can only be set with the LON Network Tool (LNT).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Default</th>
<th>Unit</th>
<th>Parameter description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DomainID</td>
<td>0 - 255</td>
<td>0</td>
<td>-</td>
<td>Domain identification number</td>
</tr>
<tr>
<td>SubnetID*</td>
<td>0 - 255, Step: 1</td>
<td>0</td>
<td>-</td>
<td>Subnet identification number</td>
</tr>
<tr>
<td>NodeID*</td>
<td>0 - 127, Step: 1</td>
<td>0</td>
<td>-</td>
<td>Node identification number</td>
</tr>
</tbody>
</table>

*Can be viewed in the local HMI

Path in the local HMI under Main menu/Configuration/Communication/SLM configuration/Rear optical LON port

These parameters can only be set with the LON Network Tool (LNT).
Table 8: **LON node information parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Default</th>
<th>Unit</th>
<th>Parameter description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NeuronID*</td>
<td>0 - 12</td>
<td>Not loaded</td>
<td>-</td>
<td>Neuron hardware identification number in hexadecimal code</td>
</tr>
<tr>
<td>Location</td>
<td>0 - 6</td>
<td>No value</td>
<td>-</td>
<td>Location of the node</td>
</tr>
</tbody>
</table>

*Can be viewed in the local HMI

Path in the local HMI under **Main menu/Configuration/Communication/SLM configuration/Rear optical LON port**

Table 8: **ADE Non group settings (basic)**

<table>
<thead>
<tr>
<th>Name</th>
<th>Values (Range)</th>
<th>Unit</th>
<th>Step</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Disabled</td>
<td>-</td>
<td>-</td>
<td>Disabled</td>
<td>Operation</td>
</tr>
<tr>
<td>TimerClass</td>
<td>Slow</td>
<td>-</td>
<td>-</td>
<td>Slow</td>
<td>Timer class</td>
</tr>
</tbody>
</table>

Path in the local HMI under **Main menu/Configuration/Communication/SLM configuration/Rear optical LON port**

Table 10: **LON commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Command description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ServicePinMsg</td>
<td>Command with confirmation. Transfers the node address to the LON Network Tool.</td>
</tr>
</tbody>
</table>

### 7.2 Optical budget calculation for serial communication with LON

Table 11: **Example**

<table>
<thead>
<tr>
<th></th>
<th>Distance 1 km Glass</th>
<th>Distance 10 m Plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum attenuation</td>
<td>-11 dB</td>
<td>-7 dB</td>
</tr>
<tr>
<td>4 dB/km multi mode: 820 nm - 62.5/125 um</td>
<td>4 dB</td>
<td>-</td>
</tr>
<tr>
<td>0.3 dB/m plastic: 620 nm - 1mm</td>
<td>-</td>
<td>3 dB</td>
</tr>
<tr>
<td>Margins for installation, aging, and so on</td>
<td>5 dB</td>
<td>2 dB</td>
</tr>
<tr>
<td>Losses in connection box, two contacts (0.75 dB/contact)</td>
<td>1.5 dB</td>
<td>-</td>
</tr>
</tbody>
</table>

Table continues on next page
### Losses in connection box, two contacts (1dB/contact)

<table>
<thead>
<tr>
<th></th>
<th>Distance 1 km Glass</th>
<th>Distance 10 m Plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses in connection box, two contacts (1dB/contact)</td>
<td>-</td>
<td>2 dB</td>
</tr>
<tr>
<td>Margin for repair splices (0.5 dB/splice)</td>
<td>0.5 dB</td>
<td>-</td>
</tr>
<tr>
<td>Maximum total attenuation</td>
<td>11 dB</td>
<td>7 dB</td>
</tr>
</tbody>
</table>
Section 8 Establishing connection and verifying the IEC 61850 communication

8.1 Overview

The rear OEM ports are used for substation bus (IEC 61850-8-1) communication and process bus (IEC 61850-9-2LE) communication.

For IEC 61850-8-1 redundant communication, both rear OEM ports are utilized. In this case IEC 61850-9-2LE communication can not be used.

8.2 Setting the station communication

To enable IEC 61850 communication the corresponding OEM ports must be activated. The rear OEM port AB and CD is used for IEC 61850-8-1 communication. The rear OEM port CD is used for IEC 61850-9-2LE communication. For IEC 61850-8-1 redundant communication, both OEM port AB and CD are used exclusively.

IEC 61850-9-2LE communication can only be used on OEM rear port X311:C, D.

To enable IEC 61850 station communication:

1. Enable IEC 61850-8-1 (substation bus) communication for port AB.
   1.1. Set values for the rear ports AB and CD.
       Navigate to: Main menu/Configuration/Communication/Ethernet configuration/LANAB:1
       Set values for Mode, IPAddress and IPMask. Mode must be set to Normal.
       Check that the correct IP address is assigned to the port.
   1.2. Enable IEC 61850-8-1 communication.
       Navigate to: Main menu/Configuration/Communication/Station communication/IEC61850-8-1/IEC61850–8–1:1
Set Operation to Enabled and PortSelGOOSE to the port used (for example LANAB).

2. Enable redundant IEC 61850-8-1 communication for port AB and CD
   2.1. Enable redundant communication.
       Navigate to: Main menu/Configuration/Communication/Ethernet configuration/PRP:1
       Set values for Operation, IPAddress and IPMask. Operation must be set to Enabled.
       The IED will restart after confirmation. Menu items LANAB:1 and LANCD:1 are hidden in local HMI after restart but are visible in PST where the values for parameter Mode is set to Duo.

3. Enable IEC 61850-9-2LE (process bus) communication for port CD.
   3.1. Set values for the rear port CD.
       Navigate to: Main menu/Configuration/Communication/Ethernet configuration/LANCD:1
       Set values for Mode, IPAddress and IPMask. Mode must be set to IEC9-2.

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

8.3 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).

The best way to verify the communication up to the application layer is to use protocol analyzer connected to the substation or process bus, and monitor the communication.

Verifying redundant IEC 61850-8-1 communication

Ensure that the IED receives IEC 61850-8-1 data on both port AB and CD. Browse in the local HMI to Main menu/Diagnostics/Communication/Redundant PRP and check that both signals LAN-A-STATUS and LAN-B-STATUS are shown as Ok.
Remove the optical connection to one of the ports AB or CD. Verify that either signal LAN-A-STATUS or LAN-B-STATUS (depending on which connection that was removed) are shown as Error and the that other signal is shown as Ok. Be sure to reconnect the removed connection after completed verification.
Section 9  Testing IED operation

9.1  Preparing for test

9.1.1  Requirements

IED test requirements:

- Calculated settings
- Application configuration diagram
- Signal matrix (SMT) configuration
- Terminal connection diagram
- Technical manual
- Three-phase test equipment
- Process bus, IEC61850-9-2LE, MU test simulator, if IEC 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 debug 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 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.

- Please consider the configured logic from the function block to the output contacts when measuring the operate time.

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

9.1.2 Preparing the IED to verify settings

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

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

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

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

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

For information about the functions to test, for example signal or parameter names, see the technical manual. The correct initiation of the disturbance recorder is made on 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.

### 9.2 Activating the test mode

Put the IED into the test mode before testing. The test mode blocks all protection functions and some of the control functions in the IED, and the individual functions to be tested can be unblocked to prevent unwanted operation caused by other functions. In this way, it is possible to test slower back-up measuring functions without the interference from faster measuring functions. The busbar differential protection is not included in the test mode and is not prevented to operate during the test operations. The test switch should then be connected to the IED. Test mode is indicated when the yellow PickupLED 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 pickupLED above the LCD will start flashing when the IED is in test mode.

### 9.3 Preparing the connection to the test equipment

The IED can be equipped with a test switch of type RTXP8, RTXP18 or RTXP24 or FT. The test switch and its associated test plug handles are a part of the COMBITEST or FT system of ABB, 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.

### 9.4 Connecting the test equipment to the IED

Connect the test equipment according to the IED specific connection diagram and the needed input and output signals for the function under test. An example of a connection is shown in figure 10.

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.

The MU test equipment must be connected to the CD port on the OEM module when process bus IEC61850-9-2LE communication is used.

To ensure correct results, make sure that the IED as well as the test equipment are properly grounded before testing.
9.5 Releasing the function to be tested

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

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

9.6 Verifying analog primary and secondary measurement

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

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

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.

Apply input signals as needed according to the actual hardware and the application configuration.
If some setting deviates, check the analog input settings under **Main menu/Settings/General settings/Analog modules**

If the IEC61850-9-2LE communication is interrupted during current injection, the report tool in PCM600 will display the current that was injected before the interruption.

*Figure 11: PCM600 report tool display after communication interruption*

### 9.7 Testing the protection functionality

Each protection function must be tested individually by secondary injection.
• Verify operating levels (trip) and timers.
• Verify alarm and blocking signals.
• Use the disturbance handling tool in PCM600 to evaluate that the protection function has received the correct data and responded correctly (signaling and timing).
• Use the event viewer tool in PCM600 to check that only expected events have occurred.
Section 10 Testing functionality by secondary injection

10.1 Testing disturbance report

10.1.1 Introduction

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

- Disturbance recorder
- Event list
- Event recorder
- Fault locator
- 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.

10.1.2 Disturbance report settings

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

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

10.1.3 Disturbance recorder (DR)

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

The Manual Trig can be started in two ways:

1. From the local HMI under Main menu/Disturbance records.
   1.1. Enter on the row at the bottom of the HMI called Manual trig.
A new recording begins. The view is updated if you leave the menu and return.

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

2. Open the Disturbance handling tool for the IED in the plant structure in PCM600.

2.1. Right-click and select **Execute manual Trig** in the window **Available recordings in IED**.

2.2. Read the required recordings from the IED.

2.3. Refresh the window **Recordings** and select a recording.

2.4. Right-click and select **Create Report** or **Open With** to export the recordings to any disturbance analyzing tool that can handle Comtrade formatted files.

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

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

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

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

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

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

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

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

1. on the local HMI under **Main menu/Events**, or in more details via
2. the **Event Viewer** in PCM600.
   - The internal FIFO register of all events will appear when the event viewer is launched.
When the IED is brought into normal service it is recommended to delete all events resulting from commissioning tests to avoid confusion in future fault analysis. All events in the IED can be cleared in the local HMI under Main Menu/Clear/Clear internal event list or Main menu/Clear/Clear process event list. It is not possible to clear the event lists from PCM600.

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

10.2 Identifying the function to test in the technical reference manual

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

10.3 Differential protection

10.3.1 High impedance differential protection HZPDIF (87)

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

10.3.1.1 Verifying the settings

1. Connect single-phase or three-phase test set to inject the operating voltage. The injection is done across the measuring branch.

   The required trip and alarm voltage, as well as the used stabilizing resistance value must be set in the function. Note as well that used CT input in the IED must have ratio set as 1:1. This is essential for the measurement of the expected value. Normally a slightly
higher operating value is no problem as the sensitivity is not influenced much.

2. Increase the voltage and make note of the operate value Pickup. This is done by manual testing and without trip of the test set.
3. Connect the trip contact to the test set to stop the test set for measurement of trip times below.
4. Reduce the voltage slowly and make note of the reset value. The reset value must be high for this function.
5. Check the operating time by injecting a voltage corresponding to \(1.2 \times \text{Pickup}\) level. Make note of the measured trip time.
6. If required, verify the trip time at another voltage. Normally \(2 \times \text{Pickup}\) is selected.
7. If used, measure the alarm level operating value. Increase the voltage and make note of the operate value AlarmPickup. This is done with manual test and without trip of the test set.
8. Measure the operating time on the alarm output by connecting the stop of the test set to an output from \(t_{\text{Alarm}}\). Inject a voltage \(1.2 \times \text{AlarmPickup}\) and measure the alarm time.
9. Check that trip and alarm outputs operate according to the configuration logic.
10. Finally check that pickup and alarm information is stored in the event menu and if a serial connection to the SA is available verify that the correct and only the required signals are presented on the local HMI and on the SCADA system.

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

10.3.1.2 Completing the test

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

10.3.2 Additional security logic for differential protection LDRGFC (11)

10.3.2.1 Verifying the settings

Prepare the IED for verification of settings outlined in section 1 “Overview” and section 2 “Preparing for test” in this chapter.

Current variation local criteria
Procedure
1. Set Operation to Enabled.
2. Connect the test set for three phase current injection to the appropriate IED terminals.
3. Inject symmetrical phase currents equal to half the rated current
4. Increase the injected current in phase A slowly by more than the set Pick Up ICV. No signal shall be activated.
5. Decrease the injected current in phase A to half the rated current.
6. Increase the injected current in phase A in a step by more than the set Pick Up ICV. Pickup shall be activated.

**Undervoltage criteria**

Procedure

1. Connect the test set for three phase current injection and three phase voltage to the appropriate IED terminals.
2. Inject symmetrical phase voltages equal to the rated voltage.
3. Decrease the injected voltage in phase A and note the operated value (pickup value) of the function.
4. Increase the voltage slowly and note the reset value.
5. Connect a trip output contact to a timer.
6. Reduce the injected voltage stepwise to 90 % of the trip level, and check the time delay.
7. Repeat points 3–6 for phases B and C.
8. Inject symmetrical phase voltages equal to the rated voltage.
9. Decrease the injected phase-phase voltage A-B and note the operated value (start value) of the function.
10. Increase the voltage slowly and note the reset value.
11. Connect a trip output contact to a timer.
12. Reduce the injected voltage stepwise to 90 % of the trip level, and check the time delay.
13. Repeat points 9 – 12 for phases B-C and C-A.

**Zero sequence overcurrent criteria**

Procedure
1. Connect the test set for three phase voltage injection (A, B, C) or residual voltage injection (N) to the appropriate IED terminals. This is dependent on how the IED is fed from the CT.
2. Increase the injected zero sequence current and note the trip value (pickup value) of the studied step of the function.
3. Decrease the current slowly and note the reset value.
4. Connect a trip output contact to a timer.
5. Set the injected current to 200 % of the trip level of the tested stage, switch on the current and check the time delay.

**Low current criteria**

Procedure

1. Connect the test set for three phase current injection to the appropriate IED terminals.
2. Inject a symmetrical three phase current larger than the set value $PU_37$
3. Decrease the injected current in phase A and note the trip value (pickup value) of the studied step of the function.
4. Increase the current slowly and note the reset value.
5. Connect a trip output contact to a timer.
6. Decrease the injected current stepwise to 50 % of the trip level and check the time delay.
7. Repeat steps 3 – 6 for phases B and C.

**10.3.2.2 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.

**10.4 Impedance protection**

**10.4.1 Distance protection zones, quadrilateral characteristic ZMOPDIS (21)**

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".
Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to its rated value or lower. But make sure it is higher than the set minimum operating current.

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

The test procedure has to take into consideration that the shaped load encroachment characteristic is active. It is therefore necessary to check the setting. To verify the settings with the shaped load encroachment characteristic the test should be carried out according to figures 12 and 13 and tables 12 and 13. In cases where the load encroachment characteristic is activated tests according to the adjusted figures should be carried out.

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

- One phase-to-phase fault
- One phase-to-ground fault

The shape of the operating characteristic depends on the values of the setting parameters.

The figures illustrating the characteristic for the distance protection function can be used for settings with and without load encroachment. The solid lines designate the diagram applicable when the load current compensation operationLdCom parameter is set to 1 (On). This is the default setting. The solid line and all test points except 13 are valid for this setting.

When it is set to 0 (Off) then the dotted lines and test point 13 are valid. Test points 5, 6, and 7 are not valid for this measurement.
Section 10
Testing functionality by secondary injection

Figure 12: Distance protection characteristic with test points for phase-to-phase measurements

Table 12: Test points for phase-to-phase loops L1-L2 (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X₁₅ₑₜ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X₁₅ₑₜ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>R₁₅ₑₜ</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 x X₁₅ₑₜ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x R₁₅ₑₜ + RFPP/2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 x X₁₅ₑₜ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x R₁₅ₑₜ + RFPP/2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 x RFPP x tan (ArgRLd)</td>
<td>ArgLd = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFPP</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFw x tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>RLdFw x tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>-0.2143 x RFPP/2</td>
<td>Exact: 0.8 x RFPP/2 (ArgDir=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RFPP/2</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
### Table 12

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>X</td>
<td>(-0.4 \times RLdFw \times \tan(\text{ArgDir}=20^\circ))</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>(0.4 \times RLdFw)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>(0.5 \times X_{1\text{set}})</td>
<td>Exact (-0.5 \times R_{1\text{set}} \times \tan(\text{ArgNegRes}=30^\circ))</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>(-0.23 \times X_{1\text{set}})</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>(0.8 \times X_{1\text{set}})</td>
<td>Exact (-0.5 \times R_{1\text{set}} \times \tan(\text{ArgNegRes}=30^\circ))</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>(-0.37 \times X_{1\text{set}})</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>(0.5 \times X_{1\text{set}})</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>(0.5 \times R_{1\text{set}})</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td>Only used when OperationLdCmp setting is 0 (Off)</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>(0.5 \times RFPP)</td>
<td></td>
</tr>
</tbody>
</table>

Table 12 is used in conjunction with figure 12.

![Diagram](ANSI05000369-2-en.vsd)

**Figure 13:** Distance protection characteristic with test points for phase-to-ground measurements

Table 13 is used in conjunction with figure 13.
Table 13: Test points for phase-to-earth L3-E (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>(2 x X1 set + X0 set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>(2 x X1 set + X0 set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>2 x R1 set + R0 set/3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 x (2 x X1 set + X0 set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x (2 x R1 set + R0 set)/3 + RFPE set</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 x (2 x X1 set + R0 set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x (2 x R1 set + R0 set)/3 + RFPE set</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 x RFPE set x tan(ArgLd set)</td>
<td>ArgLd = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFPE set</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFw set x tan(ArgLd Set)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw set</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw set</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>-0.1072 x RLdFw set</td>
<td>Exact: 0.4 x RFPE x tan (ArgDir=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.4 x RLdFw set</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>-0.8 x RLdFw set</td>
<td>Exact: 0.8 x RLdFw set x tan(ArgDir=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RLdFw set</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.17 x (2 x X1 set + X0 set)</td>
<td>Exact: 0.5 x (2 x X1 set + X0 set)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.36 x (2 x X1 set + X0 set)</td>
<td>Exact: 0.5 x (2X1 set + X0 set)/(3 x tan(ArgNegDir=30°))</td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.27 x (2 x X1 set + X0 set)</td>
<td>Exact: 0.8 x (2 x X1 set + X0 set)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.57 x (2 x X1 set + X0 set)</td>
<td>Exact: 0.8 x (2X1 set + X0 set)/(3 x tan(ArgNegDir=30°))</td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 x (2 x X1 set + X0 set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x (2 x R1 set + R0 set)/3</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RFPE</td>
<td></td>
</tr>
</tbody>
</table>

10.4.1.1 Measuring the operating limit of set values in cases without shaped load encroachment characteristics (OperationLdCmp=off)

1. Subject the IED to healthy normal load conditions for at least two seconds.

2. Apply the fault condition and slowly decrease the measured impedance to find the operating value of the phase-to-phase fault for zone 1 according to test point 1 in figure 12 and table 12. Compare the result of the measurement with the set value.

3. Repeat steps 1 to 5 to find the operating value for test point 2, 3 in table 12 and the operating value for the phase-to-earth loop according to test point 1, 2, 3 in table 13. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.

4. Repeat steps 1 to 9 to find the operating value for the phase-to-ground fault C-E according to figure 13 and table 13.

Test points 8 and 9 are intended to test the directional lines of impedance protection. Since directionality is a common function for all 5 measuring zones, it is only necessary to test points 6, 7, 8 and 9 once, in the forward direction (the largest reverse zone can be used to facilitate the test) in order to test the accuracy of directionality (directional angles). Directional functionality testing (trip inside, no-trip outside) should always be carried for all impedance zones set with directionality (forward or reverse).

10.4.1.2 Measuring the operate time of distance protection zones

1. Subject the IED to healthy normal load conditions for at least two seconds.

2. Apply the fault condition to find the operating time for the phase-to-phase fault according to test point 10 in figure 12 and table 12 for zone 1. Compare the result of the measurement with the setting $t_{1PP}$.

3. Repeat steps 1 to 5 to find the operating time for the phase-to-ground fault according to test point 10 in figure 13 and table 13. Compare the result of the measurement with the setting $t_{1PE}$.

4. Repeat steps 1 to 5 to find the operating time for all other used measuring zones. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.

When the load shaped characteristic is activated ($\text{OperationLdCmp} = \text{On}$) the test point for phase-to-phase faults is 12 in figure 12 and table 12 and for phase-earth faults according to P12 in figure 13 and table 13.
10.4.1.3 Completing the test

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

10.4.2 Phase selection with load encroachment, quadrilateral characteristic FDPSPDIS (21)

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

The phase selectors operate on the same measuring principles as the impedance measuring zones. So it is necessary to follow the same principles as for distance protection, when performing the secondary injection tests.

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to the rated value of its associated input transformer, or lower. But 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 its rated value, if the measurement of the operating characteristics runs under constant voltage conditions.

To verify the settings the operating points according to figures 14 and 15 should be tested. See also tables 14 and 15 for information.
Table 14: Test points for phase-to-ground loop CG (Ohm/loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>$[X_1+X_N]$</td>
<td>$X_N=(X_0-X_1)/3$</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>$RLdFwd$</td>
<td>When $RLdFwd &lt; RFltFwPG$</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>$RFltFwPG$</td>
<td>When $RLdFwd &gt; RFltFwPG$</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.85·$[X_1+X_N]$</td>
<td>$R=0.491·(X_1+X_N)+RFltFwPG$</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.85·$[X_1+X_N]$</td>
<td>Can be limited by $RFltFwPG$</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>$-0.85·[X_1+X_N]·\tan(\text{AngNegRes}-90^\circ)$</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>$RFltFwPG·\tan(LdAngle)$</td>
<td>Only when $RLdFwd &lt; RFltFwPG$</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>$RFltFwPG$</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>$-0.5·RLdFwd·\tan(\text{ArgDir})$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>$0.5·RLdFwd$</td>
<td></td>
</tr>
</tbody>
</table>

Table 14 is used together with figure 14.
Figure 15: Operating characteristic for phase selection function, forward direction phase-to-phase faults

Table 15: Test points for phase-to-phase loops A-B (Ohm/phase)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwd</td>
<td>When RLdFwd &lt; 0.5·RFLdFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RFLdFwPP</td>
<td>When RLdFwd &gt; 0.5·RFLdFwPP</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.85·X1</td>
<td>R=0.491·X1+0.5 RFLdFwdPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85·X1·1/tan(60°)+0.5 RFLdFwPP</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.85·X1</td>
<td>Can be limited by RFLdFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.85·X1·tan (AngNegRes-90°)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.5·RFLdFwdPP·tan (ArgLd)</td>
<td>Only when RLdFwd &lt; RFLdFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RFLdFwdPP</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>-0.5·RLdFwd·tan (ArgDir)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RLdFwd</td>
<td></td>
</tr>
</tbody>
</table>
Table 15 is used together with figure 15.

10.4.2.1 Measuring the operate limit of set values

1. Supply the IED with healthy conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operate value for of the phase-to-ground loop ECG, test point 1, according to figure 14. Compare the result of the measurement with the expected value according to table 14.
   The corresponding binary signals that inform about the operation of the phase selection measuring elements are available in the local HMI under Main menu/Test/Function status/Impedance Protection/PhaseSelection(PDIS, 21)/FDPSPDIS:x.
3. Repeat steps 1 to 3 to find the operate values for the remaining test points according to figure 14 and table 14.

   When the load encroachment characteristic is deliberately set very high in order not to have an influence, then the test points 2 and 5 can be replaced by test point 7.

4. Repeat steps 1 to 5 to find the operate value for the phase-to-phase fault in A - C according to figure 15 and table 15.

   When the load encroachment characteristic is deliberately set very high in order not to have an influence, then the test points 2 and 5 can be replaced by test point 7.

10.4.2.2 Completing the test

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

10.4.3 Full scheme distance protection, mho characteristic ZMHPDIS (21)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".
Consider releasing of the zone to be tested by setting the phase selector FMPSPDIS to *Enabled*.

The programming of the autorecloser function SMBRREC (79) determines if three-phase or single-phase trip is initiated as result of the test.

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

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

To verify the mho characteristic, at least two points should be tested.

In the following, three test points are proposed. The mho characteristic always goes through the origin, which automatically gives a fourth point for the characteristic.

### 10.4.3.1 Phase-to-phase faults

![Figure 16: Proposed test points for phase-to-phase fault](IEC07000009-4-en.vsd)

*Figure 16: Proposed test points for phase-to-phase fault*
Table 16: Test points for phase-to-phase (ohms / phase)

<table>
<thead>
<tr>
<th>Test points</th>
<th>reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>ZPP · sin(ZAngPP)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>ZPP · sin(ZAngPP)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0,5 · (ZPP · sin(ZAngPP))</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0,5 · ZPP + ΔR = 0,5 · ZPP (1 + cos(ZAngPP))</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0,5 · ZPP · sin(ZAngPP)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0,5 · ZPP - ΔR = 0,5 · ZPP (1 - cos(ZAngPP))</td>
<td></td>
</tr>
</tbody>
</table>

Change the magnitude and angle of phase-to-phase voltage to achieve impedances at test points 1, 2 and 3. For each test point, observe that the output signals, PICKUP, PU_x and PHPH_FLT are activated where x refers to the actual phase to be tested. After the timer $t_{PP}$ for the actual zone has elapsed, also the signals TRIP, TRPP and TR_x shall be activated.

10.4.3.2 Phase-to-ground faults

For simplicity, the same test points as for phase-to-phase faults are proposed, but considering new impedance values.

Figure 17: Proposed test points for phase-to-ground faults
Table 17: Test points for phase-to-ground loops A-B (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test points</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>ZPG · sin(ZAngPG)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>ZPG · cos(ZAngPG)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0.5·ZPG · sin(ZAngPG)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·ZPG + ΔR = 0.5·ZPG · (1 - cos(ZAngPG))</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.5·ZPG·sin(ZangPG)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·ZPG - ΔR = 0.5·ZPG · (1 - cos(ZAngPG))</td>
<td></td>
</tr>
</tbody>
</table>

Check also in the same way as for phase-to-ground fault for each test point that the output signals PHG_FLT, are activated where x refers to the actual phase to be tested. After the timer tPG for the zone has elapsed, also the signals TRIP, TRPG and TR_x shall be activated.

10.4.4 Faulty phase identification with load encroachment FMPSPDIS (21)

There is no specific test routine for this function. The function is tested in conjunction with other impedance (mho) functions.

10.4.5 Distance protection zones, quadrilateral characteristic, separate settings ZMRPDIS (21)

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

Consider releasing Zone 1 with the Phase selection with load encroachment, quadrilateral characteristic (FRPSDPIS). If the autorecloser is not released and in service, trip will always be three phase.

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to its rated value or lower. But make sure it is higher than 30% of the rated current.

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

The test procedure has to take into consideration that the shaped load encroachment characteristic is active. It is therefore necessary to check the setting. To verify the settings with the shaped load encroachment characteristic the test should be carried out...
according to figures 12 and 13 and tables 12 and 12. In cases where the load encroachment characteristic is activated tests according to the adjusted figures should be carried out.

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

- One phase-to-phase fault
- One phase-to-ground fault

The shape of the operating characteristic depends on the values of the setting parameters.

The figures illustrating the characteristic for the distance protection function can be used for settings with and without load encroachment. The solid lines designate the diagram applicable when the load current compensation operationLdCom parameter is set to 1 (Enabled). This is the default setting. The solid line and all test points except 13 are valid for this setting.

When it is set to 0 (Disabled) then the dotted lines and test point 13 are valid. Test points 5, 6, and 7 are not valid for this measurement.

Figure 18: Distance protection characteristic with test points for phase-to-phase measurements
Table 12 is used in conjunction with figure 12.

![Distance protection characteristic with test points for phase-to-ground measurements](image.png)

**Figure 19: Distance protection characteristic with test points for phase-to-ground measurements**

Table 12 is used in conjunction with figure 13.

**Table 18: Test points for phase-to-phase loops L1-L2 (Ohm/Loop)**

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1(_{set})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X1(_{set})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>R1(_{set})</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 x X1(_{set})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x R1(_{set})+ RFPP/2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 x X1(_{set})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x R1(_{set})+ RFPP/2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 x RFPP x tan (LdAngle)</td>
<td>(LdAngle = ) angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFPP</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFwd x tan (LdAngle)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwd</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>RLdFw x tan (LdAngle)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>X</td>
<td>−0.2143 x RFPP/2</td>
<td>Exact: 0.8 x RFPP/2 (ArgDir)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RFPP/2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>−0.4 x RLdFwd x tan(ArgDir)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.4 x RLdFwd</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.5 x X1_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>−0.23 x X1_set</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.8 x X1_set</td>
<td>Exact −0.5 x R1_set x tan(ArgNegRes-90)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>−0.37 x X1_set</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 x X1_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x R1_set</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td>Only used when OperationLdCmp setting is 0 (Disabled)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x RFPP</td>
<td></td>
</tr>
</tbody>
</table>

**Table 19:** Test points for phase-to-earth L3-G (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>(2 x X1_set + X0_set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>(2 x X1_set + X0_set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>2 x R1_set + R0_set)/3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 x (2 x X1_set + X0_set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x (2 x R1_set + R0_set)/3 + RFPG_set</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 x (2 x X1_set + R0_set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x (2 x R1_set + R0_set)/3 + RFPG_set</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 x RFPG_set x tan(LdAngle)</td>
<td>LdAngle = angle for the maximal load transfer.</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFPG</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFwd_set x tan(LdAngle)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwd_set</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwd_set</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>−0.2143 x RLdFwd_set</td>
<td>Exact: 0.8 x RFPG x tan (ArgDir)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RLdFwd_set</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>−0.8 x RLdFwd_set x tan(ArgDir)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RLdFwd_set</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
### 10.4.5.1

**Measuring the operating limit of set values in cases without shaped load encroachment characteristics (OperationLdCmp=disabled)**

Procedure for phase-to-phase fault A–B.

1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operating value of the phase-to-phase fault for zone 1 according to test point 1 in figure 12 and table 12. Compare the result of the measurement with the set value.
3. Repeat steps 1 to 5 to find the operating value for test point 2, 3 in table 12 and the operating value for the phase-to-earth loop according to test point 1, 2, 3 in table 12.
   
   Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.
4. Repeat steps 1 to 3 above to find the trip value for the phase-to-ground fault L3-G according to figure 13 and table 12.

---

Test points 8 and 9 are intended to test the directional lines of impedance protection. Since directionality is a common function for all 5 measuring zones, it is only necessary to test points 6, 7, 8 and 9 once, in the forward direction (the largest reverse zone can be used to facilitate the test) in order to test the accuracy of directionality (directional angles). Directional functionality testing (trip inside, no-trip outside) should always be carried for all impedance zones set with directionality (forward or reverse).
10.4.5.2 Measuring the trip time of distance protection zones

Procedure

1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition to find the operating time for the phase-to-phase fault according to test point 10 in figure 12 and table 12 for zone 1. Compare the result of the measurement with the setting $t_{PP}$.
3. Repeat steps 1 to 5 to find the operating time for the phase-to-ground fault according to test point 10 in figure 13 and table 12. Compare the result of the measurement with the setting $t_{PG}$.
4. Repeat steps 1 to 5 to find the trip time for all other used measuring zones. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.

When the load shaped characteristic is activated ($OperationLdCmp=Enabled$) the test point for phase-to-phase faults is 12 in figure 12 and table 12 and for phase-ground faults according to P12 in figure 13 and table 12.

10.4.6 Phase selection, quadrilateral characteristic with settable angle FRPSPDIS (21)

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

The phase selectors operate on the same measuring principles as the impedance measuring zones. So it is necessary to follow the same principles as for distance protection, when performing the secondary injection tests.

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to the rated value of its associated input transformer, or lower. But ensure that it is higher than 30% of the rated current.

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

To verify the settings the operating points according to figures _"_ and 15 should be tested. See also tables _"_ and _"_ for information.
Figure 20: Operating characteristic for phase selection function, forward direction single-phase faults

Figure 21: Operating characteristic for phase selection function, forward direction phase-to-phase faults
Table 20: Test points for phase-to-ground loop CG (Ohm/loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>[X1+XN]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>XN=(X_0-X_1)/3</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>RLdFwd</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.85·[X1+XN]</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>R=0.491·(X1+XN)+RFFwPE</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85·[X1+XN]·1/tan(60°)+RFFwPE</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.85·[X1+XN]</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>-0.85·[X1+XN]·tan (AngNegRes-90°)</td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>RFnFwd PG·tan (LdAngle)</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>RFnFwd PG</td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>-0.5·RLdFwd·tan (ArgDir)</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>0.5·RLdFwd</td>
</tr>
</tbody>
</table>

The table showing test points for phase-to-ground loops is used together with figure 14.

Table 21: Test points for phase-to-phase loops A-B

<table>
<thead>
<tr>
<th>Test point</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>RLdFwd</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.85·X1</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>R=0.491·X1+0.5 RFLdFwd PP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85·X1·1/tan(60°)+0.5 RFLdFwd PP</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.85·X1</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>-0.85·X1·tan (AngNegRes-90°)</td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.5·RFLdFwd PP·tan (ArgLd)</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>0.5·RFLdFwd PP</td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>-0.5·RLdFwd·tan (ArgDir)</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>0.5·RLdFwd</td>
</tr>
</tbody>
</table>

The table showing test points for phase-to-phase loops is used together with figure 21.
10.4.6.1 Measuring the operate limit of set values

1. Supply the IED with healthy conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operate value for of the phase-to-ground loop ECG, test point 1, according to figure 14. Compare the result of the measurement with the expected value according to table 20. The corresponding binary signals that inform about the operation of the phase selection measuring elements are available in the local HMI under Main menu/Test/Function status/Impedance Protection/PhaseSelection(PDIS, 21)/FRPSPDIS:x.
3. Repeat steps 1 to 2 to find the operate values for the remaining test points according to figures 14 and table 20.

When the load encroachment characteristic is deliberately set very high in order not to have an influence, then the test points 4, 5 and 6 can be replaced by test point 7.

4. Repeat steps 1 to 3 to find the operate value for the phase-to-phase fault in A - C according to figure 21 and table 21.

When the load encroachment characteristic is deliberately set very high in order not to have an influence, then the test points 4, 5 and 6 can be replaced by test point 7.

10.4.6.2 Completing the test

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

10.4.7 Phase selection with load encroachment, quadrilateral characteristic FDPSPDIS (21)

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

The phase selectors operate on the same measuring principles as the impedance measuring zones. So it is necessary to follow the same principles as for distance protection, when performing the secondary injection tests.
Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to the rated value of its associated input transformer, or lower. But 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 its rated value, if the measurement of the operating characteristics runs under constant voltage conditions.

To verify the settings the operating points according to figures 14 and 15 should be tested. See also tables 14 and 15 for information.

![Operating characteristic for phase selection function, forward direction single-phase faults](ANSI09000734-1-en.vsd)

**Figure 22:** Operating characteristic for phase selection function, forward direction single-phase faults

**Table 22:** Test points for phase-to-ground loop CG (Ohm/loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>([X1+XN])</td>
<td>(XN=(X_0-X_1)/3)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwd</td>
<td>When RLdFwd &lt; RFItFwPG</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RFItFwPG</td>
<td>When RLdFwdPG &gt; RFItFwPG</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.85([X1+XN])</td>
<td>(R=0.491\cdot(X1+XN)+RFItFwdPG)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
Table 14 is used together with figure 14.

Figure 23: Operating characteristic for phase selection function, forward direction phase-to-phase faults

Table 23: Test points for phase-to-phase loops A-B (Ohm/phase)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwd</td>
<td>When RLdFwd &lt; 0,5·RFltFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0,5·RFltFwPP</td>
<td>When RLdFwd &gt; 0,5·RFltFwPP</td>
</tr>
</tbody>
</table>

Table continues on next page
Table 15 is used together with figure 15.

10.4.7.1 Measuring the operate limit of set values

1. Supply the IED with healthy conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operate value for of the phase-to-ground loop ECG, test point 1, according to figure 14. Compare the result of the measurement with the expected value according to table 14.
   The corresponding binary signals that inform about the operation of the phase selection measuring elements are available in the local HMI under Main menu/Test/Function status/Impedance Protection/PhaseSelection(PDIS, 21)/FDPSPDIS:x.
3. Repeat steps 1 to 3 to find the operate values for the remaining test points according to figure 14 and table 14.

   When the load encroachment characteristic is deliberately set very high in order not to have an influence, then the test points 2 and 5 can be replaced by test point 7.

4. Repeat steps 1 to 5 to find the operate value for the phase-to-phase fault in A - C according to figure 15 and table 15.

   When the load encroachment characteristic is deliberately set very high in order not to have an influence, then the test points 2 and 5 can be replaced by test point 7.

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>X</td>
<td>0.85·X1</td>
<td>(R=0.491\cdot X1+0.5) RFLdFwdPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85·X1·tan(60°)+0.5 RFLdFwdPP</td>
<td>Can be limited by RFLdFwPP</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.85·X1</td>
<td>Only when RLdFwd &lt; RFLdFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.85·X1·tan (AngNegRes-90°)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.5·RFLdFwdPP·tan (ArgLd)</td>
<td>Only when RLdFwd &lt; RFLdFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RFLdFwdPP</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>-0.5·RLdFwd·tan (ArgDir)</td>
<td>Only when RLdFwd &lt; RFLdFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RLdFwd</td>
<td></td>
</tr>
</tbody>
</table>
10.4.7.2 Completing the test

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

10.4.8 Distance protection zones, quadrilateral characteristic

ZMFPDIS (21)

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

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

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

The test procedure has to take into consideration that the shaped load encroachment characteristic is active. It is therefore necessary to check the setting. To verify the settings with the shaped load encroachment characteristic the test should be carried out according to Figure 12 and Figure 13 and Table 12 and Table 13. In cases where the load encroachment characteristic is activated tests according to the adjusted figures should be carried out.

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

• One phase-to-phase fault
• One phase-to-ground fault

The shape of the operating characteristic depends on the values of the setting parameters.

The figures illustrating the characteristic for the distance protection function can be used for settings with and without load encroachment. The solid lines designate the diagram applicable when the load current compensation operationLdCom parameter is set to 1 (Enabled). This is the default setting. The solid line and all test points except 13 are valid for this setting.

When operationLdCom parameter is set to Disabled then the dotted lines and test point 13 are valid. Test points 5, 6, and 7 are not valid for this measurement.
Figure 24: Distance protection characteristic with test points for phase-to-phase measurements

Table 24: Test points for phase-to-phase loops A-B (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1\text{set}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X1\text{set}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>R1\text{set}</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 \times X1\text{set}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times R1\text{set} + \text{RFPP}/2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 \times X1\text{set}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 \times R1\text{set} + \text{RFPP}/2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 \times \text{RFPP} \times \tan (\text{LdAngle})</td>
<td>\text{LdAngle} = \text{angle for the maximal load transfer}</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 \times \text{RFPP}</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>\text{RLdFwd} \times \tan (\text{LdAngle})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>\text{RLdFwd}</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>\text{RLdFw}</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>-0.2143 \times \text{RFPP}/2</td>
<td>Exact: 0.8 \times \text{RFPP}/2 (\text{ArgDir}=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times \text{RFPP}/2</td>
<td></td>
</tr>
<tr>
<td>Test point</td>
<td>Reach</td>
<td>Set value</td>
<td>Comments</td>
</tr>
<tr>
<td>------------</td>
<td>-------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>–0.4 x RLdFwd x tan(ArgDir=20°)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.4 x RLdFwd</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.5 x X1_set</td>
<td>Exact –0.5 x R1_set x tan(ArgNegRes=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>–0.23 x X1_set</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.8 x X1_set</td>
<td>Exact –0.5 x R1_set x tan(ArgNegRes=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>–0.37 x X1_set</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 x X1_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x R1_set</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td>Only used when <em>OperationLdCmp</em> setting is 0 (Disabled)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x RFPP</td>
<td></td>
</tr>
</tbody>
</table>

*Table 12* is used in conjunction with *Figure 12*.

*Figure 25: Distance protection characteristic with test points for phase-to-ground measurements*

*Table 13* is used in conjunction with *Figure 13*. 

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### Table 25: Test points for phase-to-ground C-G (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>((2 \times X_{1\text{set}} + X_{0\text{set}})/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>((2 \times X_{1\text{set}} + X_{0\text{set}})/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(2 \times R_{1\text{set}} + R_{0\text{set}})/3)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>(0.8 \times (2 \times X_{1\text{set}} + X_{0\text{set}})/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(0.8 \times (2 \times R_{1\text{set}} + R_{0\text{set}})/3 + \text{RFPG}_{\text{set}})</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>(0.5 \times (2 \times X_{1\text{set}} + R_{0\text{set}})/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(0.5 \times (2 \times R_{1\text{set}} + R_{0\text{set}})/3 + \text{RFPG}_{\text{set}})</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>(0.85 \times \text{RFPG}<em>{\text{set}} \times \text{tan}(Ld\text{Angle}</em>{\text{set}}))</td>
<td>\text{LdAngle} = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 \times \text{RFPG}</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>\text{RLdFwd}<em>{\text{set}} \times \text{tan}(Ld\text{Angle}</em>{\text{set}})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>\text{RLdFwd}_{\text{set}}</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>\text{RLdFwd}_{\text{set}}</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>(-0.2143 \times \text{RLdFwd}_{\text{set}})</td>
<td>Exact: (0.8 \times \text{RFPE} \times \text{tan}(\text{ArgDir}=20^\circ))</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times \text{RLdFwd}_{\text{set}}</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>(-0.8 \times \text{RLdFwd}_{\text{set}} \times \text{tan} (\text{ArgDir}=20^\circ))</td>
<td>Exact: (-0.8 \times \text{RLdFwd}_{\text{set}} \times \text{tan} (\text{ArgDir}=20^\circ))</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times \text{RLdFwd}_{\text{set}}</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>(0.17 \times (2 \times X_{1\text{set}} + X_{0\text{set}}))</td>
<td>Exact: (0.5 \times (2 \times X_{1\text{set}} + X_{0\text{set}})/3)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(-0.36 \times (2 \times X_{1\text{set}} + X_{0\text{set}}))</td>
<td>Exact: (0.5 \times (2 \times X_{1\text{set}} + X_{0\text{set}})/(3 \times \text{tan}(\text{AgNegDir}=30^\circ)))</td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>(0.27 \times (2 \times X_{1\text{set}} + X_{0\text{set}}))</td>
<td>Exact: (0.8 \times (2 \times X_{1\text{set}} + X_{0\text{set}})/3)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(-0.57 \times (2 \times X_{1\text{set}} + X_{0\text{set}}))</td>
<td>Exact: (0.8 \times (2 \times X_{1\text{set}} + X_{0\text{set}})/(3 \times \text{tan}(\text{AgNegDir}=30^\circ)))</td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>(0.5 \times (2 \times X_{1\text{set}} + X_{0\text{set}})/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(0.5 \times (2 \times R_{1\text{set}} + R_{0\text{set}})/3)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>\text{RFPG}</td>
<td></td>
</tr>
</tbody>
</table>

### 10.4.8.1 Measuring the operating limit of set values in cases without shaped load encroachment characteristics (OperationLdCmp=disabled)

Procedure for phase-to-phase fault A–B.
1. Subject the IED to healthy normal load conditions for at least two seconds.

2. Apply the fault condition and slowly decrease the measured impedance to find the operating value of the phase-to-phase fault for zone 1 according to test point 1 in Figure 12 and Table 12. Compare the result of the measurement with the set value.

3. Repeat steps 1 to 5 to find the operating value for test point 2, 3 in Table 12 and the trip value for the phase-to-ground loop according to test point 1, 2, 3 in Table 13. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.

4. Repeat steps 1 to 9 to find the trip value for the phase-to-ground fault C-G according to Figure 13 and Table 13.

Test points 8 and 9 are intended to test the directional lines of impedance protection. Since directionality is a common function for all 5 measuring zones, it is only necessary to test points 6, 7, 8 and 9 once, in the forward direction (the largest reverse zone can be used to facilitate the test) in order to test the accuracy of directionality (directional angles). Directional functionality testing (trip inside, no-trip outside) should always be carried for all impedance zones set with directionality (forward or reverse).

10.4.8.2 Measuring the operating time of distance protection zones

1. Subject the IED to healthy normal load conditions for at least two seconds.

2. Apply the fault condition to find the operating time for the phase-to-phase fault according to test point 12 in Figure 12 and Table 12 for zone 1. Compare the result of the measurement to the setting $t_{PPZ1}$.

3. Repeat steps 1 to 5 to find the trip time for the phase-to-ground fault according to test point 12 in Figure 13 and Table 13. Compare the result of the measurement to the setting $t_{1PG}$.

4. Repeat steps 1 to 5 to find the operating time for all other used measuring zones. The zones that are not tested have to be blocked and the zone that is tested has to be released.

When the load-shaped characteristic is activated ($OperationLdCmp = "Enabled")$, the test point for phase-to-phase faults is 12 in Figure 12 and Table 12 and for phase-ground faults according to P12 in Figure 13 and Table 13.
10.4.8.3 Completing the test

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

10.4.9 Distance protection zones, quadrilateral characteristic
ZMFCPDIS (21)

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

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

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

The test procedure has to take into consideration that the shaped load encroachment characteristic is active. It is therefore necessary to check the setting. To verify the settings with the shaped load encroachment characteristic the test should be carried out according to figures 12 and 13 and tables 12 and 13. In cases where the load encroachment characteristic is activated tests according to the adjusted figures should be carried out.

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

- One phase-to-phase fault
- One phase-to-ground fault

The shape of the operating characteristic depends on the values of the setting parameters.

The figures illustrating the characteristic for the distance protection function can be used for settings with and without load encroachment. The solid lines designate the diagram applicable when the load current compensation operationLdCom parameter is set to 1 (Enabled). This is the default setting. The solid line and all test points except 13 are valid for this setting.

When it is set to 0 (Disabled) then the dotted lines and test point 13 are valid. Test points 5, 6, and 7 are not valid for this measurement.
Figure 26: Distance protection characteristic with test points for phase-to-phase measurements

Table 26: Test points for phase-to-phase loops A-B (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X_{1_{\text{set}}}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X_{1_{\text{set}}}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>R_{1_{\text{set}}}</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 \times X_{1_{\text{set}}}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times R_{1_{\text{set}}} + \text{RFPP/2}</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 \times X_{1_{\text{set}}}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 \times R_{1_{\text{set}}} + \text{RFPP/2}</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 \times \text{RFPP} \times \tan(LdAngle)</td>
<td>$LdAngle$ = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 \times \text{RFPP}</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>\text{RLdFwd} \times \tan(LdAngle)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>\text{RLdFwd}</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>\text{RLdFwd} \times \tan(LdAngle)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>-0.2143 \times \text{RFPP/2}</td>
<td>Exact: 0.8 \times \text{RFPP/2} (ArgDir=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times \text{RFPP/2}</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>X</td>
<td>-0.4 x RLdFwd x tan(ArgDir=20°)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.4 x RLdFwd</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.5 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td>Exact -0.5 x R1&lt;sub&gt;set&lt;/sub&gt; x tan(ArgNegRes=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.23 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.8 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td>Exact -0.5 x R1&lt;sub&gt;set&lt;/sub&gt; x tan(ArgNegRes=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.37 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x R1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td>Only used when OperationLdCmp setting is 0 (Disabled)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x RFPP</td>
<td></td>
</tr>
</tbody>
</table>

Table 12 is used in conjunction with figure 12.

Figure 27: Distance protection characteristic with test points for phase-to-ground measurements

Table 13 is used in conjunction with figure 13.
**Table 27:** Test points for phase-to-ground C-G (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>(2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>(2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>2 x R&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ R&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;/3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 x (2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x (2 x R&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ R&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/3 +RFPG&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 x (2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ R&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x (2 x R&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+R&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/3 + RFPG&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 x RFPG&lt;sub&gt;set&lt;/sub&gt; x tan(LdAngle&lt;sup&gt;set&lt;/sup&gt;)</td>
<td>LdAngle = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFPG</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFwd&lt;sub&gt;set&lt;/sub&gt; x tan(LdAngle&lt;sup&gt;set&lt;/sup&gt;)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwd&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwd&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>-0.2143 x RLdFwd&lt;sub&gt;set&lt;/sub&gt;</td>
<td>Exact: 0.8 x RFPG x tan (ArgDir=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RLdFwd&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>-0.8 x RLdFwd&lt;sub&gt;set&lt;/sub&gt;x tan(ArgDir=20°)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RLdFwd&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.17 x (2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)</td>
<td>Exact: 0.5 x (2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.36 x (2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)</td>
<td>Exact: 0.5 x (2X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/(3 x tan(AgNegDir=30°))</td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.27 x (2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)</td>
<td>Exact: 0.8 x (2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.57 x (2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)</td>
<td>Exact: 0.8 x (2X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/(3 x tan(AgNegDir=30°))</td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 x (2 x X&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ X&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x (2 x R&lt;sub&gt;1&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;+ R&lt;sub&gt;0&lt;/sub&gt;&lt;sup&gt;set&lt;/sup&gt;)/3</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**10.4.9.1**

Measuring the operating limit of set values in cases without shaped load encroachment characteristics (OperationLdCmp=Disabled)

Procedure for phase-to-phase fault A–B.
1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operating value of the phase-to-phase fault for zone 1 according to test point 1 in figure 12 and table 12. Compare the result of the measurement with the set value.
3. Repeat steps 1 to 5 to find the operating value for test point 2, 3 in table 12 and the operating value for the phase-to-ground loop according to test point 1, 2, 3 in table 13.
   Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.
4. Repeat steps 1 to 9 to find the operating value for the phase-to-ground fault C-G according to figure 13 and table 13.

Test points 8 and 9 are intended to test the directional lines of impedance protection. Since directionality is a common function for all 5 measuring zones, it is only necessary to test points 6, 7, 8 and 9 once, in the forward direction (the largest reverse zone can be used to facilitate the test) in order to test the accuracy of directionality (directional angles). Directional functionality testing (trip inside, no-trip outside) should always be carried for all impedance zones set with directionality (forward or reverse).

10.4.9.2 Measuring the operate time of distance protection zones

1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition to find the operating time for the phase-to-phase fault according to test point 10 in figure 12 and table 12 for zone 1. Compare the result of the measurement with the setting \( t_{PP} \).
3. Repeat steps 1 to 5 to find the operating time for the phase-to-ground fault according to test point 10 in figure 13 and table 13. Compare the result of the measurement with the setting \( t_{PG} \).
4. Repeat steps 1 to 5 to find the operating time for all other used measuring zones. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.

When the load shaped characteristic is activated (\( \text{OperationLdCmp} = \text{Enabled} \)) the test point for phase-to-phase faults is 12 in figure 12 and table 12 and for phase-ground faults according to P12 in figure 13 and table 13.
10.4.9.3 Completing the test

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

10.4.10 Power swing detection ZMRPSB (68)

The aim is to verify that the settings of the Power swing detection function ZMRPSB (68) is according to the setting table and to verify that ZMRPSB (68) operates as expected.

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

Before starting this process, all impedance measuring zones shall be set and in operation. Test the outer resistive border in forward and reverse direction, \( RLdOutFw \) and \( RLdOutRv \) and the inner reactive border in forward and reverse direction \( X1InFw \) and \( X1InRv \). See figure 28.

The corresponding resistive border for the inner resistive boundary and outer resistive boundary is calculated automatically from the setting of \( kLdRFw \) and \( kLdRRv \).

The inner zone of ZMRPSB (68) must cover all zones by at least 10% margin.

The test is mainly divided into two parts, one which aim is to verify that the settings are in accordance to the selectivity plan and a second part to verify the operation of ZMRPSB (68). The proposed test points for validation of the settings are numbered according to figure 28.

Test of the interactions or combinations that are not configured are not considered in this instruction.
**Figure 28:** Operating principle and characteristic of the power swing detection function (settings parameters in italic)

Where:

- \( RLdInFw = RLdOutFw \cdot k_{LdRFw} \)
- \( RLdInRv = RLdOutRv \cdot k_{LdRRv} \)
- \( X1OutFw = X1InFw + (RLdOutFw - RLdInFw) \)
- \( X1OutRv = X1InRv + (RLdOutFw - RLdInFw) \)

### 10.4.10.1 Verifying the settings

**Preconditions**

The following output signal shall be configured to binary output available: ZOUT, measured impedance within outer impedance boundary.
1. Keep the measured current as close as possible to its rated value or lower. Keep it constant during the test, but ensure that it is higher than the set minimum operating current.

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

3. Make the necessary connections and settings of the test equipment for test of point 1 according to figure 28.

4. Decrease the measured three-phase impedance slowly and observe the operation value for the signal ZOUT.

5. Compare the operation value with the set value.

6. Do the necessary change of the setting of the test equipment and repeat step 4 and step 5 for point 2, 3 and 4 according to figure 28.

### 10.4.10.2 Testing the power swing detection function ZMRPSB (68)

**Preconditions**

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

1. Slowly decrease the measured impedance in all three phases until the PICKUP signal gets activated.

2. Increase the measured voltages to their rated values.

3. Decrease instantaneously voltages in all three phases to the values, which are approximately 20% lower than the voltage that gives the set value $R1LIn$ at the predefined test current.

4. The PICKUP signal must not appear.

5. Increase the measured voltages to their rated values.

### 10.4.10.3 Testing the $tR1$ timer

**Preconditions**

- The input I0CHECK, residual current ($3I_0$) detection used to inhibit the pickup output must be configured to the output signal PHG_FLT on the FDPSPDIS (21) or FRPSPDIS (21) function.
- The input BLK_SS, block inhibit of the pickup output for subsequent residual current detection is connected to FALSE.
1. Program the test equipment for a single-phase to ground fault and energize FDPSPDIS (21) or FRPSDIS (21) and check that the input BLOCK on the power swing detection function ZMRPSB (68) is activated.

2. Make a test sequence so that a single-phase to ground fault occurs after that the trajectory of the impedance has passed the outer and inner boundary of ZMRPSB (68) during power swing. Use the result from test of ZMRPSB (68) above to determine when the fault shall be applied. The ground-fault must be activated before \( tR1 \) has elapsed.

3. Start the sequence and observe that the PICKUP signal will not be activated.

10.4.10.4 Testing the block input, interaction between FDPSPDIS (21) or FRPSDIS (21) and ZMRPSB (78)

Precondition

The BLOCK input is configured and connected to PHG_FLT output on the FDPSPDIS (21) or FRPSDIS (21) function.

1. Make a test sequence so that a single phase-to-ground-fault occurs after that the trajectory of the impedance has passed the outer boundary but not the inner boundary of the power swing detection function ZMRPSB (68). Use the result from test of ZMRPSB (68) above to instance when the fault shall be applied.

2. Start the test sequence by continuously reducing the voltage and observe that the output signal ZOUT may come, but not PICKUP.

If the input I0CHECK is configured (connected to output signal PHG_FLT on FDPSPDIS (21) or FRPSDIS (21), the test of inhibit of ZMRPSB (68) at ground-fault during power swing can be done in the same way as for test of \( tR1 \). The inhibit of ZMRPSB (68) shall be instantaneous if the input TRSP is activated at the same time as the input I0CHECK during power swing.

10.4.10.5 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.

10.4.11 Power swing logic PSLPSCH

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

Most readily available test equipment does not permit simulation of power-swing conditions and the simultaneous occurrence of different faults with controlled fault
impedance. For this reason it is necessary to enable the logic by connecting the PUPSD input signal to some other functional signal, which is used for testing purposes.

Make sure that the existing configuration permits monitoring of the CS, TRIP signals on the binary outputs of the IED. If not, configure connections to unused binary outputs, for test purposes.

10.4.11.1 Testing the carrier send and trip signals

Procedure

1. Set the operation of all distance zones, which are supposed to be blocked by the operation of ZMRPSB (78), to Disabled.
2. Configure the PUPSD functional inputs to the TRIP output of the underreaching power-swing zone, if the underreaching communication scheme is used.
3. Start instantaneously any kind of fault within the underreaching power-swing zone and check, that:
   - The CS signal appears after the time delay, which is equal to the sum of set time delays for the underreaching zone \( t_{PP} \) or \( t_{PG} \) (dependent on the type of fault) and for the carrier send security timer \( t_{CS} \). Also add the usual trip time for the underreaching zone (approximately 30ms).
   - The TRIP signal appears after the time delay, which is equal to the sum of set time delays for the underreaching zone \( t_{PP} \) or \( t_{PG} \) (dependent on the type of fault) and for the trip security timer \( t_{Trip} \). Also add the usual operate time for the underreaching zone (approximately 30ms).
4. Simulate the receiving of the carrier signal so that the functional input signal CR becomes a logical one.
5. Configure the PUPSD input to connect to the output PICKUP of the carrier accelerating zone (Power-swing overreaching zone).
6. Initiate any kind of fault within the carrier accelerating zone and check that the TRIP signal appears after the time, which is equal to the time delay set on the trip timer \( t_{Trip} \). Also consider the (average) trip time of the carrier acceleration zone (approximately 30ms).

10.4.11.2 Testing the influence of the residual overcurrent protection

Additionally connect the IED according to the test instructions for the four step residual overcurrent protection function EF4PTOC (51N/67N), if the Power swing logic (PSLPSCH) is configured in a way that is controlled by this protection.

Procedure
1. Initiate a single phase-to-ground fault within both power-swing zones. Make sure that none of CS or TRIP output signals appear after the time delays $t_{CS}$ and $t_{Trip}$. BLKZMUR must appear together with the fault and must remain active until the fault has been switched off plus the time delay, as set on the $t_{BlkTr}$ timer.
2. Initiate a phase-to-phase fault within the operating area of both power-swing zones. Make sure that CS and TRIP output signals appear after the time delays $t_{CS}$.
3. Switch the operation of the zone 1 distance protection function on and fulfill all the conditions for single-pole autoreclosing.
4. Simulate a single phase-to-ground fault within the reach of zone 1 and both power-swing zones. The fault should cause a single-pole tripping with the normal operating time of zone 1.
5. Repeat the fault within the dead time of single-pole autoreclosing. Make sure, that PSLPSCH generates a BLKZMUR signal and no CS and TRIP.

10.4.11.3 Checking the underreaching zone

Procedure

1. Set the operation of all normal distance protection zones to Enabled.
2. Simulate a fault without fault resistance in the middle of distance protection zone 1. Make sure that the trip appears within the operate time for the distance protection zone 1 and no BLKZMOR output signal appears.
3. Switch off the fault and prepare a new fault without fault resistance within the normal distance protection zone 2 operate area, but outside the zone 1 operate area.
4. Switch on the fault and move it into the zone 1 operate area with a time delay longer than the time set on the $t_{DZ}$ timer and faster than the time set on timer $t_{ZL}$.
5. Observe the trip time, which must be equal to the trip time of zone 1, after the measured impedance enters its operate area. No delayed operation of zone 1 must be observed.
6. Configure the PUPSD functional input to connect to the PICKUP functional output and repeat the previous fault. Fast trip, caused by the operation of zone 1 must appear with a time delay, which is equal to the set time delay on the timer $t_{ZL}$ plus zone 1 normal otrip time. Also, observe the BLKZMOR functional output signal, which must appear for a short time.
7. Be sure to establish the original configuration of the IED and the original settings of all setting parameters.
10.4.11.4 Completing the test

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

10.4.12 Pole slip protection PSPPPAM (78)

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

10.4.12.1 Verifying the settings

It is assumed that setting of the pole slip protection function PSPPPAM (78) is done according to impedances as seen in figure 29 and figure 30.

The test is done by means of injection of three-phase current and three-phase voltage from a modern test device. This test device shall be able to give voltage and current with the possibility to change voltage and current amplitude and the angle between the injected voltage and current. The parameter setting shall be according to the real application chosen values.

Procedure

1. Feed the IED with current and voltage corresponding to a normal operation point. Injected voltage V equal to base voltage (VBase) and the injected current I equal to half the base current (IBase). The angle between the voltage and current shall be 0°.

2. With maintained amplitude of the injected voltage the current amplitude and angle is changed to a value ZC/2. This is done with a speed so that the final impedance is reached after 1 second. As the injected voltage is higher than 0.92 VBase no PICKUP signal should be activated.

3. With reduced amplitude of the injected voltage to 0.8 VBase the current amplitude and angle is changed to a value ZC/2. This is done with a speed so that the final impedance is reached after 1 second. As the injected voltage is lower than 0.92 VBase the PICKUP signal should be activated.

4. With reduced amplitude of the injected voltage to 0.8 VBase the current amplitude and angle is changed via ZC/2 to a value corresponding to half IBase and 180° between the injected current and voltage. This is done with a speed so that the final impedance is reached after 1 second. As the injected voltage is lower than 0.92 VBase the PICKUP signal should be activated. In addition to this the signal ZONE1 should be activated.
5. Set $N1Limit$ to 1 and repeat step 4.
Now the signals TRIP1 and TRIP should be activated.

6. With reduced amplitude of the injected voltage to 0.8 $V_{Base}$ the current amplitude and angle is changed via $Z_C + (Z_A - Z_C)/2$ to a value corresponding to half $I_{Base}$ and 180° between the injected current and voltage. This is done with a speed so that the final impedance is reached after 1s. As the injected voltage is lower than 0.92 $V_{Base}$ the PICKUP signal should be activated. In addition to this the signal ZONE2 should be activated.

7. Set $N2Limit$ to 1 and repeat step 6.
Now the signals TRIP2 and TRIP should be activated.
Figure 29: Setting of the pole slip protection PSPPPAM (78)
10.4.12.2 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.

10.4.13 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.

10.4.14 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 $\text{TripAngle}$ and $\text{tBreaker}$

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 31:

- the point RE (RE = Receiving End)
- the intersection between the line segment SE-RE and the X-line, which is defined
  through the setting $\text{ReachZ1}$
- the point SE (SE = Sending End)
Equation 1

\[
I_T \leq I_{\text{ovrl}} = 4 \times I_s = 4A
\]

Equation 2

\[
I_T \leq I_{\text{ovrl, p}} = I_{\text{ovrl}} \times \frac{I_s}{I_n} = 4 \times \frac{9000}{1} = 36000A
\]

Equation 3

\[
I_T = 2.5 \times I_{\text{base}} = 2.5 \times 8367 = 20918A
\]
The parameter \( \text{ReachZ1} \) defines the boundary between zone 1 and zone 2; it is expressed in percent of the parameter \( \text{ForwardX} \). If the setting of \( \text{ReachZ1} = 12\% \), then corresponding primary value of the reactance is

\[
X_{xz1} = \frac{\text{ReachZ1}}{100} \times \frac{\text{ForwardX}}{100} \times \text{ZBase} = \frac{12}{100} \times \frac{59.33}{100} \times 0.9522 = 0.068 \Omega
\]

(Equation 4)

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

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

(Equation 5)

The magnitude of the impedance \( Z_{RZ1} \) is:

\[
Z_{xz1} = \sqrt{R_{xz1}^2 + X_{xz1}^2} = \sqrt{0.009^2 + 0.068^2} = 0.069 \Omega
\]

(Equation 6)

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

\[
V_{t,RZ1} = Z_{xz1} \times I_t = 0.069 \times 20918 = 1435 V
\]

(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 (\( \text{ForwardR} \), \( \text{ForwardX} \)) and (\( \text{ReverseR} \), \( \text{ReverseX} \)):

\[
R_{Fwd} = \frac{\text{ForwardR}}{100} \times \text{ZBase} = \frac{8.19}{100} \times 0.9522 = 0.078 \Omega
\]

(Equation 8)

\[
X_{Fwd} = \frac{\text{ForwardX}}{100} \times \text{ZBase} = \frac{59.33}{100} \times 0.9522 = 0.565 \Omega
\]

(Equation 9)

\[
R_{Rev} = \frac{\text{ReverseR}}{100} \times \text{ZBase} = \frac{0.29}{100} \times 0.9522 = 0.003 \Omega
\]

(Equation 10)

\[
X_{Rev} = \frac{\text{ReverseX}}{100} \times \text{ZBase} = \frac{29.6}{100} \times 0.9522 = 0.282 \Omega
\]

(Equation 11)

and the voltages that are related to them:
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\sub{FwdR}, X\sub{FwdX}):**

\[
V_{\text{FwdR}} = Z_{\text{FwdR}} \times I = \sqrt{R^2 + X^2} \times I = \sqrt{0.078^2 + 0.565^2} \times 20918 = 0.570 \times 20918 = 11931V
\]

(Equation 12)

**SE (R\sub{RvsR}, X\sub{RvsX}):**

\[
V_{\text{RvsR}} = Z_{\text{RvsR}} \times I = \sqrt{R^2 + X^2} \times I = \sqrt{0.003^2 + 0.282^2} \times 20918 = 0.282 \times 20918 = 5899V
\]

(Equation 13)

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:
• \( \arctan\left(\frac{ForwardX}{ForwardR}\right) \) for tests in the quadrant 1 and 2 of the R-X plane
• \( \arctan\left(\frac{ReverseX}{ReverseR}\right) - 180^\circ \) 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.

\[
I_{50} = I_y = \frac{I}{2} = \frac{20918}{2} = 10459 \text{A}
\]

(Equation 16)

The first current \( I_{50} \) has frequency 50 Hz, magnitude 10459 A (that is, 1.162 A secondary) and phase angle 0°.
The second current \( I_y \) has magnitude 10459 A (that is, 1.162 A secondary), phase angle 180° (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 not 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.
10.4.14.1 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.

10.4.15 Test of point RE (R\textsubscript{Fwd}, X\textsubscript{Fwd})

10.4.15.1 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):

\[
V_u = 1.1 \times V_{\text{Fwd}} \times \frac{V_{FwdX}}{V_{FwdR}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1V
\]

(Equation 17)

\[
\angle V_u = \arctan \left( \frac{ForwardX}{ForwardR} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ
\]

(Equation 18)

frequency of \(V_{IS} = 50\) Hz
\[ I_{so} = I_{50s} \times \frac{I_{sy}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \ A \]  
(Equation 19)

\[ \angle I_{50s} = 0^\circ \]
frequency of \( I_{50s} = 50 \) Hz

\[ I_{fs} = I_{f} \times \frac{I_{sy}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \ A \]  
(Equation 20)

\[ \angle I_{fs} = 0^\circ \]
frequency of \( I_{fs} = 50 \) 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):

\[ V_n = 1.1 \times V_{r,fad} \times \frac{V_{yt}}{V_{yr,p}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1V \]  
(Equation 21)

\[ \angle V_n = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 22)

frequency of \( V_{ts} = 50 \) Hz
\[ I_{50s}=0 \, \text{A} \]
\[ I_{tfs}=0 \, \text{A} \]

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

\[ V_u = 1.1 \times V_{r,pacl} \times \frac{V_{tr,p}}{V_{t,p}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1 \, \text{V} \]  
(Equation 23)

\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 24)

frequency of \( V_{ts} = 50 \, \text{Hz} \)

\[ I_{so} = I_{50} \times \frac{I_{ct}}{I_{ct}} = 10459 \times \frac{1}{9000} = 1.162 \, \text{A} \]  
(Equation 25)

\[ \angle I_{50s} = 0^\circ \]
frequency of \( I_{50s} = 50 \, \text{Hz} \)

\[ I_{t} = I_{t} \times \frac{I_{ct}}{I_{ct}} = 10459 \times \frac{1}{9000} = 1.162 \, \text{A} \]  
(Equation 26)

\[ \angle I_{tfs} = 180^\circ \]
frequency of \( I_{tfs} = 49.5 \, \text{Hz} \)

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

### 10.4.15.2

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):
$V_v = 0.9 \times V_{v,\text{fwd}} \times \frac{V_{v,\text{fwd}}}{V_{v,\text{p}}}; V_v = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81V$

(Equation 27)

$\angle V_v = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ$

(Equation 28)

frequency of $V_{ts} = 50$ Hz

$I_{ts} = I_{t0} \times \frac{I_{ts}}{I_{tp}} = 10459 \times \frac{1}{9000} = 1.162$ A

(Equation 29)

$\angle I_{ts} = 0^\circ$

frequency of $I_{50s} = 50$ Hz

$I_{50s} = I_{t0} \times \frac{I_{50s}}{I_{tp}} = 10459 \times \frac{1}{9000} = 1.162$ A

(Equation 30)

$\angle I_{50s} = 0^\circ$

frequency of $I_{ts} = 50$ Hz

$\angle I_{ts} = 0^\circ$

• 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):
\[
V_u = 0.9 \times V_{F,rad} \times \frac{V_{F,R}}{V_{F,p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81V
\]

(Equation 31)

\[
\angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ
\]

(Equation 32)

frequency of \( V_{ts} = 50 \text{ Hz} \)
\( I_{50s} = 0 \text{ A} \)
\( I_{tfs} = 0 \text{ A} \)

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

\[
V_u = 0.9 \times V_{F,rad} \times \frac{V_{F,R}}{V_{F,p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81V
\]

(Equation 33)

\[
\angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ
\]

(Equation 34)

frequency of \( V_{ts} = 50 \text{ Hz} \)
\( I_{so} = I_{so} \times \frac{I_{Cp}}{I_{Cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \)

(Equation 35)

\( \angle I_{50s} = 0^\circ \)

frequency of \( I_{50s} = 50 \text{ Hz} \)
\( I_{tfs} = I_{tfs} \times \frac{I_{Cp}}{I_{Cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \)

(Equation 36)

\( \angle I_{tfs} = 180^\circ \)

frequency of \( I_{tfs} = 49.5 \text{ Hz} \)

Expected result: start of the protection function and trip in zone 2, when trip conditions are fulfilled.
10.4.16 Test of the boundary between zone 1 and zone 2, which is defined by the parameter *ReachZ1*

10.4.16.1 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):

  \[ V_s = 1.1 \times V_{s,22} \times \frac{V_{F,R}}{V_{F,P}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44V \]

  (Equation 37)

  \[ \angle V_s = \arctan \left( \frac{ForwardX}{ForwardR} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]

  (Equation 38)

  frequency of \( V_{ts} = 50 \text{ Hz} \)

  \[ I_{ns} = I_n \times \frac{I_{tn}}{I_{tP}} = 10459 \times \frac{1}{9000} = 1.162A \]

  (Equation 39)

  \[ \angle I_{50ns} = 0^\circ \]

  frequency of \( I_{50ns} = 50 \text{ Hz} \)

  \[ I_{fs} = I_f \times \frac{I_{tf}}{I_{tP}} = 10459 \times \frac{1}{9000} = 1.162A \]

  (Equation 40)

  \[ \angle I_{tfs} = 0^\circ \]

  frequency of \( I_{tfs} = 50 \text{ Hz} \)

- 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):

\[
V_u = 1.1 \times V_{r,z1} \times \frac{V_{v,t}}{V_{v,p}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44 V
\]

(Equation 41)

\[
\angle V_u = \arctan \left( \frac{\text{Forward}_X}{\text{Forward}_R} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ
\]

(Equation 42)

frequency of \( V = 50 \) Hz.
I_{50s} = 0 A
I_{fss} = 0 A

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

\[
V_u = 1.1 \times V_{r,z1} \times \frac{V_{v,t}}{V_{v,p}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44 V
\]

(Equation 43)

\[
\angle V_u = \arctan \left( \frac{\text{Forward}_X}{\text{Forward}_R} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ
\]

(Equation 44)

frequency of \( V = 50 \) Hz
\[ I_{50s} = I_{50} \times \frac{I_{CT}}{I_{CP}} = 10459 \times \frac{1}{9000} = 1.162 \; A \]  
(Equation 45)

\[ \angle I_{50s} = 0^\circ \]
frequency of \( I_{50s} = 50 \; Hz \)

\[ I_{fs} = I_{f} \times \frac{I_{CT}}{I_{CP}} = 10459 \times \frac{1}{9000} = 1.162 \; A \]  
(Equation 46)

\[ \angle I_{fs} = 180^\circ \]
frequency of \( I_{fs} = 49.5 \; Hz \)

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

### 10.4.16.2

**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):

\[ V_{ts} = 0.9 \times V_{r} \times \frac{V_{VX}}{V_{VR}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36 \; V \]  
(Equation 47)

\[ \angle V_{ts} = \arctan \left( \frac{ForwardX}{ForwardR} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 48)

frequency of \( V_{ts} = 50 \; Hz \)

\[ I_{ts} = I_{50} \times \frac{I_{CT}}{I_{CP}} = 10459 \times \frac{1}{9000} = 1.162 \; A \]  
(Equation 49)

\[ \angle I_{50s} = 0^\circ \]
frequency of \( I_{50s} = 50 \; Hz \)
It I I
I Afs
CTs
CTp
tf= × = × = 10459 1
9000 1 162.

(Equation 50)

∠ \text{I}_{\text{fs}} = 0^\circ

frequency of \text{I}_f = 50 \text{ 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):

\[
V_u = 0.9 \times V_{\text{fs}} \times \frac{V_{\text{fs}}}{V_{\text{fs},p}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36V
\]

(Equation 51)

\[
∠ V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ
\]

(Equation 52)

frequency of \text{V}_{\text{fs}} = 50 \text{ Hz}
\text{I}_{50}\text{s} = 0 \text{ A}
\text{I}_{\text{fs}} = 0 \text{ A}

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

\[
I_{50}s = 0 \text{ A}
I_{\text{fs}} = 0 \text{ A}
\]
\[ V_{se} = 0.9 \times V_{br2} \times \frac{V_{f1r}}{V_{f1p}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36V \]  
(Equation 53)

\[ \angle V_{se} = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 54)

Frequency of \( V_{ts} = 50 \) Hz

\[ I_{50s} = I_5 \times \frac{I_{cp}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]  
(Equation 55)

\[ \angle I_{50s} = 0^\circ \]

Frequency of \( I_{50s} = 50 \) Hz

\[ I_{\text{fs}} = I_f \times \frac{I_{cp}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]  
(Equation 56)

\[ \angle I_{\text{fs}} = 180^\circ \]

Frequency of \( I_{\text{fs}} = 49.5 \) Hz

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

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

10.4.17.1 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):

\[ V_{se} = 0.9 \times V_{br2} \times \frac{V_{f1r}}{V_{f1p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V \]  
(Equation 57)
\[ \angle V_o = \arctan \left( \frac{\text{Reverse}X}{\text{Reverse}R} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]

(Equation 58)

frequency of \( V_{ts} = 50 \) Hz

\[ I_{so} = I_{so} \times \frac{I_{c0}}{I_{c0}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]

(Equation 59)

\[ \angle I_{50s} = 0^\circ \]

frequency of \( I_{50s} = 50 \) Hz

\[ I_{t} = I_{t} \times \frac{I_{ct}}{I_{ct}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]

(Equation 60)

\[ \angle I_{ts} = 0^\circ \]

frequency of \( I_{ts} = 50 \) 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):

  \[ V_v = 0.9 \times V_{v,rad} \times \frac{V_{v,t}}{V_{v,p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47 \text{ V} \]

  (Equation 61)
\[ \angle V_x = \arctan \left( \frac{\text{Reverse}X}{\text{Reverse}R} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]

(Equation 62)

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

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

\[ V_x = 0.9 \times V_{L_{aux}} \times \frac{V_{Vr}}{V_{Vr, p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V \]

(Equation 63)

\[ \angle V_x = \arctan \left( \frac{\text{Reverse}X}{\text{Reverse}R} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]

(Equation 64)

frequency of \( V_{ts} = 50 \) Hz

\[ I_{50s} = I_{50} \times \frac{I_{CP}}{I_{CTP}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]

(Equation 65)

\( \angle I_{50s} = 0^\circ \)
frequency of \( I_{50s} = 50 \) Hz

\[ I_{ts} = I_{f} \times \frac{I_{CP}}{I_{CTP}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]

(Equation 66)

\( \angle I_{ts} = 180^\circ \)
frequency of \( I_{ts} = 50.5 \) Hz

Expected result: start of the protection function and trip in zone 1 when trip conditions are fulfilled.
10.4.17.2 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):

  \[
  V_u = 1.1 \times V_{r,rel} \times \frac{V_{ct,s}}{V_{ct,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02 \text{V}
  \]

  (Equation 67)

  \[
  \angle V_u = \arctan \left( \frac{\text{ReverseX}}{\text{ReverseR}} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ
  \]

  (Equation 68)

  - frequency of \( V_{ts} = 50 \text{ Hz} \)

  \[
  I_{so,s} = I_{so} \times \frac{I_{ct,s}}{I_{ct,p}} = 10459 \times \frac{1}{9000} = 1.162 \text{A}
  \]

  (Equation 69)

  \[
  \angle I_{50s} = 0^\circ
  \]

  - frequency of \( I_{50s} = 50 \text{ Hz} \)

  \[
  I_{ts} = I_{tf} \times \frac{I_{ct,s}}{I_{ct,p}} = 10459 \times \frac{1}{9000} = 1.162 \text{A}
  \]

  (Equation 70)

  \[
  \angle I_{ts} = 0^\circ
  \]

  - frequency of \( I_{ts} = 50 \text{ Hz} \)

- 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):

  \[
  V_n = 1.1 \times V_{r,0a2} \times \frac{V_{tr,a}}{V_{tr,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02 \text{V}
  \]

  \[
  \angle V_n = \arctan \left( \frac{\text{ReverseX}}{\text{ReverseR}} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ
  \]

  frequency of \( V_{ts} = 50 \text{ Hz} \)

  \( I_{50s} = 0 \text{ A} \)

  \( I_{ts} = 0 \text{ A} \)

- **State 2: main test step.**

  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

  \[
  V_n = 1.1 \times V_{r,0a2} \times \frac{V_{tr,a}}{V_{tr,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02 \text{V}
  \]

  \[
  \angle V_n = \arctan \left( \frac{\text{ReverseX}}{\text{ReverseR}} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ
  \]

  frequency of \( V_{ts} = 50 \text{ Hz} \)

  \( I_{s} = I_{50} \times \frac{I_{cty}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \)

  \( \angle I_{50s} = 0^\circ \)

  frequency of \( I_{50s} = 50 \text{ Hz} \)

  \( I_{fr} = I_{fr} \times \frac{I_{cty}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \)
$\angle I_{fs} = 180^\circ$

frequency of $I_{fs} = 50.5$ 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.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{IEC10000142-1-en.vsd}
\caption{Boolean output signals for the injected current with two components: a 50 Hz current component and a 49.5 Hz current component} 
\end{figure}

10.4.18 Automatic switch onto fault logic, voltage and current based ZCVPSOF

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

Automatic switch onto fault logic, voltage and current based function ZCVPSOF is checked using secondary injection tests together with the Scheme communication logic.
for distance or overcurrent protection function and with the dead line detection function (DLD), which is embedded in ZCVPSOF. ZCVPSOF is activated either by the external input BC, or by the internal DLD. FUFSPOCV is done with a pre-fault condition where the phase voltages and currents are at zero. A reverse three-phase fault with zero impedance and a three-phase fault with an impedance corresponding to the whole line is applied. This fault shall cause an instantaneous trip and result in a TRIP indication.

10.4.18.1 Activating ZCVPSOF externally

1. Activate the switch onto fault BC input.
   During normal operating conditions, the BC input is de-energized.
2. Set AutoInitMode to DLD disabled and Mode to Impedance.
3. Apply a three-phase fault condition corresponding to a fault at approximately 45% of the line or with impedance at 50% of the used zone setting and current greater than 30% of IBase.
   The ZACC input is activated.
4. Check that the TRIP output, external signals and indication are obtained.

10.4.18.2 Initiating ZCVPSOF automatically and setting mode to impedance

1. Deactivate the switch onto fault BC input.
2. Set the current and voltage inputs to lower than IphPickup and UVPickup for at least one second.
3. Set AutoInitMode to Voltage and Mode to Impedance.
4. Apply a three-phase fault condition corresponding to a fault at approximately 45% of the line or with impedance at 50% of the used zone setting and current greater than 30% of IBase.
   The ZACC input is activated.
5. Check that the correct TRIP output, external signals and indication are obtained.
10.4.18.3 Initiating ZCVPSOF automatically and setting mode to VILevel

1. Deactivate the switch onto fault BC input.
2. Set the current and voltage inputs to lower than \(I_{ph\text{Pickup}}\) and \(U_{VPickup}\) for at least one second.
3. Set AutoInitMode to Voltage and Mode to VILevel.
4. Apply the three-phase currents in such a way that the magnitudes are greater than \(I_{ph\text{Pickup}}\) and the three-phase voltages in such a way that the magnitudes and lower than \(U_{VPickup}\) at least for the duration of the \(t\text{Duration}\) setting.
5. Check that the correct TRIP output, external signals and indication are obtained.

10.4.18.4 Completing the test

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

10.4.19 Phase preference logic PPLPHIZ

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

The Phase preference logic function PPLPHIZ is tested with a three-phase testing equipment for distance protections. PPLPHIZ is tested in co-operation with the Distance protection zone, quadrilateral characteristic function ZMQPDIS (21). The distance protection and the phase preference logic 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 following binary signals (outputs) shall be monitored:

- Trip signal from distance protection
- Trip signal from phase preference logic

1. Connect the test set for injection of voltage and current.
2. Inject voltages and currents corresponding to a phase-to-phase to ground fault within zone 1 of the distance protection function. In the test one of the current inputs (one of the faulted phases) is disconnected. The remaining current is the fault current out on the protected line. All combinations of two phase-to-ground faults with one phase current are tested. The result shall be according to table 28. It should be checked that the fault will give phase-to-phase voltage, phase-to-ground...
voltage, zero-sequence voltage and phase current so that the conditions set for the logic are fulfilled.

**Table 28: Operation at different combinations of faults and operation mode**

<table>
<thead>
<tr>
<th>OperMode</th>
<th>Fault type/Faulted phase current to the IED</th>
<th>A_BG/IA</th>
<th>A_BG/IB</th>
<th>B_CG/IB</th>
<th>B_CG/IC</th>
<th>C_CG/IA</th>
<th>C_AG/IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Filter</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
<tr>
<td>No Pref</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
<tr>
<td>1231c</td>
<td>Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
<tr>
<td>1321c</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
</tr>
<tr>
<td>123a</td>
<td>Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
</tr>
<tr>
<td>132a</td>
<td>Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
</tr>
<tr>
<td>213a</td>
<td>No Trip</td>
<td>Trip</td>
<td>Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
</tr>
<tr>
<td>231a</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
</tr>
<tr>
<td>312a</td>
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<td>No Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
</tr>
<tr>
<td>321a</td>
<td>No Trip</td>
<td>Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>No Trip</td>
<td>Trip</td>
<td>Trip</td>
</tr>
</tbody>
</table>

**10.4.19.1 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.

**10.5 Current protection**

**10.5.1 Instantaneous phase overcurrent protection 3-phase output PHPIOC (50)**

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

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

- Phase-to-ground fault

Ensure that the maximum continuous current, supplied from the current source used for the test of the IED, does not exceed four times the rated current value of the IED.
10.5.1.1  Measuring the operate limit of set values

1. Inject a phase current into the IED with an initial value below that of the setting.
2. Set the operation mode to 1 out of 3.
3. Increase the injected current in the Ln phase until the TR_A (TR_B or TR_C) signal appears.
4. Switch the fault current off.

   ![Information icon] Observe: Do not exceed the maximum permitted overloading of the current circuits in the IED.

5. Compare the measured operating current with the set value.
6. Set the operation mode to 2 out of 3 and inject current into one of the phases. Check - no operation.

10.5.1.2  Completing the test

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

10.5.2  Four step phase overcurrent protection 3-phase output

**OC4PTOC (51_67)**

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

10.5.2.1  Verifying the settings

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 for operation is chosen: Connect the injection current to phases A and neutral.
   If 2 out of 3 currents for operation is chosen: Connect the injection current into phase A and out from phase B.
If 3 out of 3 currents for operation is chosen: 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. Set the injected polarizing voltage slightly larger than the set minimum polarizing voltage (default is 5% of $V_{\text{Base}}$) 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 for operation is chosen: The voltage angle of phase A is the reference.

If 2 out of 3 currents for operation is chosen: The voltage angle of phase A – the voltage angle of B is the reference.

If 3 out of 3 currents for operation is chosen: 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°).

4. Increase the injected current and note the trip value of the tested step of the function.

5. Decrease the current slowly and note the reset value.

6. 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).

7. 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.

8. Block higher set stages when testing lower set stages by following the procedure described below.

9. Connect a trip output contact to a timer.

10. Set the injected current to 200% of the operate level of the tested stage, switch on the current and check the time delay.
    For inverse time curves, check the trip time at a current equal to 110% of the trip current for $tx_{\text{Min}}$.

11. Check that all trip and pickup contacts operate according to the configuration (signal matrixes)

12. Reverse the direction of the injected current and check that the protection does not operate.

13. If 2 out of 3 or 3 out of 3 currents for operation is chosen: Check that the function will not trip with current in one phase only.

14. Repeat the above described tests for the higher set stages.

15. Finally check that pickup and trip information is stored in the event menu.

Verification of the non-directional phase overcurrent function is done as instructed above, without applying any polarizing voltage.
10.5.2.2 Completing the test

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

10.5.3 Instantaneous residual overcurrent protection EFPIOC (50N)

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

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

- Phase-to-ground fault

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

10.5.3.1 Measuring the operate limit of set values

1. Inject a phase current into the IED with an initial value below that of the setting.
2. Increase the injected current in the Ln or in the neutral (summated current input) phase until the TRIP signal appears.
3. Disable the fault current
   - Observe to not exceed the maximum permitted overloading of the current circuits in the IED.
4. Compare the measured operating current with the set value.

10.5.3.2 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.

10.5.4 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".
10.5.4.1 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 (default 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 operates.
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 operate level of the tested step, switch on the current and check the time delay. For inverse time curves, check the operate time at a current equal to 110% of the operate current for \( txMin \).
9. Check that all trip and trip contacts operate according to the configuration (signal matrixes)
10. Reverse the direction of the injected current and check that the step does not operate.
11. Check that the protection does not operate 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.

10.5.4.2 Four step non-directional ground fault protection

1. Do as described in "Four step directional ground fault protection", but without applying any polarizing voltage.

10.5.4.3 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.
10.5.5 Four step negative sequence overcurrent protection
NS4PTOC (46I2)

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

When inverse time overcurrent characteristic is selected, the operate
time of the stage will be the sum of the inverse time delay and the set
definite time delay. Thus, if only the inverse time delay is required, it is
of utmost importance 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 operates.
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 operate level of the tested step, switch on
the current and check the time delay.
For inverse time curves, check the operate time at a current equal to 110% of the
operate current in order to test parameter tXmin.
9. Check that all trip and pickup contacts operate according to the configuration
(signal matrixes)
10. Reverse the direction of the injected current and check that the step does not operate.
11. Check that the protection does not operate 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.
10.5.5.1 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.

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

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

Figure 33: 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

10.5.6.1 Measuring the operate and time limit for set values
Operation mode $3I_0 \cdot \cos \phi$

Procedure

1. Set the polarizing voltage to $1.2 \cdot VNRelPU$ and set the phase angle between voltage and current to the set characteristic angle ($RCADir$). Note that 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 operate current of the set directional element is equal to the $INcosPhiPU$ setting. The I Dir ($3I_0 \cdot \cos \phi$) function activates the PICKUP and PUNDIN output.

3. Assume that $\phi'$ is the phase angle between injected voltage ($3V_0$) and current ($3I_0$) i.e. $\phi' = RCADir - \phi$. Change $\phi'$ to for example 45 degrees. Increase the injected current until the function operates.

4. Compare the result with the set value and make sure that the new injected $3I_0 \cdot \cos \phi$ is equal to the setting $INcosPhiPU$.

5. Measure the operate time of the timer by injecting a current two times the set $INCosPhiPU$ value and the polarizing voltage $1.2 \cdot VNRelPU$.

\[
T_{inv} = \frac{TDSN \cdot SRef}{3I_0 \cdot 3V_{test} \cdot \cos(\phi)}
\]

(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 34: Characteristic with ROAdir restriction
Operation mode \( 3I_0 \cdot 3V_0 \cdot \cos \varphi \)

1. Set the polarizing voltage to \( 1.2 \cdot VNRelPU \) and set the phase angle between voltage and current to the set characteristic angle (\( RCA_{Dir} \)). Note that the current lagging the voltage.
2. Inject current until the function picks up, and make sure that the operate 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 \( \varphi' \) is the phase angle between injected voltage (\( 3V_0 \)) and current (\( 3I_0 \)) i.e. \( \varphi' = RCA_{Dir} - \varphi \). Change \( \varphi' \) to for example 45 degrees. Increase the injected current until the function operates.
4. Compare the result with the set value and make sure that the new injected $3I_0 \cdot 3V_0 \cdot \cos \phi$ is equal to the setting $SN \_PU$. Take the set characteristic into consideration, see figure 34 and figure 35.

5. Measure the trip time of the timer by injecting $1.2 \cdot VNRelPU$ and a current to get two times the set $SN \_PU$ trip value.

$$T_{inv} = \frac{TDSN \cdot SRef}{3I_{0_{test}} \cdot 3V_{0_{test}} \cdot \cos(\phi)}$$

(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 $1.2 \cdot VNRelPU$ 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 operate 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 PICKUP and PUDIRIN output.

3. Measure with angles $\phi$ around $RCADir \pm ROAdir$.

4. Compare the result with the set values, refer to figure 36 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.

$$T_{inv} = \frac{TDSN \cdot SRef}{3I_{0_{test}} \cdot 3V_{0_{test}} \cdot \cos(\phi)}$$

(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.
Non-directional ground fault current protection

Procedure

1. Measure that the operate current is equal to the $IN_{NonDirPU}$ 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 $tIN_{NonDir}$ 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 operate 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 $0.8 \cdot VNRelPU$ 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.

10.5.6.2 Completing the test

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

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

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

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

10.5.7.1 Measuring the operate 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.

10.5.7.2 Completing the test

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

10.5.8 Breaker failure protection, phase segregated activation and
output CCRBRF (50BF)

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

The Breaker failure protection, 3-phase activation and output function CCRBRF
(50BF) should normally be tested in conjunction with some other function that
provides an initiate signal. An external BFI_3P signal can also be used.

To verify the settings in the most common back-up trip mode 1 out of 3, it is sufficient
to test phase-to-ground faults.

At mode 2 out of 4 the phase current setting, Pickup_PH can be checked by single-
phase injection where the return current is connected to the summated current input.
The value of residual (ground fault) current IN set lower than Pickup_PH is easiest
checked in back-up trip mode 1 out of 4.

10.5.8.1 Checking the phase current operate value, Pickup_PH

The check of the Pickup_PH current level is best made in FunctionMode = Current
and BuTripMode = 1 out of 3 or 2 out of 4.
1. Apply the fault condition, including BFI_3P of CCRBRF (50BF), with a current below set $\text{Pickup\_PH}$.
2. Repeat the fault condition and increase the current in steps until a trip occurs.
3. Compare the result with the set $\text{Pickup\_PH}$.
4. Disconnect AC and BFI_3P input signals.

Note! If $\text{No\ CBPos\ Check}$ or $\text{Retrip\ off}$ is set, only back-up trip can be used to check set $\text{IP}>$. 

10.5.8.2 Checking the residual (ground fault) current operate value $\text{Pickup\_N}$ set below $\text{Pickup\_PH}$

Check the low set $\text{Pickup\_N}$ current where setting $\text{FunctionMode} = \text{Current}$ and setting $\text{BuTripMode} = 1$ out of 4

1. Apply the fault condition, including BFI_3P of CCRBRF (50BF), with a current just below set $\text{Pickup\_N}$.
2. Repeat the fault condition and increase the current in steps until trip appears.
3. Compare the result with the set $\text{Pickup\_N}$.
4. Disconnect AC and BFI_3P input signals.

10.5.8.3 Checking the re-trip and back-up times

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

Choose the applicable function and trip mode, such as $\text{FunctionMode} = \text{Current}$ and $\text{RetripMode} = \text{CB\ Pos\ Check}$.

1. Apply the fault condition, including initiation of CCRBRF (50BF), well above the set current value. Measure time from BFI_3P of CCRBRF (50BF).
2. Check the re-trip $t1$ and back-up trip times $t2$ and $t3$.
   In applicable cases, the back-up trip for multi-phase pickup2MPh and back-up trip 2, $t2$ and $t3$ can also be checked. To check $t2MPh$, a two-phase or three-phase initiation shall be applied.
3. Disconnect AC and BFI_3P input signals.

10.5.8.4 Verifying the re-trip mode

Choose the mode below, which corresponds to the actual case.
In the cases below it is assumed that $\text{FunctionMode} = \text{Current}$ is selected.

**Checking the case without re-trip, $\text{RetripMode} = \text{Retrip Off}$**

1. Set $\text{RetripMode} = \text{Retrip Off}$.
2. Apply the fault condition, including initiation of CCRBRF (50BF), well above the set current value.
3. Verify that no re-trip, but back-up trip is achieved after set time.
4. Disconnect AC and BFI_3P input signals.

**Checking the re-trip with current check, $\text{RetripMode} = \text{CB Pos Check}$**

1. Set $\text{RetripMode} = \text{CB Pos Check}$.
2. Apply the fault condition, including initiation of CCRBRF (50BF), well above the set current value.
3. Verify that re-trip is achieved after set time $t_1$ and back-up trip after time $t_2$.
4. Apply the fault condition, including initiation of CCRBRF (50BF), with current below set current value.
5. Verify that no re-trip, and no back-up trip is obtained.
6. Disconnect AC and BFI_3P input signals.

**Checking re-trip without current check, $\text{RetripMode} = \text{No CBPos Check}$**

1. Set $\text{RetripMode} = \text{No CBPos Check}$.
2. Apply the fault condition, including initiation of CCRBRF (50BF), well above the set current value.
3. Verify that re-trip is achieved after set time $t_1$, and back-up trip after time $t_2$.
4. Apply the fault condition, including initiation of CCRBRF (50BF), with current below set current value.
5. Verify that re-trip is achieved after set time $t_1$, but no back-up trip is obtained.
6. Disconnect AC and BFI_3P input signals.

**10.5.8.5 Verifying the back-up trip mode**

In the cases below it is assumed that $\text{FunctionMode} = \text{Current}$ is selected.

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

Use the actual tripping modes. The case below applies to re-trip with current check.
1. Apply the fault condition, including initiation of CCRBRF (50BF), with phase current well above set value Pickup_PH.
2. Interrupt the current, with a margin before back-up trip time, \( t_2 \). It may be made at issue of re-trip command.
3. Check that re-trip is achieved, if selected, but no back-up trip is obtained.
4. Disconnect AC and BFI_3P input signals.

The normal mode \( \text{BuTripMode} = 1 \text{ out of 3} \) should have been verified in the tests above. In applicable cases the modes \( 1 \text{ out of 4} \) and \( 2 \text{ out of 4} \) can be checked. Choose the mode below, which corresponds to the actual case.

**Checking the case \( \text{BuTripMode} = 1 \text{ out of 4} \)**

It is assumed that the ground-fault current setting \( \text{Pickup}_N \) is below phase current setting \( \text{Pickup}_PH \).

1. Set \( \text{BuTripMode} = 1 \text{ out of 4} \).
2. Apply the fault condition, including initiation of CCRBRF (50BF), with one-phase current below set \( \text{Pickup}_PH \) but above \( \text{Pickup}_N \). The residual ground-fault should then be above set \( \text{Pickup}_N \).
3. Verify that back-up trip is achieved after set time. If selected, re-trip should also appear.
4. Disconnect AC and BFI_3P input signals.

**Checking the case \( \text{BuTripMode} = 2 \text{ out of 4} \)**

The ground-fault current setting \( \text{Pickup}_N \) may be equal to or below phase-current setting \( \text{Pickup}_PH \).

1. Set \( \text{BuTripMode} = 2 \text{ out of 4} \).
2. Apply the fault condition, including initiation of CCRBRF (50BF), with one-phase current above set \( \text{Pickup}_PH \) and residual (ground fault) above set \( \text{Pickup}_N \).
3. Verify that back-up trip is achieved after set time. If selected, re-trip should also appear.
4. Apply the fault condition, including initiation of CCRBRF (50BF), with at least one-phase current below set \( \text{Pickup}_PH \) and residual (ground fault) above set \( \text{Pickup}_N \). The current may be arranged by feeding three- (or two-) phase currents with equal phase angle (I0-component) below \( \text{Pickup}_PH \), but of such value that the residual (ground fault) current \( (3I_0) \) will be above set value \( \text{Pickup}_N \).
5. Verify that back-up trip is not achieved.
6. Disconnect AC and BFI_3P input signals.
10.5.8.6 Verifying instantaneous back-up trip at CB faulty condition

Applies in a case where a signal from CB supervision function regarding CB being faulty and unable to trip is connected to input 52FAIL.

1. Repeat the check of back-up trip time. Disconnect current and input signals.
2. Activate the input 52FAIL. The output CBALARM (CB faulty alarm) should appear after set time \( t_{CBA\text{alarm}} \). Keep the input activated.
3. Apply the fault condition, including initiation of CCRBRF (50BF), with current above set current value.
4. Verify that back-up trip is obtained without intentional delay, for example within 20ms from application of initiation.
5. Disconnect injected AC and BFI_3P input signals.

10.5.8.7 Verifying the case RetripMode = Contact

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

1. Set FunctionMode = Contact
2. Apply input signal for CB closed to relevant input or inputs 52a_A (B or C).
3. Apply input signal, or signals for initiation of CCRBRF (50BF).
4. Verify that phase selection re-trip and back-up trip are achieved after set times.
5. Disconnect the trip signal(s). Keep the CB closed signal(s).
6. Apply input signal(s), for initiation of CCRBRF (50BF).
7. Arrange disconnection of CB closed signal(s) well before set back-up trip time \( t_2 \).
8. Verify that back-up trip is not achieved.
9. Disconnect injected AC and BFI_3P input signals.

10.5.8.8 Verifying the function mode Current&Contact

To be made only when FunctionMode = Current&Contact is selected. It is suggested to make the tests in one phase only, or at three-pole trip applications for just three-pole tripping.

Checking the case with fault current above set value Pickup_PH

The operation shall be as in FunctionMode = Current.

1. Set FunctionMode = Current&Contact.
2. Leave the inputs for CB close inactivated. These signals should not influence.
3. Apply the fault condition, including initiation of CCRBRF (50BF), with current above the set Pickup_PH value.
4. Check that the re-trip, if selected, and back-up trip commands are achieved.
5. Disconnect injected AC and BFI_3P input signals.
Checking the case with fault current below set value Pickup_BlkCont

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

1. Set FunctionMode = Current&Contact.
2. Apply input signal for CB closed to relevant input or inputs 52a_A (B or C)
3. Apply the fault condition with input signal(s) for initiation of CCRBRF (50BF).
   The value of current should be below the set value Pickup_BlkCont
4. Verify that phase selection re-trip (if selected) and back-up trip are achieved after set times. Failure to trip is simulated by keeping the signal(s) CB closed activated.
5. Disconnect the AC and the BFI_3P signal(s). Keep the CB closed signal(s).
6. Apply the fault and the initiation again. The value of current should be below the set value Pickup_BlkCont.
7. Arrange disconnection of BC closed signal(s) well before set back-up trip time t2.
   It simulates a correct CB tripping.
8. Verify that back-up trip is not achieved. Re-trip can appear for example, due to selection “Re-trip without current check”.
9. Disconnect injected AC and BFI_3P input signals.

10.5.8.9 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.

10.5.9 Stub protection STBPTOC (50STB)

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

Logical signals for STBPTOC (50STB) protection are available on the local HMI under Main menu/Settings/Setting group N/Current protection/Stub(PTOC, 50STB)/STBPTOC:x

10.5.9.1 Measuring the operate limit of set values

1. Check that the input logical signals BLOCK and ENABLE and the output logical signal TRIP are all logical zero.
2. Activate the input ENABLE on the STBPTOC (50STB) function block
3. For a short while inject a current (fault current) in one phase to about 110% of the set operating current, and switch the current off.
Observe to not exceed the maximum permitted overloading of the current circuits in the IED.

4. Switch the fault current on and measure the operating time of STBPTOC (50STB). Use the TRIP signal from the configured binary output to stop the timer. The operation should be instantaneously.

5. Activate the input BLOCK on the STBPTOC (50STB) function block.
6. Switch on the fault current (110% of the setting). No TRIP signal should appear.
7. Switch off the fault current.
8. For a short while inject a current (fault current) in same phase to about 90% of the set operating current, and switch the current off.
9. Switch the fault current on. No TRIP signal should appear.
10. Switch off the fault current.
11. Reset the ENABLE binary input.
12. Switch the fault current on.
13. Disable the fault current.

10.5.9.2 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.

10.5.10 Pole discrepancy protection CCPDSC (52PD)

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

10.5.10.1 Verifying the settings

1. External detection logic, Contact function selection = ContactSel setting equals CCPDSC (52PD) signal from CB. Activate the EXTPDIND binary input, and measure the operating time of CCPDSC (52PD). Use the TRIP signal from the configured binary output to stop the timer.
2. Compare the measured time with the set value $t_{Trip}$.
3. Reset the EXTPDIND input.
4. Activate the BLKDBYAR binary input. This test should be performed together with Autorecloser SMBRREC (79).
5. Activate the EXTPDIND binary input.
No TRIP signal should appear.
6. Reset both BLKDBYAR and EXTPDIND binary inputs.
7. Activate the BLOCK binary input.
8. Activate EXTPDIND binary input.
   NO TRIP signal should appear.
9. Reset both BLOCK and EXTPDIND binary inputs.
10. If Internal detection logic Contact function selection = ContactSel setting equals Pole position from auxiliary contacts. Then set inputs 52b_A...52a_C in a status that activates the pole discordance logic and repeats step 2 to step 6.
11. Unsymmetrical current detection with CB monitoring: Set measured current in one phase to 110% of current release level. Activate CLOSECMD and measure the operating time of the CCPDSC (52PD) protection. Use the TRIP signal from the configured binary output to stop the timer.
12. Deactivate the CLOSECMD: Set measured current in one phase to 90% of Current Release level. Activate CLOSECMD.
   NO TRIP signal should appear.
13. Repeat the previous two steps using OPENCMD instead of CLOSECMD. Asymmetry current detection with CB monitoring: Set all three currents to 110% of Current Release level. Activate CLOSECMD.
   NO TRIP signal should appear due to symmetrical condition.
14. Deactivate the CLOSECMD. Decrease one current with 120% of the current unsymmetrical level compared to the other two phases. Activate CLOSECMD and measure the operating time of the CCPDSC (52PD) protection. Use the TRIP signal from the configured binary output to stop the timer.
15. Deactivate the CLOSECMD. Decrease one current with 80% of the current unsymmetrical level compared to the other two phases. Activate CLOSECMD.
   NO TRIP signal should appear.

10.5.10.2 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.

10.5.11 Directional underpower protection GUPPDUP (37)

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

10.5.11.1 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>
<thead>
<tr>
<th>Set value: Mode</th>
<th>Formula used for complex power calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, B, C</td>
<td>$\bar{S} = \bar{V}_A \cdot \bar{I}_A^* + \bar{V}_B \cdot \bar{I}_B^* + \bar{V}_C \cdot \bar{I}_C^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 80)</td>
</tr>
<tr>
<td>Arone</td>
<td>$\bar{S} = \bar{V}_{AB} \cdot \bar{I}<em>A^* - \bar{V}</em>{BC} \cdot \bar{I}_C^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 81)</td>
</tr>
<tr>
<td>PosSeq</td>
<td>$\bar{S} = 3 \cdot \bar{V}<em>{PosSeq} \cdot \bar{I}</em>{PosSeq}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 82)</td>
</tr>
<tr>
<td>AB</td>
<td>$\bar{S} = \bar{V}_{AB} \cdot (\bar{I}_A^* - \bar{I}_B^*)$</td>
</tr>
<tr>
<td></td>
<td>(Equation 83)</td>
</tr>
<tr>
<td>BC</td>
<td>$\bar{S} = \bar{V}_{BC} \cdot (\bar{I}_B^* - \bar{I}_C^*)$</td>
</tr>
<tr>
<td></td>
<td>(Equation 84)</td>
</tr>
<tr>
<td>CA</td>
<td>$\bar{S} = \bar{V}_{CA} \cdot (\bar{I}_C^* - \bar{I}_A^*)$</td>
</tr>
<tr>
<td></td>
<td>(Equation 85)</td>
</tr>
</tbody>
</table>

Table continues on next page
### Set value: Mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>Formula used for complex power calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$\mathbf{S} = 3 \cdot \mathbf{V}_A \cdot \mathbf{I}_A^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 86)</td>
</tr>
<tr>
<td>B</td>
<td>$\mathbf{S} = 3 \cdot \mathbf{V}_B \cdot \mathbf{I}_B^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 87)</td>
</tr>
<tr>
<td>C</td>
<td>$\mathbf{S} = 3 \cdot \mathbf{V}_C \cdot \mathbf{I}_C^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 88)</td>
</tr>
</tbody>
</table>

2. Adjust the injected current and voltage to the set values in % of $IB_{\text{Base}}$ and $V_{\text{Base}}$ (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 $Angle1 + 90^\circ$. 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 $I_{\text{Base}}$.

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.

#### 10.5.11.2 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.

#### 10.5.12 Directional overpower protection GOPPDOP (32)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".
10.5.12.1 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 $I_{Base}$ and $V_{Base}$ (converted to secondary current and voltage). The angle between the injected current and voltage shall be set equal to the set direction $Angle_1$, 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 $Angle_1 + 90°$. 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 $Angle_1$ value.

5. 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 $Power_1$, power setting for stage 1 in % of $S_{base}$.

6. Increase the current to 100% of $I_{Base}$ and switch the current off.

7. Switch the current on and measure the time for activation of TRIP1, trip of stage 1.

8. If a second stage is used, repeat steps 2 to 6 for the second stage.

10.5.12.2 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.

10.5.13 Broken conductor check BRCPTOC (46)

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

10.5.13.1 Measuring the operate and time limit of set values
1. Check that the input logical signal BLOCK to the BRCPTOC (46) function block is logical zero and note on the local HMI that the output signal TRIP from the BRCPTOC (46) function block is equal to the logical 0.

2. Set the measured current (fault current) in one phase to about 110% of the set operating current $Pickup_{PH}$.
   Observe to not exceed the maximum permitted overloading of the current circuits in the terminal.

3. Switch on the fault current and measure the operating time of BRCPTOC (46). TRIP is controlled by Gate 13 in the configuration.
   Use the TRIP signal from the configured binary output to stop the timer.

4. Compare the measured time with the set value $t_{Oper}$.

5. Activate the BLOCK binary input.

6. Switch on the fault current (110% of the setting) and wait longer than the set value $t_{Oper}$.
   No TRIP signal should appear.

7. Switch off the fault current.

8. Set the measured current (fault current) in same phase to about 90% of the set operating current $Pickup_{PH}$. Switch off the current.

9. Switch on the fault current and wait longer than the set value $t_{Oper}$.
   No TRIP signal should appear.

10. Switch off the fault current.

10.5.13.2 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.

10.5.14 Voltage-restrained time overcurrent protection VRPVOC(51V)

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

10.5.14.1 Verifying the settings

Verifying settings by secondary injection
1. Connect the test set for three-phase current injection and three-phase voltage injection to the appropriate IED terminals.

2. Go to **Main menu/Settings/IED Settings/Current protection/VoltageRestOverCurr (51V,2(I>/U<))/VRPVOC (51V,2(I>/U<))/1/General** and make sure that the function is enabled, that is, *Operation* is set to *Enabled*.

3. The test of the function may be performed by injecting restrain voltage and increasing the injected current(s). Note the value at which the PICKUP and STOC signals are set.

In the following equations, restrain voltage is the magnitude of the minimum phase-to-phase voltage in secondary volts.

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

**First part of the characteristic** (Restrain voltage ≤ 25% of $V_{Base}$): 

$$\frac{Picup\_Curr}{100} \times \frac{IBase}{CT\,sec} \times \frac{CT\,prim}{100} \times \frac{VDepFact}{sec}$$

(Equation 89)

**Second part of the characteristic** (25% of $V_{Base}$ ≤ Restrain voltage ≤ $V_{High\,Limit}/100\times V_{Base}$), valid when setting parameter $VDepMode = Slope$:

$$\left(\frac{Picup\_Curr}{100} \times \frac{IBase}{CT\,sec}\times \frac{CT\,prim}{100}\right) \times \left(\frac{VDepFact}{V_{Base}}\times \frac{V_{Dep\,Fact}}{100}\right) \times \left(\frac{Restrain\,Voltage}{100} \times \frac{V_{sec}}{V_{prim}}\right)$$

(Equation 90)

**Third part of the characteristic** ($V_{High\,Limit}/100\times V_{Base}$ ≤ Restrain voltage):

$$\frac{Picup\_Curr}{100} \times \frac{IBase}{CT\,sec} \times \frac{CT\,prim}{100}$$

(Equation 91)

**Example** (rated secondary current = 1A):

<table>
<thead>
<tr>
<th>CT ratio</th>
<th>10 000/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT ratio</td>
<td>10 kV/100 V</td>
</tr>
<tr>
<td>Pickup_Curr</td>
<td>100%</td>
</tr>
<tr>
<td>VDepFact</td>
<td>25%</td>
</tr>
<tr>
<td>VHighLimit</td>
<td>100%</td>
</tr>
<tr>
<td>IBase</td>
<td>10 000 A</td>
</tr>
<tr>
<td>VBase</td>
<td>10 kV</td>
</tr>
</tbody>
</table>
A test for each section of the characteristic of the function VRPVOC may be performed; that may be achieved by applying the following voltages:

First section of the characteristic:
If $V_{DepMode} = \text{Slope}$, the minimum measured phase-to-phase voltage is lower than $0.25*U_{Base}$; if $V_{DepMode} = \text{Step}$, the minimum measured phase-to-phase voltage is lower than $V_{HighLimit}/100*V_{Base}$:
- $V_A$: Ampl = $10 / \sqrt{3}$; Angle = $0^\circ$
- $V_B$: Ampl = $10 / \sqrt{3}$; Angle = $240^\circ$
- $V_C$: Ampl = $100 / \sqrt{3}$; Angle = $120^\circ$

Second section of the characteristic only:
If $V_{DepMode} = \text{Slope}$, the minimum measured phase-to-phase voltage is between $0.25*V_{Base}$ and $V_{HighLimit}/100*V_{Base}$:
- $V_A$: Ampl = $50 / \sqrt{3}$; Angle = $0^\circ$
- $V_B$: Ampl = $50 / \sqrt{3}$; Angle = $240^\circ$
- $V_C$: Ampl = $100 / \sqrt{3}$; Angle = $120^\circ$

Last section of the characteristic:
If $V_{DepMode} = \text{either Slope or Step}$, the minimum measured phase-to-phase voltage is higher than $V_{HighLimit}/100*V_{Base}$:
- $V_A$: Ampl = $105 / \sqrt{3}$; Angle = $0^\circ$
- $V_B$: Ampl = $105 / \sqrt{3}$; Angle = $240^\circ$
- $V_C$: Ampl = $105 / \sqrt{3}$; Angle = $120^\circ$

4. Inject the voltages that are related to the first part of the characteristic, and then slowly increase the phase current $I_A$ from 0.0 A up to the value the function operates. The PICKUP and STOC signals must be activated when the amplitude of the phase current $I_A$ is slightly above 0.25 A on the secondary side. The corresponding trip signals TROC and TRIP will be activated after the pre-set time delay has expired.

5. Decrease the current $I_A$ slowly and note the reset value.

6. Repeat steps 4 and 5 applying voltages that are related to the second and the last section of the characteristic; the function operates when $I_A$ is slightly higher than: 0.5 A in the second section; 1A in the last section.

7. Connect the trip output contact to the input channel of the test set in order to stop the injection and measure the trip time.

8. If definite time delay is used for the overcurrent step, set the setting $\text{Characterist} = \text{ANSI Def. Time}$. Apply the voltages related to the last part of the characteristic and inject a current $I_A$ 200% higher than the set operation level, and check the definite time delay for trip (the signals TROC and TRIP of the protection function VRPVOC are active in trip condition).

9. If inverse time delay is used for the overcurrent step, the parameter setting $\text{Characterist}$ shall be properly set; we can refer, for example, to the setting IEC $\text{Very inv.}$; If the IEC Very inverse time characteristic is selected, the trip signals TROC and TRIP will operate after a time defined by the equation:
\[ t[s] = \frac{13.5 \times k}{\frac{l}{\text{Pickup_Curr}}} - 1 \]

(Equation 92)

where:
- \( t \) Operate time in seconds
- \( l \) Measured value (for example, phase current)
- \( \text{Pickup_Curr} \) Set trip value

This means that if the measured phase current jumps from 0 to 2 times the set operate level and time multiplier \( k \) is set to 1.0 s (default value), then the TROC and TRIP signals will operate after a time delay equal to 13.5 s ± tolerance.

Taking into account the above explanation, inject the voltages related to the last part of the characteristic and inject a current IA 200% higher than the set operation level, and check the trip time delay.

If \( t_{\text{Def_OC}} \) is set to a value different from 0 s, then this time delay is added to the one that is defined by the IDMT characteristic.

10. Check the start and trip information that are stored in the event menu.
11. The previous step 8 or 9 may be repeated also for the first and second section of the characteristic.
12. Supply the IED with symmetric three-phase voltages at their rated values. Go to Main menu/Settings/IED Settings/Current protection/VoltageRestOverCurr(51V,2(I>/U<))/VRPVOC(51V,2(I>/U<)):1/Undervoltage and set the setting Operation_UV = Enabled to activate the undervoltage stage.
13. Slowly decrease the voltage in two phases simultaneously, until the STUV and PICKUP signals appear.
14. Note the operate value. The set operate value in secondary volts is calculated according to the following equation:

\[ \frac{\text{Pickup_Volt}}{100} \times \frac{\text{VBase}}{\sqrt{3}} \times \frac{\text{VT sec}}{\text{VTprim}} \]

(Equation 93)

If the VRPVOC function is used as an overcurrent protection with undervoltage seal-in, it is necessary to first inject sufficient current to activate the STOC signal before the under-voltage step is allowed to trip. In order to achieve that, apply symmetric three-phase voltages at their rated value and then inject a current IA that
is 200% higher than the set operation level. Then slowly decrease the voltage in two phases simultaneously, until the STUV and PICKUP signals appear.

15. Increase slowly the applied voltages of the previous two phases and note the reset value.
16. Check that the trip output of the relay is connected to the input channel of the test in order to stop the injection and measure the trip time.
17. Inject symmetric three-phase voltages at their rated value and check that the STUV and PICKUP signals reset as well as the trip signals of the function block (TRIP and TRUV).
18. Instantaneously decrease the voltage in two phases simultaneously to a value 20% lower than the set operate value (take into account the previous note if VRPVOC is configured in ACT with the undervoltage seal-in feature).
19. Measure the definite time delay for the TRUV and TRIP signals and compare it with the set value $t_{Def\_UV}$.
20. Check that start and trip information is stored in the event menu.

10.5.14.2 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.

10.6 Voltage protection

10.6.1 Two step undervoltage protection UV2PTUV (27)

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

10.6.1.1 Verifying the settings

Verification of PICKUP value and time delay to operate 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 operate value and compare it with the set value.

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

For phase-to-ground measurement:

\[
\frac{V_{\text{pickup}}}{100} < \frac{V_{\text{Base}}}{\sqrt{3}} \times \frac{V_T}{V_{\text{prim}}} \times \frac{\text{sec}}{\text{VT Prim}}
\]

(Equation 94)

For phase-to-phase measurement:

\[
\frac{V_{\text{pickup}}}{100} < \frac{V_{\text{Base}}}{\sqrt{3}} \times \frac{V_T}{V_{\text{prim}}} \times \frac{\text{sec}}{\text{VT Prim}}
\]

(Equation 95)

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 operate 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 \( V_{\text{pickup}} < \).

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

\[
t(s) = \frac{TD1}{\left(1 - \frac{V}{V_{\text{pickup}} <}\right)}
\]

(Equation 96)

where:
- \( t(s) \) Operate time in seconds
- \( TD1 \) Settable time multiplier of the function for step 1
- \( V \) Measured voltage
- \( V_{\text{pickup}} < \) 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 operate 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.

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

10.6.2 Two step overvoltage protection OV2PTOV (59)
Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

10.6.2.1 Verifying the settings

Verification of single-phase voltage and time delay to operate 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 operate value and compare it with the set value.

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

For phase-to-ground measurement:

\[
\frac{V_{pickup}}{100} \times \frac{V_{Base}}{\sqrt{3}} \times \frac{VT_{sec}}{VT_{prim}} \]

(Equation 97)

For phase-to-phase measurement:

\[
\frac{V_{pickup}}{100} \times V_{Base} \times \frac{VT_{sec}}{VT_{prim}} \]

(Equation 98)
4. Decrease the voltage slowly and note the reset value.
5. Set and apply about 20% higher voltage than the measured operate 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 $1.2 \times V_{\text{pickup}}$.

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

$$t(s) = \frac{TD1}{V \left( \frac{V_{\text{pickup}}}{V_{\text{pickup}}} - 1 \right)}$$

(Equation 99)

where:
- $t(s)$ Operate time in seconds
- $TD1$ Settable time multiplier of the function for step 1
- $V$ Measured voltage
- $V_{\text{pickup}}$ Set pickup voltage for step 1

For example, if the measured voltage jumps from 0 to 1.2 times the set pickup voltage level and time multiplier $TD1$ is set to 0.05 s (default value), then the TRST1 and TRIP signals operate at a time equal to 0.250 s ± tolerance.

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

10.6.2.2 Extended testing

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

10.6.2.3 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.
10.6.3 Two step residual overvoltage protection ROV2PTOV (59N)

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

10.6.3.1 Verifying the settings

1. Apply the single-phase voltage either to a single-phase voltage input or to a residual voltage input with the pickup value below the set value $Pickup_1$.
2. Slowly increase the value until PU_ST1 appears.
3. Note the operate value and compare it with the set value.
4. Decrease the voltage slowly and note the reset value.
5. Set and apply about 20% higher voltage than the measured operate 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 $1.2 \times V_{pickup}>$.

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

$$t(s) = \frac{TD1}{\left(\frac{V}{V_{pickup}>} - 1\right)}$$

(Equation 100)

where:
- $t(s)$: Operate time in seconds
- $TD1$: Settable time multiplier of the function for step 1
- $V$: Measured voltage
- $V_{pickup}>$: Set pickup voltage for step 1

For example, if the measured voltage jumps from 0 to 1.2 times the set pickup voltage level and time multiplier $TD1$ is set to 0.05 s (default value), then the TRST1 and TRIP signals operate at a time equal to 0.250 s ± tolerance.
8. Repeat the test for Step 2 of the function.
10.6.3.2 Completing the test

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

10.6.4 Overexcitation protection OEXPVPH (24)

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

10.6.4.1 Verifying the settings

1. Enable function.
2. Connect a symmetrical three-phase voltage input from the test set to the appropriate connection terminals of the overexcitation protection OEXPVPH (24) is configured for a three-phase voltage input. A single-phase injection voltage is applied if the function is configured for a phase-to-phase voltage input. OEXPVPH (24) is conveniently tested using rated frequency for the injection voltage and increasing the injection voltage to get the desired overexcitation level.
3. Connect the alarm contact to the timer and set the time delay $t_{Alarm}$ temporarily to zero.
4. Increase the voltage and note the operate value $Pickup1$.
5. Reduce the voltage slowly and note the reset value.
6. Set the alarm time delay to the correct value according to the setting plan and check the time delay, injecting a voltage corresponding to $1.2 \cdot Pickup1$.
7. Connect a trip output contact to the timer and temporarily set the time delay $t_{MinTripDelay}$ to 0.5s.
8. Increase the voltage and note the $Pickup2$ operate value
9. Reduce the voltage slowly and note the reset value.
10. Set the time delay to the correct value according to the setting plan and check the time delay $t_{MinTripDelay}$, injecting a voltage corresponding to $1.2 \cdot Pickup2$.
11. Check that trip and alarm contacts operate according to the configuration logic.
12. Set the cooling time constant temporarily to min value (1min.) to quickly lower the thermal content.
13. Wait for a period equal to 6 times $t_{CoolingK}$ switch 20 minutes on a voltage $1.15 \cdot Pickup1$ and check the inverse operate time. Wait until the thermal memory is emptied, set the cooling time constant according to the setting plan and check another point on the inverse time curve injecting a voltage $1.3 \cdot Pickup1$.
14. Finally check that PICKUP and TRIP information is stored in the event menu.
10.6.4.2 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.

10.6.5 Voltage differential protection VDCPTOV (60)

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

10.6.5.1 Check of undervoltage levels

This test is relevant if the setting BlkDiffAtVLow = Yes.

Check of V1Low

Procedure

1. Connect voltages to the IED according to valid connection diagram and figure 37.
2. Apply voltage higher than the highest set value of VDTrip, V1Low and V2Low to the V1 three-phase inputs and to one phase of the V2 inputs according to figure 37.
   The voltage differential PICKUP signal is set.
Figure 37: Connection of the test set to the IED for test of V1 block level

where:
1 is three-phase voltage group1 (V1)
2 is three-phase voltage group2 (V2)

3. Decrease slowly the voltage in phase VA of the test set until the PICKUP signal resets.
4. Check V1 blocking level by comparing the voltage level at reset with the set undervoltage blocking \( V1_{Low} \).
5. Repeat steps 2 to 4 to check \( V1_{Low} \) for the other phases.

![Diagram of test set connection to IED](ANSI0700106-1-en.vsd)

The connections to V1 must be shifted to test another phase. (VA to VB, VB to VC, VC to VA)

**Check of V2Low**

Procedure

1. Connect voltages to the IED according to valid connection diagram and figure 38.
2. Apply voltage higher than the highest set value of $V_{DTrip}$, $V_{1Low}$ and $V_{2Low}$ to the V1 three-phase inputs and to one phase of the V2 inputs according to figure 38. The voltage differential PICKUP signal is set.
3. Decrease slowly the voltage in phase VC of the test set until the PICKUP signal resets.
4. Check V2 blocking level by comparing the voltage level at reset with the set undervoltage blocking $V_{2Low}$.

10.6.5.2 Check of voltage differential trip and alarm levels

Procedure

1. Connect voltages to the IED according to valid connection diagram and figure 39.
Figure 39: Connection of the test set to the IED for test of alarm levels, trip levels and trip timer

where:
1 is three-phase voltage group 1 (V1)
2 is three-phase voltage group 2 (V2)

2. Apply \(1.2 \cdot V_n\) (rated voltage) to the V1 and V2 inputs.
3. Decrease slowly the voltage of in phase VA of the test set until the ALARM signal is activated.

The ALARM signal is delayed with timer \(t_{Alarm}\)

4. Check the alarm operation level by comparing the differential voltage level at ALARM with the set alarm level \(V_{DAlarm}\).
5. Continue to slowly decrease the voltage until PICKUP signal is activated.
6. Check the differential voltage operation level by comparing the differential voltage level at PICKUP with the set trip level \(V_{DTrip}\).
7. Repeat steps 1 to 6 to check the other phases.
Observe that the connections to V1 must be shifted to test another phase. (VA to VB, VB to VC, VC to VA)
10.6.5.3 Check of trip and trip reset timers

Procedure

1. Connect voltages to the IED according to valid connection diagram and figure 39.
2. Set Vn (rated voltage) to the V1 inputs and increase V2 voltage until differential voltage is $1.5 \cdot$ operating level ($V_{DTrip}$).
3. Switch on the test set. Measure the time from activation of the PICKUP signal until TRIP signal is activated.
4. Check the measured time by comparing it to the set trip time $t_{Trip}$.
5. Increase the voltage until PICKUP signal resets. Measure the time from reset of PICKUP signal to reset of TRIP signal.
6. Check the measured time by comparing it to the set trip reset time $t_{Reset}$.

10.6.5.4 Final adjustment of compensation for VT ratio differences

Procedure

1. With the protection in test mode, view the differential voltage service values in each phase on the local HMI under Main menu/Test/Function status/Voltage protection/VoltageDiff(PTOV,60)/VDCPTOV:x.

   The IED voltage inputs should be connected to the VTs according to valid connection diagram.

2. Record the differential voltages.
3. Calculate the compensation factor $RF_x$ for each phase.
   For information about calculation of the compensation factor, see the application manual.
4. Set the compensation factors on the local HMI under Main menu/Settings/Settings group N/Voltage protection/VoltageDiff(PTOV,60)/VDCPTOV:x
5. Check that the differential voltages are close to zero.

10.6.5.5 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.
10.6.6 Loss of voltage check LOVPTUV (27)

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

10.6.6.1 Measuring the operate limit of set values

1. Check that the input logical signals BLOCK, CBOPEN and BLKU are logical zero.
2. Supply a three-phase rated voltage in all three phases and note on the local HMI that the TRIP logical signal is equal to the logical 0.
3. Switch off the voltage in all three phases. After set $t_{\text{Trip}}$ time a TRIP signal appears on the corresponding binary output or on the local HMI.

   Note that TRIP at this time is a pulse signal, duration should be according to set $t_{\text{Pulse}}$.

4. Inject the measured voltages at rated values for at least set $t_{\text{Restore}}$ time.
5. Activate the CBOPEN binary input.
6. Simultaneously disconnect all the three-phase voltages from the IED. No TRIP signal should appear.
7. Inject the measured voltages at rated values for at least set $t_{\text{Restore}}$ time.
8. Activate the BLKU binary input.
9. Simultaneously disconnect all the three-phase voltages from the IED. No TRIP signal should appear.
10. Reset the BLKU binary input.
11. Inject the measured voltages at rated values for at least set $t_{\text{Restore}}$ time.
12. Activate the BLOCK binary input.
13. Simultaneously disconnect all the three-phase voltages from the IED. No TRIP signal should appear.
14. Reset the BLOCK binary input.

10.6.6.2 Completing the test

Continue to test another function or end the test by changing the TestMode setting to **Disabled**. Restore connections and settings to their original values, if they were changed for testing purposes.
10.6.7 Radial feeder protection PAPGAPC (27)

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

10.6.7.1 Verifying the settings

Values of the logical signals for PAPGAPC (27) are available on the local HMI under:

Main menu/Tests/Function status/Voltage protection/RadialFeeder(27, V<T)/PAPGAPC(27, V<T):1

Test for fast fault clearing

- Connect the test set for the injection of three phase voltages and currents to the appropriate terminals of the IED.
- Enable the fast fault clearance by setting FastOperation to TRUE, and also connect the inputs BLKDLFLT to TRUE and FUSEFAIL to FALSE.
- Also assume circuit breaker is in closed position, that is CBCLOSED is high, prior to fault occurrence.
- Create a single phase fault on phase A such that phase A voltage is lower than VPhSel<T times quadrature phase to phase voltage and set Tau to default value.
- Activate carrier receive CR signal.
- Check that TRIP, TR_A, ARST and ARST_A are generated with the conditions described.
- Check that activated trip signals and pickup signals are blocked by enabling BLKTR and BLKST.
- Check that all activated signals are disabled by BLOCK input.
- If required, perform creating faults on the remaining phases in the similar way.

Test of delayed fault clearing for single pole tripping

- Connect the test set for the injection of three phase voltages and currents to the appropriate terminals of the IED.
- Enable the delayed fault clearance for single pole tripping by setting Del1phOp to 1Ph (Enabled), Del3phOp to FALSE (Disabled) and also connect the inputs BLKDLFLT and FUSEFAIL to FALSE.
- Also assume circuit breaker is in closed position, that is input CBCLD is high, prior to fault occurrence.
- Create a single phase fault on phase A such that phase A voltage is lower than VPhSel<T times quadrature phase to phase voltage and set Tau to default value and also inject the residual current such that it exceeds set Pickup_N value.
- Check that output TRIN is activated after a set delay of tResCurr if ResCurrOper is set to high.
- Check that TRIP and TR_A are generated with the conditions described after a set delay time of t1Ph and the outputs ARST and ARST_A are also activated.
• Check that activated trip signals and pickup signals are blocked by enabling BLKTR and BLKST.
• Check that all activated signals are disabled by BLOCK input.
• If required, perform creating faults on the remaining phases in the similar way.

Test of delayed fault clearing for three pole tripping

• Connect the test set for the injection of three phase voltages and currents to the appropriate terminals of the IED.
• Enable the delayed fault clearance for three pole tripping by setting Del3phOp to TRUE (Enabled), Del1PhOp to 3Ph (Disabled) and also set the inputs BLKDLFLT and FUSEFAIL to FALSE.
• Also assume circuit breaker is in closed position, that is, the input CBCLOSED is high prior to fault occurrence.
• Create a BC fault such that their phase voltage magnitudes are lower than $V_{PhSel}$ times corresponding quadrature phase to phase voltage and set Tau to default value.
• Check that TRIP, TR_A, TR_B and TR_C are generated after the set delay time of $t_{3Ph}$ and ARST, ARST3PH, ARST_A, ARST_B and ARST_C are also activated.
• Check that activated trip signals and pickup signals are blocked by enabling BLKTR and BLKST.
• Check that all activated signals are disabled by BLOCK input.

10.6.7.2 Completing the test

Continue to test another function or end the testing by setting the parameter TestMode to Disabled under: Main menu/Tests/IED test mode/TESTMODE:1

Restore connections and settings to their original values if they were changed for testing purposes.

10.7 Frequency protection

10.7.1 Underfrequency protection SAPTUF (81)

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

10.7.1.1 Verifying the settings
Verification of 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.
3. Slowly decrease the frequency of the applied voltage, until the PICKUP signal appears.
4. Note the trip value and compare it with the set value.
5. Increase the frequency until rated operating levels are reached.
6. Check that the PICKUP signal resets.
7. Instantaneously decrease the frequency of the applied voltage to a value about 1% lower than the trip value (a step change more than 2% will increase the time delay).
8. Measure the time delay of 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 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 \(PUF\)requency, \(VMin\), 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 \(PUF\)requency.
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.

10.7.1.2 Completing the test

Continue to test another function or end the test by changing the \(TestMode\) setting to \(Disabled\). Restore connections and settings to their original values, if they were changed for testing purposes.
10.7.2 Overfrequency protection SAPTOF (81)

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

10.7.2.1 Verifying the settings

Verification of PICKUP value and time delay to trip

1. Check that the settings in the IED are appropriate, for example the PICKUP value and the time delay.
2. Supply the IED with three-phase voltages at their rated values.
3. Slowly increase the frequency of the applied voltage, until the PICKUP signal appears.
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. Instantaneously increase the frequency of the applied voltage to a value about 1% lower than the trip value (a step change more than 2% will increase the time delay).
8. 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 \( PUFrequency \), \( VMin \), 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, \( VMin \).
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.
10.7.2.2 Completing the test

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

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

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

10.7.3.1 Verifying the settings

PICKUP value and time delay to operate

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 operate 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.

10.7.3.2 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.
10.8 Multipurpose protection

10.8.1 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 new 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.

10.8.1.1 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 in the 670 series.
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 operates and check against the set operate 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 operate value of low set stage, switch on the current and check the time delay.
For inverse time curves, check the operate time at a current equal to 110% of the operate current at $t_{\text{MinTripDelay}}$.

8. Check that TRIP and PICKUP contacts operate according to the configuration logic.

9. Release the blocking of the high set stage and check the operate 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.

10.8.1.2 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 operate value is done.

Procedure

1. Operate 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 operate value is done.

10.8.1.3 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. Operate 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 operate value has to be calculated when testing of the operate value is done.

4. Operate 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.
10.8.1.4 **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 operate value also is dependent on the angle between current and polarizing voltage according to the $I \cdot \cos(\Phi)$ law (setting parameter DirPrinc_OC1 or DirPrinc_OC2 set to $I \cdot \cos(\Phi)$). 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 CTWYPnt configuration parameter is set to ToObject.
   If reverse directional feature is selected or CTWYPnt 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 principle as above (non-directional overcurrent feature)
5. Reverse the direction of the injection current and check that the protection does not operate.
6. Check with low polarization voltage that the feature becomes non-directional, blocked or with memory according to the setting.

10.8.1.5 **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 principle as above (non-directional overcurrent feature) and correspondingly for the undervoltage feature.
10.8.1.6 Completing the test

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

10.9 Secondary system supervision

10.9.1 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.

10.9.1.1 Verifying the settings

1. Check the input circuits and the operate value of the IMinOp current level detector by injecting current, one phase at a time.
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 current input and check that FAIL output is obtained when the current is about 0.9 · IBase.

10.9.1.2 Completing the test

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

10.9.2 Fuse failure supervision FUFSPVC

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".
The verification is divided in two main parts. The first part is common to all fuse failure supervision options, and checks that binary inputs and outputs operate as expected according to actual configuration. In the second part the relevant set operate values are measured.

### 10.9.2.1 Checking that the binary inputs and outputs operate 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 operate.
   - Undervoltage-dependent functions must not operate.
3. Disconnect the dc voltage from the 89b binary input terminal.
4. Connect the nominal dc voltage to the MCBOP binary input.
   - The BLKV and 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 whether 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

### 10.9.2.2 Measuring the operate value for the negative sequence function

Measure the operate value for the negative sequence function, if included in the IED.
Section 10
Testing functionality by secondary injection

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):

\[ 3 \cdot \bar{V}_2 = \bar{V}_a + a^2 \cdot \bar{V}_b + a \cdot \bar{V}_c \]

(Equation 101)

Where:
\[ \bar{V}_a, \bar{V}_b, and \bar{V}_c \]
are the measured phase voltages

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

4. Compare the result with the set value of the negative-sequence operating voltage (consider that the set value \(3V_{2PU}\) is in percentage of the base voltage \(V_{Base}\)).
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):

\[ 3 \cdot \bar{I}_2 = \bar{I}_a + a^2 \cdot \bar{I}_b + a \cdot \bar{I}_c \]

(Equation 104)

Where:
\[ \bar{I}_a, \bar{I}_b, and \bar{I}_c \]
are the measured phase currents

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

7. Compare the result with the set value of the negative-sequence operating current. Consider that the set value \(3I_{2<}\) is in percentage of the base current \(I_{Base}\).
10.9.2.3 Measuring the operate value for the zero-sequence function

Measure the operate 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 107)

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 operating voltage (consider that the set value \( 3V_0\text{Pickup} \) 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):

\[ 3 \cdot \overline{I_0} = \overline{I_A} + \overline{I_B} + \overline{I_C} \]

(Equation 109)

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 operating current. Consider that the set value \( 3I_0< \) is in percentage of the base current \( I_{\text{Base}} \).

10.9.2.4 Measuring the operate 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 $V_{Base}$).
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 $I_{Base}$).

### 10.9.2.5 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 dead line 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 operate 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.

### 10.9.2.6 Completing the test

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

### 10.9.3 Fuse failure supervision

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

#### Checking the operation of binary input and output

1. Simulate normal operation conditions with three-phase voltage on the main fuse group and the pilot fuse group. Ensure the values are equal to their rated values.
2. Disconnect one of the phase voltage from the main fuse group or the pilot fuse group. Observe the binary outputs of the IED. The MAINFUF or the PILOTFUF signals are simultaneously activated. Only the output circuit related to the open phase will be active i.e either MAINFUF or PILOTFUF.
3. Establish a normal voltage operating condition and observe the corresponding output signals. MAINFUF or PILOTFUF should change to 0 in about 27 ms.
4. Set normal conditions as mentioned in step 1.
5. Enable the BLOCK binary input and repeat step 2. MAINFUF or PILOTFUF should not appear.

#### Checking the operation of MAINFUF and PILOTFUF

1. Simulate normal operation conditions with three-phase voltage on the main fuse group and the pilot fuse group. Ensure the values are equal to their rated values.
2. Decrease one of the three-phase voltages on main fuse group or pilot fuse group. The voltage change must be greater than the set value for $Vdif$ Main block or $Vdif$ Pilot alarm. MAINFUF or PILOTFUF signals are activated without any time delay.
3. Set normal conditions as mentioned in step 1. MAINFUF or PILOTFUF signals should reset.
4. Set SealIn to On, $Vdif$ Main block to 20% of $VBase$ and $VSealIn$ to 70% of $VBase$.
5. Apply three-phase voltages with the value slightly below $VSealIn$ level.
6. Decrease one of the three-phase voltages on main fuse group. The voltage change must be greater than the set value for $V_{dif\, Main\, block}$. MAINFUF signal is activated.
7. After more than 5 seconds increase the measured voltage back to the value slightly below $V_{Seal\, In}$ level. MAINFUF signal should not reset.
8. Slowly increase measured voltage to the value slightly above $V_{Seal\, In}$ until MAINFUF signal resets.
9. Record the measured voltage and compare with the set value $V_{Seal\, In}$.

10.9.3.1 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.

10.10 Control

10.10.1 Synchrocheck, energizing check, and synchronizing SESRSYN (25)

This section contains instructions on how to test the synchrocheck, synchronism check, energizing check, and synchronizing function SESRSYN (25) for single, double and breaker-and-a-half arrangements.

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

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

- $AutoEnerg = Disabled/DLLB/DBLL/Both$
- $ManEnerg = Disabled$
- $Operation = Disabled/Enabled$
- Activation of the voltage selection function if applicable

The tests explained in the test procedures below describe the settings, which can be used as references during testing before the final settings are specified. After testing, restore the equipment to the normal or desired settings.
A secondary injection test set with the possibility to alter the phase angle and amplitude of the voltage is needed. The test set must also be able to generate different frequencies on different outputs.

The description below applies for a system with a nominal frequency of 60 Hz but can be directly applicable to 50 Hz. SESRSYN (25) can be set to use different phases, phase to ground or phase to phase. Use the set voltages instead of what is indicated below.

Figure 40 shows the general test connection principle, which can be used during testing. This description describes the test of the version intended for one bay.

Figure 41 shows the general test connection for a breaker-and-a-half diameter with one-phase voltage connected to the line side.

**Figure 40:** General test connection with three-phase voltage connected to the line side
10.10.1.1 Testing the synchronizing function

The voltage inputs used are:

- V3PL1: VA, VB or VC line 1 voltage inputs on the IED
- V3PBB1: Bus1 voltage input on the IED

Testing the frequency difference

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

$FreqDiffMax = 50.2$ Hz

$FreqDiffMin = 50.01$ Hz

$tBreaker = 0.080$ s

1. Apply voltages
1.1. V-Line = 100% $V_{BaseLine}$ and f-Line = 60.0 Hz
1.2. V-Bus = 100% $V_{BaseBus}$ and f-Bus = 60.15 Hz

2. Check that a closing pulse is submitted at a closing angle equal to calculated phase angle value from the formula below. Modern test sets will evaluate this automatically.

\[
\text{Closing Angle} = |(f_{Bus} - f_{Line}) \times t_{Breaker} \times 360 \text{ degrees}| \\
f_{Bus} = \text{Bus frequency} \\
f_{Line} = \text{Line frequency} \\
t_{Breaker} = \text{Set closing time of the breaker}
\]

3. Repeat with

3.1. V-Bus = 100% $V_{BaseBus}$ and f-bus = 60.25 Hz, to verify that the function does not operate when frequency difference is above limit.

4. Verify that the closing command is not issued when the frequency difference is less than the set value $FreqDiffMin$.

10.10.1.2 Testing the synchrocheck check

During the test of SESRSYN (25) for a single bay arrangement, these voltage inputs are used:

- V-Line VA, VB or VC line 1 voltage input on the IED according to the connection in SMT
- V-Bus V5 voltage input on the IED according to the connection in SMT

**Testing the voltage difference**

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

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

Test with no voltage difference between the inputs.

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

**Testing the phase angle difference**

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

Test with no voltage difference.

1. Apply voltages V-Line (for example) = 100% $GblBaseSelLine$ and V-Bus = 100% $GblBaseSelBus$, with a phase difference equal to 0 degrees and a frequency difference lower than $FreqDiffA$ and $FreqDiffM$.
2. Check that the AUTOSYOK and MANSYOK outputs are activated. The test can be repeated with other phase difference values to verify that the function operates for values lower than the set ones, $PhaseDiffM$ and $PhaseDiffA$. By changing the phase angle on the voltage connected to V-Bus, between ± $d\phi$ degrees, the user can check that the two outputs are activated for a phase difference lower than the set value. It should not operate for other values. See figure 42.
3. Change the phase angle between +dφ and -dφ and verify that the two outputs are activated for phase differences between these values but not for phase differences outside, see figure 42.

**Testing the frequency difference**

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

Test with frequency difference = 0 mHz

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

1. Apply voltages V-Line equal to 100\% \( GblBaseSelLine \) and V-Bus equal to 100\% \( GblBaseSelBus \), with a frequency difference equal to 0 mHz and a phase difference lower than the set value.
2. Check that the AUTOSYOK and MANSYOK outputs are activated.
3. Apply voltage to the V-Line equal to 100\% \( GblBaseSelLine \) with a frequency equal to 50 Hz and voltage V-Bus equal to 100\% \( GblBaseSelBus \), with a frequency outside the set limit.
4. Check that the two outputs are not activated. The test can be repeated with different frequency values to verify that the function operates for values lower than the set ones. If a modern test set is used, the frequency can be changed continuously.

**Testing the reference voltage**

1. Use the same basic test connection as in figure 40.
The voltage difference between the voltage connected to V-Bus and V-Line should be 0%, so that the AUTOSYOK and MANSYOK outputs are activated first.

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

### 10.10.1.3 Testing the energizing check

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

<table>
<thead>
<tr>
<th>V-Line</th>
<th>VA, VB or VC line1 voltage inputs on the IED</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-Bus</td>
<td>Bus voltage input on the IED</td>
</tr>
</tbody>
</table>

#### General

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

Live voltage level is fixed to 80% \( V_{Base} \) and dead voltage level to fixed 40% \( V_{Base} \).

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

#### Testing the dead line live bus (DLLB)

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

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

#### Testing the dead bus live line (DBLL)

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

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

**Testing both directions (DLLB or DBLL)**

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

**Testing the dead bus dead line (DBDL)**
The test should verify that the energizing check function operates for a low voltage on both the V-Bus and the V-Line, that is, closing of the breaker in a non-energized system. Test is valid only when this function is used.

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

### 10.10.1.4 Testing the voltage selection
Testing the voltage selection for single CB arrangements
This test should verify that the correct voltage is selected for the measurement in the SESRSYN function used in a double-bus arrangement. Apply a single-phase voltage of 100% GblBaseSelLine to the V-Line and a single-phase voltage of 100% GblBaseSelBus to the V-Bus.

If the VB1/2OK inputs for the fuse failure are used, they must be activated, during tests below. Also verify that deactivation prevents operation and gives an alarm.

1. Connect the signals above to binary inputs and binary outputs.
2. Connect the voltage inputs to the analog inputs used for each bus or line depending of the type of busbar arrangement and verify that correct output signals are generated.

Testing the voltage selection for double breaker
This test should verify that correct voltage is selected for the measurement in the SESRSYN function used for a diameter in a Breaker-and-a-half arrangement. Apply a single-phase voltage of 100% GblBaseSelLine to the V-Line and a single-phase voltage of 100% GblBaseSelBus to the V-Bus. Verify that correct output signals are generated.

1. Connect the analog signals to the voltage inputs, in pair of two for V1 and V2. (Inputs V3PB1, V3PB2, V3PL1, V3PL2)
2. Activate the binary signals according to the used alternative. Verify the measuring voltage on the synchronizing check function SESRSYN (25). Normally it can be good to verify synchronizing check with the same voltages and phase angles on both voltages. The voltages should be verified to be available when selected and not available when another input is activated so connect only one voltage transformer reference at each time.
3. Record the voltage selection tests in a matrix table showing read values and AUTOSYOK/MANSYOK signals to document the test performed.

Testing the voltage selection for 1 1/2 CB arrangements
At test of the SESRSYN (25) function for a breaker-and-a-half diameter the following alternative voltage inputs can be used for the three SESRSYN (SESRSYN 1, SESRSYN 2, SESRSYN 3) functions. These three SESRSYN functions can either be in one, two or three different IEDs. Table 30 describes the scenario when SESRSYN 1, SESRSYN 2 and SESRSYN 3 all are in the same IED. If SESRSYN 3 is in another IED, WA1 will be considered as WA2 and LINE2 as LINE1. The voltage is selected by activation of different inputs in the voltage selection logic as shown in table 30 and figure 43.
Table 30: Voltage selection logic

<table>
<thead>
<tr>
<th>SESRSYN</th>
<th>CBConfig setting</th>
<th>Section to be synchronized</th>
<th>Activated B1QCLD input on IED from</th>
<th>Activated B2QCLD input on IED from</th>
<th>Activated LN1QCLD input on IED from</th>
<th>Activated LN2QCLD input on IED from</th>
<th>Indication from SESRSYN on IED</th>
</tr>
</thead>
<tbody>
<tr>
<td>SESRSYN 1 (Operates on CB1 52)</td>
<td>breaker-and-a-half bus CB</td>
<td>Bus1 – Line1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus1 – Line2</td>
<td>CB2 252</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus1 – Bus2</td>
<td>CB2 252</td>
<td>CB3 352</td>
<td></td>
<td></td>
<td>B1SEL, B2SEL</td>
</tr>
<tr>
<td>SESRSYN 2 (Operates on CB2 252)</td>
<td>Tie CB</td>
<td>Line1 – Line2</td>
<td></td>
<td>LN1 989</td>
<td>LN2 989</td>
<td></td>
<td>LN1SEL, LN2SEL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus1 – Line2</td>
<td>CB1 52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus2 – Line1</td>
<td>CB3 352</td>
<td>LN1 989</td>
<td></td>
<td></td>
<td>B2SEL, LN1SEL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus1 – Bus2</td>
<td>CB1 52</td>
<td>CB3 352</td>
<td></td>
<td></td>
<td>B1SEL, B2SEL</td>
</tr>
<tr>
<td>SESRSYN 3 (Operates on CB3 352)</td>
<td>breaker-and-a-half bus alt. CB (mirrored)</td>
<td>Bus2 – Line2</td>
<td></td>
<td></td>
<td></td>
<td>LN2 989</td>
<td>B2SEL, LN2SEL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus2 – Line1</td>
<td>CB2 252</td>
<td>LN1 989</td>
<td></td>
<td></td>
<td>B2SEL, LN1SEL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus2 – Bus1</td>
<td>CB2 252</td>
<td>CB1 52</td>
<td></td>
<td></td>
<td>B1SEL, B2SEL</td>
</tr>
</tbody>
</table>
Figure 43: Objects used in the voltage selection logic

10.10.1.5 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.

10.10.2 Autorecloser for 1/2/3-phase operation SMBRREC (79)

Verification of the Autorecloser for 1/2/3-phase operation function SMBRREC (79) for single-phase, two-phase or three-phase reclosing attempts can be considered to consist of two parts.

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

This section deals with verification of SMBRREC (79) itself. However, it is practical to initiate SMBRREC (79) by activating a protection function, for example, by secondary injection tests.
Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

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

The verification test is performed together with protection and trip functions. Figure 44 illustrates a suggested testing arrangement, where the circuit-breaker (CB) is simulated by an external bi-stable relay (BR), for example a relay type RXMVB2 or RXMD or Breaker Simulator of ABB. The following manual switches are used:

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

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

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

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

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

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

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

Information and material for the verification:
Section 10
Testing functionality by secondary injection

- Protection or control unit, IED, configured and with settings entered.
- Configuration diagram for the IED
- Terminal diagram for the IED, or plant circuit diagram including the IED
- Technical reference manual for the IED
- IED test set for secondary injection
- Means to indicate, measure and record operation and times, for example an event recording facility
- A bi-stable relay (BR) or two auxiliary relays to simulate a CB
- Two push-buttons (SC, ST) to operate the BR and a change-over switch (SRY) to simulate CBREADY
- Possibly a switch simulation the synchronizing check SESRSYN (25) condition
To test set

Figure 44: Simulating the CB operation by a bi-stable relay/breaker simulator and manual switches

10.10.2.1 Preparation of the verification

1. Check the function settings on the local HMI under Main menu/Settings/Setting group N/Control/Autorecloser 79, 5(0->1)/SMBRREC:x
If any timer settings are reduced to speed up or facilitate the testing, they shall be set to normal after testing. A temporary label on the IED can be a reminder to restore normal settings after which a verification test should be performed.

2. Decide if a synchronizing check function SESRSYN (25) shall be included in the test.
   If SESRSYN (25) as an internal function or external device is not operated by the injection, input signal SYNC must be connected as a permanent high signal or controlled by a switch.

3. Read and make notes of the reclosing operation counters on the local HMI under Main menu/Test/Function status/Control/AutoRecloser79,5(0–>1)/SMBRREC:x
   Possibly reset the counters to Zero. Counters are reset in the reset menu.

4. Make arrangements for the simulation of the CB, for example as in figure 44.

5. Make arrangements for indication, recording and time measurements.
   The signals for ,52a, RI, CLOSECMD, READY and other relevant signals should preferably be arranged for event recording with time tagging. If that is not possible, other means of time measurement and recording should be arranged.

10.10.2.2 Switching the autorecloser for 1/2/3-phase operation function to Enabled and Disabled

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

10.10.2.3 Verifying the autorecloser function SMBRREC (79)

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

- three-phase single-shot reclosing
- two-shot reclosing
- single-phase and three-phase single-shot reclosing

Below, a case with single-phase and three-phase single-shot reclosing is described.
1. Set *Operation = Enabled*.
2. If the synchronizing check SESRSYN (25) is not to be operated, ensure that the signal SYNC input is activated. If SESRSYN (25) is to be included, ensure that it is supplied with the appropriate AC quantities.
3. Simulate CB closed position by closing switch SC to make the BR relay pick-up.
4. Simulate CBREADY by closing the switch SRY, and leave it closed.
5. Inject AC quantities to give a trip, for example, one-pole trip, to the BR and to the RI input.
   Observe and preferably record the operation. The BR relay shall trip and reclose (pick-up). After reclosing, the SRY switch can be opened for about 5s and then closed again.
   The autoreclosing open time and the sequence should be checked, for example in the event recording. Check also the operation indications (disturbance report) and the operation counters on the local HMI under **Main menu/Test/Function status/Control/AutoRecloser79,5(0->1)/SMRREC:x**
   Should the operation not be as expected, this should be investigated. It could be caused by an inappropriate setting or missing condition such as CBREADY.
6. Repeat the sequence by simulating a permanent fault.
   Shortly after the reclosing shot, a new fault is applied. If a single-shot reclosing program is selected, there shall be one reclosing operation and then blocking of SMRREC (79) for the set Reset time.
   Before a new reclosing sequence can be run, the CBREADY and 52a (CB closed) must be set manually.
7. Repeat the sequence by simulating a three-phase transient and permanent faults, and other applicable cases, such as signal to RI_HS and high-speed reclosing. If just single-phase reclosing is selected, *FirstShot = 1ph*, a check can be run to make sure that a three-pole trip does not result in any reclosing. Other similar cases can be checked as required.

**10.10.2.4 Checking the reclosing conditions**

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

**Checking the influence of the INHIBIT signal**
1. Check that the autorecloser function SMBRREC (79) is operative, for example, by making a reclosing shot without the INHIBIT signal.
2. Apply a fault and thereby a RI signal. At the same time, or during the open time, apply a signal to the input INHIBIT.
3. Check that the reclosing sequence is interrupted and no reclosing takes place.

**Check closing onto a fault**

1. Check that the autorecloser function SMBRREC (79) is operative, for example by making a reclosing shot.
   Keep the CBREADY signal high.
2. Set the breaker simulating relay BR in Open position.
3. Close the BR relay and apply immediately a fault and thereby a RI signal.
4. Check that no reclosing takes place.

**Checking the influence of CB not ready for reclosing**

1. Check that the autorecloser function SMBRREC (79) is operative, for example by making a reclosing shot.
   Keep the CB simulator BR closed. Remove the CBREADY signal by opening SRY.
2. Apply a fault and thereby a RI signal.
3. Check that no reclosing takes place.

**Checking the influence of synchronizing check (at three-pole reclosing)**

1. Check that the autorecloser function SMBRREC (79) is operative, for example, by making a three-pole reclosing shot with the SESRSYN (25) synchronizing check condition.
   Set the SESRSYN (25) function to Off to eliminate the signal connected to input signal SYNC.
2. Apply a fault causing three-phase trip and thereby a RI and a TR3P signal.
3. Wait for the tSync time out limit.
   Check that no reclosing is made.

**Checking the response when autoreclosing is Off**

Procedure

1. Check that the autorecloser function SMBRREC (79) is operative, for example by making a reclosing shot.
   Set the autoreclosing operation to Off, for example by external control.
The output READY shall be low, and PREP3P shall be high.

2. Apply a single phase fault and thereby a RI signal.
3. Check that a definitive three phase trip and no reclosing takes place.

**Testing autoreclosing in a multi-breaker arrangement**

The usual arrangement is to have an autorecloser function SMBRREC (79) per circuit-breaker. They can be in different CB related IEDs or in a common IED.

- A master SMBRREC (79) function is set with Priority = High.
- A slave SMBRREC (79) function is set with Priority = Low.

See the application manual for an illustration of typical interconnections.

The two functions can be checked individually by carefully applying RI, WAIT, and INHIBIT signals.

It is also possible to verify the two functions together by using CB simulating equipment for two CB circuits. There should be interconnections from the master to the slave function, WFMAS - WAIT, and UNSUCC - INHIBIT, as shown in the illustration referred to above.

**Restoring equipment**

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

1. Check the operation counters.
   - Reset the counters to zero, if that is the user's preference. The counter reset function is found on the local HMI under Main menu/Reset/Reset counters/AutoReclouser79,5(0→1)/SMBRREC:x
2. Restore settings that may have been modified for the tests back to normal.
3. Disconnect the test switch, CB simulating arrangement and test circuits.
   - Reconnect any links or connection terminals, which may have been opened for the tests.
4. Reset indications, alarms and disturbance recordings.
   - Clearing of the disturbance report can be done via the Disturbance Handling in PCM600 or the local HMI.

**10.10.2.5 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.
10.10.3 Apparatus control APC

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

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

10.10.4 Single command, 16 signals SINGLECMD

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

10.10.5 Interlocking

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

Values of the logical signals are available on the local HMI under Main menu/Tests/Function status/Control/<Function>/<Function:1>. The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

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

10.11.1 Scheme communication logic for distance or overcurrent protection ZCPSCH (85)

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

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

Activating of the different zones verifies that the CS signal is issued from the intended zones. The CS signal from the independent tripping zone must have a $t_{SendMin}$ minimum time.

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

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

10.11.1.1 Testing permissive underreaching

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

10.11.1.2 Testing permissive overreaching

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

10.11.1.3 Testing blocking scheme

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

10.11.1.4 Checking of unblocking logic

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

Command function with continuous unblocking (Unblock = 1)

Procedure

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

Phase segregated scheme communication logic for distance or overcurrent protection ZC1PPSCH (85)

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

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

Activating of the different zones and phases verifies that the CS_x signal are issued from the intended zones. The CS_x signal from the independent tripping zone must have a tSendMin minimum time.

Check the tripping function by activating the CRLx inputs with the overreaching zone used to achieve the CACCLx signals.

It is sufficient to activate the zones with all types of fault with the secondary injection.

Testing permissive underreaching

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

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

10.11.2.3 Testing blocking scheme

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

10.11.2.4 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.
10.11.3 Current reversal and Weak-end infeed logic for distance protection 3-phase ZCRWPSCH (85)

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

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

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

The current reversal logic and the weak-end infeed functions are tested during the secondary-injection test of the impedance or overcurrent protection zones together with the scheme communication logic for the distance protection function ZCPSCH (85).

10.11.3.1 Current reversal logic

It is possible to check the delay of the CS send signal with $t_{DelayRev}$ by changing from a reverse to a forward fault.

By continuously activating the CR input and changing from a reverse to a forward fault, the delay $t_{DelayRev}$ can be checked.

**Checking of current reversal**

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

- The forward zone timer must be set longer than the $t_{DelayRev}$ set value.

1. Activate the receive (CRL) signal.
2. Set the healthy condition to an impedance at 50% of the reach of the reverse zone connected to IRVL.
3. After the pickup condition is obtained for reverse zone, apply a fault at 50% of the reach of the forward zone connected to WEIBLK2.
4. Check that correct trip outputs and external signals are obtained for the type of fault generated. The operation time should be about the $t_{DelayRev}$ setting longer
than the carrier accelerated trip (TRIP) recorded for the permissive overreach scheme communication.

5. Restore the forward and reverse zone timer to its original setting.

10.11.3.2 Weak end infeed logic

Weak-end infeed logic at permissive overreach schemes

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

Testing conditions

Only one type of fault is sufficient, with the current reversal and weak-end infeed logic for distance protection function ZCRWPSCH (85). Apply three faults (one in each phase). For phase A-G fault, set these parameters:

<table>
<thead>
<tr>
<th>Phase</th>
<th>I (Amps)</th>
<th>Phase-angle (Deg)</th>
<th>V (Volts)</th>
<th>Phase-angle (Deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
<td>Set less than UPN&lt;PU27PN</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>240</td>
<td>69.3</td>
<td>240</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>120</td>
<td>69.3</td>
<td>120</td>
</tr>
</tbody>
</table>

If wanted, change all settings cyclically for other faults (BG and CG).

The setting parameter WEI is set to Echo & Trip.

1. Apply input signals according Table 31.
2. Activate the receive (CR) signal.
3. After the IED has operated, turn off the input signals.
4. Check that trip, send signal, and indication are obtained.

The ECHO output gives only a 200 ms pulse.
10.11.3.3  Completing the test

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

10.11.4  Local acceleration logic ZCL CPSCH

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

The logic is checked during the secondary injection test of the impedance measuring zones.

10.11.4.1  Verifying the settings

1. Provide the IED with conditions equivalent to normal load for at least two seconds.
2. Deactivate the conditions for accelerated function.
3. Apply a phase-to-ground fault at 100% of line impedance.
4. Check that the fault is tripped with the second zone time delay.
5. Provide the IED with conditions equivalent to normal load for at least two seconds.
6. Activate the condition for accelerated function either by the autorecloser or by the loss-of-load.
7. Apply a phase-to-ground fault at 100% of line impedance.
8. Check that the fault is tripped instantaneously.

10.11.4.2  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.

10.11.5  Scheme communication logic for residual overcurrent protection ECPSCH (85)

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

Before testing the communication logic for residual overcurrent protection function ECPSCH (85), the four step residual overcurrent protection function EF4PTOC (51N/67N) has to be tested according to the corresponding instruction. Once this is done, continue with the instructions below.
If the current reversal and weak-end infeed logic for ground-fault protection is included, proceed with the testing according to the corresponding instruction after the testing the communication logic for residual overcurrent protection. The current reversal and weak-end-infeed functions shall be tested together with the permissive scheme.

10.11.5.1 Testing the directional comparison logic function

Blocking scheme

1. Inject the polarizing voltage 3V0 at 5% of $V_{Base}$ (EF4PTOC, 51N67N) where the current is lagging the voltage by 65°.
2. Inject current (65° lagging the voltage) in one phase at about 110% of the set operating current, and switch the current off with the switch.
3. Switch the fault current on and measure the operating time of the communication logic.
   Use the TRIP signal from the configured binary output to stop the timer.
4. Compare the measured time with the set value $t_{Coord}$.
5. Activate the CR binary input.
6. Check that the CRL output is activated when the CR input is activated.
7. Switch the fault current on (110% of the set operating current) and wait longer than the set value $t_{Coord}$.
   No TRIP signal should appear.
8. Switch the fault current off.
9. Reset the CR binary input.
10. Activate the BLOCK digital input.
11. Switch the fault current on (110% of the set operating current) and wait for a period longer than the set value $t_{Coord}$.
   No TRIP signal should appear.
12. Switch the fault current and the polarizing voltage off.
13. Reset the BLOCK digital input.

Permissive scheme
1. Inject the polarizing voltage 3V0, which is 5% of $U_{Base}V_{Base}$ (EF4PTOC, 51N67N) where the current is lagging the voltage by 65°.

2. Inject current (65° lagging the voltage) into one phase at about 110% of the set operating current, and switch the current off with the switch.

3. Switch the fault current on, (110% of the set operating current) and wait longer than the set value $t_{Coord}$.

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

4. Switch the fault current off.

5. Activate the CR binary input.

6. Switch the fault current on (110% of the set operating current) and measure the operating time of the ECPSCH (85) logic. Use the TRIP signal from the configured binary output to stop the timer.

7. Compare the measured time with the setting for $t_{Coord}$.

8. Activate the BLOCK digital input.

9. Switch the fault current on (110% of the set operating current) and wait for a period longer than the set value $t_{Coord}$.

   No TRIP signal should appear.

10. Switch the fault current off.

11. Reset the CR binary input and the BLOCK digital input.

### 10.11.5.2 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.

### 10.11.6 Current reversal and weak-end infeed logic for residual overcurrent protection ECRWPSCH (85)

Prepare the IED for verification of settings as outlined in the section "".

Values of the logical signals for ECRWPSCH are available on the Local HMI under Main menu/Tests/Function status/Scheme communication/ECRWPSCH(85)/ECRWPSCH:1.
The Signal Monitoring in PCM600 shows service values that are available on the Local HMI as well.

First, test the four step residual overcurrent protection function EF4PTOC (51N/67N) and then the current reversal and weak-end infeed logic according to the corresponding instructions. Then continue with the instructions below.

10.11.6.1 Testing the current reversal logic

1. Inject the polarizing voltage 3V0 to 5% of \( V_{Base} \) and the phase angle between voltage and current to 155°, the current leads the voltage.
2. Inject current \((180° - \text{AngleRCA})\) in one phase to about 110% of the set operating current of the four step residual overcurrent protection \((INDir)\).
3. Check that the IRVL output is activated in the disturbance recorder after the set time \( t_{PickUpRev} \).
4. Abruptly reverse the current to \( \text{AngleRCA} \) setting lagging the voltage, to operate the forward directional element.
5. Check that the IRVL output still is activated after the reversal with a time delay that complies with the setting \( t_{DelayRev} \).
6. Switch off the polarizing voltage and the current.

10.11.6.2 Testing the weak-end infeed logic

If setting \( WEI = \text{Echo} \)

1. Inject the polarizing voltage 3V0 to \((180° - \text{AngleRCA})\) of \( V_{Base} \) and the phase angle between voltage and current to 155°, the current leads the voltage.
2. Inject current \((180° - \text{AngleRCA})\) in one phase to about 110% of the setting operating current \((INDir)\).
3. Activate the CRL binary input. No ECHO and CS should appear.
4. Abruptly reverse the current to the setting of \( \text{AngleRCA} \) setup lagging the voltage, to operate the forward directional element. No ECHO and CS should appear.
5. Switch off the current and check that the ECHO and CS appear on the corresponding binary output during 200ms after resetting the directional element.
6. Switch off the CRL binary input.
7. Activate the BLOCK binary input.
8. Activate the CRL binary input.

No ECHO and CS should appear.

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

If setting $WEI = \text{Echo & Trip}$

1. Inject the polarizing voltage 3V0 to about 90% of the setting ($3V0PU$) operating voltage.
2. Activate the CRL binary input.

No ECHO, CS and TRWEI outputs should appear.

3. Increase the injected voltage to about 110% of the setting ($3V0PU$) operating voltage.
4. Activate the CRL binary input.
5. Check that the ECHO, CS and TRWEI appear on the corresponding binary output or on the local HMI.
6. Reset the CRL binary input.
7. Activate the BLOCK binary input.
8. Activate the CRL binary input.

No ECHO, CS and TRWEI outputs should appear.

9. Reset the CRL and BLOCK binary input.
10. Inject the polarizing voltage 3V0 to about 110% of the setting ($3V0PU>$) and adjust the phase angle between the voltage and current to ($180^\circ - \text{AnglRCA}$) setting, the current leads the voltage.
11. Inject current in one phase to about 110% of the set operate current ($\text{INDir}$).
12. Activate the CRL binary input.

No ECHO and TRWEI should appear.
13. Abruptly reverse the current to 65° lagging the voltage, to operate the forward directional element. No ECHO and TRWEI should appear.

14. Switch the current off and check that the ECHO, CS and TRWEI appear on the corresponding binary output during 200ms after resetting the directional element. If EF4PTOC also operates in forward direction, CS should be obtained.

15. Switch the polarizing voltage off and reset the CRL binary input.

10.11.6.3 Completing the test

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

10.11.7 Direct transfer trip logic

10.11.7.1 Low active power and power factor local criteria LAPPGAPC (37_55)

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

1. Connect the test set for three-phase current injection and three-phase voltage to the appropriate IED terminals.
2. Inject symmetrical phase voltages equal to the rated voltage.
3. Decrease the injected current in phase A and note the operated value (pickup value) of the studied step of the function. This current shall have the same phase angle as the injected phase voltage. The active power for operation is calculated as: \( P = V_{ph} \cdot I_{ph} \) (single-phase active power).
4. Increase the current slowly and note the reset value.
5. Connect a trip output contact to a timer.
6. Set the injected current to 50% of the operate level in the tested stage. Switch on the current and check the time delay.
7. Check that all trip and pickup contacts operate according to the configuration (signal matrices).
8. Finally check that pickup and trip information is stored in the event memory. Repeat steps 3 – 6 for phases B and C.
9. Inject symmetrical phase voltages and phase currents in all three phases, equal to \( S_{Base} \) (rated voltage and current).
10. Increase the phase angle between the injected phase voltages and phase current, and note the operate value $\phi$. The corresponding power factor is equal to 

$$\text{pf} = \cos \phi$$.

11. Decrease the phase angle and note the reset value.

12. Set the phase angle of the injected current slightly higher than the operate value. Switch on the current and check the time delay.

13. Check that all trip and pickup contacts operate according to the configuration (signal matrices).

14. Finally check that pickup and trip information is stored in the event memory.

**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.

### 10.11.7.2 Compensated over- and undervoltage protection COUVGAPC (59_27)

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

1. Set OperationOV to Enabled.
2. Connect the test set for three-phase current injection and three-phase voltage to the appropriate IED terminals.
3. Inject symmetrical phase voltages equal to the rated voltage.
4. Decrease the injected voltage in phase A and note the operated value (pickup value) of the function.
5. Increase the voltage slowly and note the reset value.
6. Connect a trip output contact to a timer.
7. Reduce the injected voltage stepwise to 90% of the operate level, and check the time delay.
8. Check that all trip and pickup contacts operate according to the configuration (signal matrices).
9. Finally, check that pickup and trip information is stored in the event menu. Repeat steps 4 – 9 for phases B and C.

If voltage compensation will be used, do the following steps:

10. Set EnShuntReactor to Enabled and activate input signal SWIPOS.
11. Check that the line impedance (R1 and X1) and reactor impedance (Xc) are set to the correct values.
12. Inject symmetrical phase voltages equal to the rated voltage.
13. Increase the injected current (same phase angle as the injected voltage) in phase A from zero and note the operated value (pickup value) of the function. Check

\[ V = V_{\text{injected}} \cdot \left[ I_{\text{injected}} - j \frac{V_{\text{injected}}}{X_{\text{sy}}} + j \frac{V_{\text{injected}}}{X_{\text{cp}}} \right] \cdot (R_L + jX_L) \]

that this value is equal to:

14. Repeat step 13 for phases B and C.
15. Set OperationOV to Enabled.
16. Connect the test set for three-phase current injection and three-phase voltage to the appropriate IED terminals.
17. Inject symmetrical phase voltages equal to the rated voltage.
18. Increase the injected voltage in phase A and note the operated value (pickup value) of the function.
19. Decrease the voltage slowly and note the reset value.
20. Connect a trip output contact to a timer.
21. Increase stepwise the injected voltage to 110% of the operate level, and check the time delay.
22. Check that all trip and pickup contacts operate according to the configuration (signal matrices).
23. Finally check that pickup and trip information is stored in the event memory.
   Repeat steps 17 – 22 for phases B and C.
   If voltage compensation will be used do the following steps:
24. Set EnShuntReacto to Enabled and activate input signal SWIPOS.
25. Check that the line impedance (R1 and X1) and reactor impedance (Xc) are set to the correct values.
26. Inject symmetrical phase voltages equal to 120% of the rated voltage.
27. Increase the injected current (same phase angle as the injected voltage) in phase A from zero and note the operated value (pickup value) of the function. Check

\[ V = V_{\text{injected}} \cdot \left[ I_{\text{injected}} - j \frac{V_{\text{injected}}}{X_{\text{sy}}} + j \frac{V_{\text{injected}}}{X_{\text{cp}}} \right] \cdot (R_L + jX_L) \]

that this value is equal to:

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.

10.11.7.3 Sudden change in current variation SCCVPTOC (51)
Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.
1. Set Operation to Enabled.
2. Connect the test set for three-phase current injection to the appropriate IED terminals.
3. Inject symmetrical phase currents equal to half the rated current.
4. Increase the injected current in phase A slowly by more than the set IPickup. No signal shall be activated.
5. Decrease the injected current in phase A to half the rated current.
6. Increase the injected current in phase A in a step by more than the set IPickup. Pickup and trip signal shall be activated.

10.11.7.4 Carrier receive logic LCCRPTRC (94)

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

1. Set Operation to Enable.
2. Select OpMode according to the application: If two carrier channels are used and high security shall be used set OpMode = 2 Out Of 2, otherwise 1 Out Of 2.
3. Connect switchable binary signal/s CR! and CR2 to the binary input/s to be used for the carrier receive (CR) signal/s.
4. Connect switchable binary signal/s to the binary input to be used for the local check signal. If three pole trip is used only one LOCTR is used. If single pole trip is used in addition the phase selective signals LOCTR_A, LOCTR_B and LOCTR_C are connected.
5. Connect switchable binary signal/s to the binary input to be used for the communication supervision signal/s CHERR1 and CHERR2.
   If OpMode = 2 Out Of 2:
6. Activate input and check output signals according to table 32 and 33.

<table>
<thead>
<tr>
<th>INPut</th>
<th>CR!</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>CHERR1</th>
<th>X</th>
<th>LOCTR</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>LOCTR_A</th>
<th>X</th>
<th>LOCTR_B</th>
<th>X</th>
<th>LOCTR_C</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 33: Activate output signals if OpMode = 2 Out Of 2

<table>
<thead>
<tr>
<th>OUTPUT</th>
<th>Non</th>
<th>TRIP</th>
<th>TR_A</th>
<th>TR_B</th>
<th>TR_C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

7. Connect the trip output to a timer.
8. Have inputs CR! and CR2 activated. Start the timer from activation of input LOCTR and stop the timer from TRIP output.
9. Check the trip time.
   If OpMode = 1 Out Of 2:
10. Activate input and check output signals according to table 34 and 35.

Table 34: Activate input signals if OpMode = 1 Out Of 2

<table>
<thead>
<tr>
<th>INPUT</th>
<th>CR!</th>
<th>CHERR1</th>
<th>CR2</th>
<th>CHER2</th>
<th>LOCTR</th>
<th>LOCTR_A</th>
<th>LOCTR_B</th>
<th>LOCTR_C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

11. Connect the trip output to a timer.
12. Have inputs CR! and CR2 activated. Start the timer from activation from activation of input LOCTR and stop the timer from TRIP output.
13. Check the trip time.

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

### 10.11.7.5 Negative sequence overvoltage protection LCNSPTOV (47)

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

![Connection of test equipment](ANSI10000014-1-en.vsd)

\textit{Figure 45: Connection of test equipment}

1. Connect the test set for three-phase voltage injection to the appropriate IED terminals as shown in Figure 45.
2. Increase the injected voltage and note the operated value (pickup value) of the studied step of the function.
3. Decrease the voltage slowly and note the reset value.
4. Connect a trip output contact to a timer.
5. Set the injected voltage to 110\% of the operate level of the tested stage. Switch on the current and check the time delay.
6. Check that all trip and pickup contacts operate according to the configuration (signal matrices).
7. Finally check that pickup and trip information is stored in the event memory.

\textbf{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.

10.11.7.6 **Zero sequence overvoltage protection LCZSPTOV (59N)**

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

1. Connect the test set for three-phase voltage injection (A, B, C) or residual voltage injection (N) to the appropriate IED terminals. This depends on how the IED is fed from the VT.
2. Increase the injected zero sequence voltage and note the operated value (pickup value) of the studied step of the function.
3. Decrease the voltage slowly and note the reset value.
4. Connect a trip output contact to a timer.
5. Set the injected voltage to 110% of the operate level in the tested stage, switch on the current and check the time delay.
6. Check that all trip and pickup contacts operate according to the configuration (signal matrices).
7. Finally check that pickup and trip information is stored in the event memory.

**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.

10.11.7.7 **Negative sequence overcurrent protection LCNSPTOC (46)**

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.
1. Connect the test set for three-phase current injection to the appropriate IED terminals as shown in Figure 46.
2. Increase the injected current and note the operated value (pickup value) of the studied step of the function.
3. Decrease the current slowly and note the reset value.
4. Connect a trip output contact to a timer.
5. Set the injected current to 200% of the operate level of the tested stage. Switch on the current and check the time delay.
6. Check that all trip and pickup contacts operate according to the configuration (signal matrices).
7. Finally check that pickup and trip information is stored in the event memory.

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.

10.11.7.8 Zero sequence overcurrent protection LCZSPTOC (51N)

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.
1. Connect the test set for three-phase voltage injection (A, B, C) or residual voltage injection (N) to the appropriate IED terminals. This is dependent on how the IED is fed from the CT.

2. Increase the injected zero-sequence current and note the operated value (pickup value) of the studied step of the function.

3. Decrease the current slowly and note the reset value.

4. Connect a trip output contact to a timer.

5. Set the injected current to 200% of the operate level of the tested stage. Switch on the current and check the time delay.

6. Check that all trip and pickup contacts operate according to the configuration (signal matrices).

7. Finally check that pickup and trip information is stored in the event memory.

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.

10.11.7.9 Three phase overcurrent LCP3PTOC (51)

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

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

2. Increase the injected current in phase A and note the operated value (pickup value) of the studied step of the function.

3. Decrease the current slowly and note the reset value.

4. Connect a trip output contact to a timer.

5. Set the injected current to 200% of the operate level of the tested stage. Switch on the current and check the time delay.

6. Check that all trip and pickup contacts operate according to the configuration (signal matrices).

7. Finally check that pickup and trip information is stored in the event memory.

8. Repeat steps 2 – 7 for phases B and C.

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.
10.11.7.10 Three phase undercurrent LCP3PTUC (37)

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

1. Connect the test set for three-phase current injection to the appropriate IED terminals.
2. Inject a symmetrical three-phase current larger than the set value I<.
3. Decrease the injected current in phase A and note the operated value (pickup value) of the studied step of the function.
4. Increase the current slowly and note the reset value.
5. Connect a trip output contact to a timer.
6. Decrease the injected current step-wise to 50% of the operate level and check the time delay.
7. Check that all trip and pickup contacts operate according to the configuration (signal matrices).
8. Finally check that pickup and trip information is stored in the event memory.
9. Repeat steps 2 – 7 for phases B and C.

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.

10.12 Logic

10.12.1 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. The instances of SMPPTRC (94) are identical except for the name of the function block SMPPTRC (94). The testing is preferably done in conjunction with the protection system and autoreclosing function.

10.12.1.1 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.

### 10.12.1.2 1ph/3ph 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.
10.12.1.3 1ph/2ph/3ph 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.

10.12.1.4 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.

10.12.1.5 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.

10.13 Monitoring

10.13.1 Gas medium supervision SSIMG

Prepare the IED for verification of settings as outlined in section "Testing the liquid medium supervision for alarm and lock out conditions" and section "Completing the test" in this chapter.

Check that the input logical signal BLOCK is logical zero and that on the local HMI, the logical signals PRES_ALM, PRES_LO, TEMP_ALM and TEMP_LO are equal to logical zero.
10.13.1.1 Testing the liquid medium supervision for alarm and lock out conditions

1. Connect binary inputs to consider gas pressure and gas density to initiate the alarms.
2. Consider the analogue pressure input PRESSURE to initiate the alarms.
3. Gas pressure lock out input can be used to set PRES_LO signal, check the signal status in local HMI under Main menu/Test/Function status/Monitoring/Gas medium supervision SSIMG/PRES_LO
4. Reduce the pressure level input below Pres_AlmLimit, check for PRES_ALM signal status in local HMI under Main menu/Test/Function status/Monitoring/Gas medium supervision SSIMG/PRES_ALM
5. Activate BLOCK binary input, the signals PRES_ALM, PRES_LO should disappear.
6. Reset the BLOCK binary input.
7. Check for reset lock out input RESET_LO to reset PRES_LO lock out signal.
8. Conduct these steps for temperature input as well to detect and reset TEMP_ALM and TEMP_LO signals.
9. Continue to test another function or end the test by changing the TestMode setting to off.

10.13.1.2 Completing the test

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

10.13.2 Liquid medium supervision SSIML

Prepare the IED for verification of settings as outlined in section "Liquid medium supervision SSIML" and section "Completing the test" in this chapter.

Check that the input logical signal BLOCK is logical zero and that on the local HMI, the logical signals LVL_ALM, LVL_LO, TEMP_ALM and TEMP_LO are equal to logical zero.

10.13.2.1 Testing the liquid medium supervision for alarm and lock out conditions

1. Connect the binary inputs to consider liquid level to initiate the alarms.
2. Consider the analogue level input LEVEL to initiate the alarms.
3. Liquid level lock out input can be used to set LVL_LO signal, check the signal status in local HMI under Main menu/Test/Function status/Monitoring/Liquid medium supervision SSIML/LVL_LO
4. Reduce the liquid level input below LevelAlmLimit, check for LVL_ALM signal status in local HMI under Main menu/Test/Function status/Monitoring/Liquid medium supervision SSIML/LVL_ALM
5. Activate BLOCK binary input, the signals LVL_ALM, LVL_LO should disappear.
6. Reset the BLOCK binary input.
7. Check for reset lock out input RESET_LO to reset the LVL_LO lock out signal.
8. Conduct these steps for temperature input as well to detect and reset TEMP_ALM and TEMP_LO signals.
9. Continue to test another function or end the test by changing the TestMode setting to Off.

10.13.2.2 Completing the test

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

10.13.3 Breaker monitoring SSCBR

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

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

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

10.13.3.1 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:

<table>
<thead>
<tr>
<th>POSCLOSE</th>
<th>0</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSOPEN</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

4. Test of CB contact travel time

4.1. Test the set timing defined by OpenTimeCorr, CloseTimeCorr, tTrOpenAlm and tTrCloseAlm.

4.2. Change the status of the auxiliary contacts such that travel time to open TTRVOP and travel time to close TTRVCL exceed the respective set values
(\(t_{TrOpenAlm}\) and \(t_{TrCloseAlm}\)). The measured travel time for opening and closing is shown on \(TTRVOP\) and \(TTRVCL\) respectively.

4.3. Check that \(TRVTOPAL\) and \(TRVTCLAL\) are activated.

5. Test of CB status

5.1. Test the set current level defined by \(AccStopCurr\).

5.2. Check the \(CLOSEPOS\) output by changing the \(POSOPEN\) to 0 and \(POSCLOSE\) to 1.

5.3. Check the \(OPENPOS\) output by changing the \(POSOPEN\) to 1 and \(POSCLOSE\) to 0 and also inject the current in the selected phase slightly lower and higher than \(AccStopCurr\) set value. Only for a current lower than set \(AccStopCurr\) should activate the output \(POSOPEN\).

5.4. Check the circuit breaker is in \(INVDPOS\) if auxiliary contacts read same value or CB is open and inject the current in selected phase more than \(AccStopCurr\) set value.

6. Test of remaining life of CB

6.1. Test the set timing defined by \(RatedOperCurr\), \(RatedFltCurr\), \(OperNoRated\), \(OperNoFault\), \(DirCoef\), \(CBLifeAlmLevel\).

6.2. Vary the phase current in the selected phase from below rated operated current, \(RatedOperCurr\) to above rated fault current, \(RatedFltCurr\) of a breaker.

6.3. The remaining life of CB output \(CBLIFEPH\) is estimated when the CB is changed from closed to open position. Check that the output \(CBLIFEPH\) is decreased with a value that corresponds to the injected current.

6.4. \(CBLIFEAL\) is activated as soon as \(CBLIFEPH\) is below the set \(CBLifeAlmLevel\) value.

7. Test of accumulated energy

7.1. Test the actual set values defined by \(AccSelCal\) to \(Aux Contact\), \(ContTrCorr\) and \(AlmAccCurrPwr\).

7.2. Inject phase current in the selected phase such that its value is greater than set \(AccStopCurr\) value.

7.3. When the breaker goes to open position, accumulated energy \(IPOWPH\) is calculated. The calculated value can be seen on the output \(IPOWPH\).

7.4. Alarm signal \(IPOWALPH\) appears when \(IPOWPH\) is greater than set \(AlmAccCurrPwr\) value.

7.5. Lockout signal \(IPOWLOPH\) appears if \(IPOWPH\) exceeds further to the threshold value \(LOAccCurrPwr\).

7.6. Calculation of accumulated energy \(IPOWPH\) is stopped when injected current is lower than set \(AccStopCurr\) value.

8. Test of CB operation cycles
8.1. Test the actual set values defined by \textit{OperAlmLevel} and \textit{OperLOLevel}.

8.2. The operation counter, NOOPER is updated for every close-open sequence of the breaker by changing the position of auxiliary contacts \textit{POSCLOSE} and \textit{POSOPEN}.

8.3. \textit{OPERALM} is activated when NOOPER value exceeds the set \textit{OperAlmLevel} value. The actual value can be read on the output NOOPER.

8.4. \textit{OPERLO} is activated when NOOPER value exceeds the set \textit{OperLOLevel} value.

9. Test of CB spring charge monitoring

9.1. Test the actual set value defined by \textit{SpChAlmTime}.

9.2. Enable \textit{SPRCHRST} input. Also activate \textit{SPRCHRD} after a time greater than set time \textit{SpChAlmTime}.

9.3. At this condition, \textit{SPCHALM} is activated.

10. Test of CB gas pressure indication

10.1. Test the actual set value defined by \textit{tDGasPresAlm} and \textit{tDGasPresLO}.

10.2. The output \textit{GPRESALM} is activated after a time greater than set time of \textit{tDGasPresAlm} value if the input \textit{PRESALM} is enabled.

10.3. The output \textit{GPRESLO} is activated after a set time of \textit{tDGasPresLO} value if the input \textit{PRESLO} is enabled.

\section*{10.13.3.2 \textbf{Completing the test}}

1. Continue to test another function or end the test by changing the Test mode setting to \textit{Disabled}.

2. Restore connections and settings to their original values if they were changed for testing purposes.

\section*{10.13.4 \textbf{Event function EVENT}}

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

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

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

In test mode, individual event blocks can be blocked from PCM600.
10.13.5 Fault locator LMBRFLO

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

The Fault locator function LMBRFLO depends on other functions to work properly, that is, phase selection information from distance protection function and analog information supplied by the trip value recorder function. Check that proper binary initiate (pickup or tripping) and phase selection signals are connected and voltage and current signals are configured (parameter settings).

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

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

**Table 36: Test settings**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td></td>
</tr>
<tr>
<td>Healthy conditions</td>
<td>$V = 69.3,V, I = 0,A &amp; ZF = 0^\circ$</td>
</tr>
</tbody>
</table>

Impedance $|Z|$  
Test point  
Note:  
- $Z < (X0 + 2 \cdot X1)/3$ For single-phase faults  
- $Z < X1$ For three and two phase faults  
- $Z < (X0 + 2 \cdot X1 XM)/3$ For single-phase fault with mutual zero-sequence current

Impedance angle $\angle Z\phi$  
Test angle  
- $\angle Z\phi \arctan((X0 + 2 \cdot X1)/(R0 + 2R1))$ For single-phase faults  
- $\angle Z\phi \arctan(X1/R1)$ For two-phase faults

10.13.5.1 Measuring the operate limit

1. Set the test point ($|Z|$ fault impedance and $\angle Z\phi$ impedance phase angle) for a condition that meets the requirements in table 36.
2. Subject the IED to healthy normal load conditions for at least two seconds.
3. Apply a fault condition.  
   Check that the distance-to-fault value displayed on the HMI complies with equations 111, 112 and 113.
\[ p = \frac{Z_x}{X1} \cdot 100 \]  
(Equation 111)

in % for two- and three-pole faults

\[ p = \frac{3 \cdot Z_x}{X0 + 2 \cdot X1} \cdot 100 \]  
(Equation 112)

in % for single-phase-to-ground faults

\[ p = \frac{3 \cdot Z_x}{X0 + 2 \cdot X1 \pm XM} \cdot 100 \]  
(Equation 113)

in % for single-phase-to-ground faults with mutual zero sequence current.

Where:

\[ p \] = the expected value of a distance to fault in percent

\[ Z_x \] = set test point on the test set

\[ X0 \] = set zero-sequence reactance of a line

\[ X1 \] = set positive-sequence reactance of a line

\[ XM \] = set mutual zero-sequence impedance of a line

10.13.5.2 Completing the test

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

10.13.6 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. Trig the function and check that the counter result corresponds to the number of operations.
10.13.6.1 Completing the test

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

10.14 Metering

10.14.1 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.

10.14.2 Function for energy calculation and demand handling ETPMMTR

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

10.14.2.1 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.
10.14.2.2 Completing the test

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

10.15 Station communication

10.15.1 Multiple command and transmit MULTICMDRCV / MULTICMDSND

The multiple command and transmit function (MULTICMDRCV / MULTICMDSND) is only applicable for horizontal communication.

Test of the multiple command function block and multiple transmit is recommended to be performed in a system, that is, either in a complete delivery system as an acceptance test (FAT/SAT) or as parts of that system, because the command function blocks are connected in a delivery-specific way between bays and the station level and transmit.

Command and transmit function blocks included in the operation of different built-in functions must be tested at the same time as their corresponding functions.

10.16 Remote communication

10.16.1 Binary signal transfer BinSignReceive, BinSignTransm

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

To perform a test of Binary signal transfer function (BinSignReceive/BinSignTransm), 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 BinSignReceive/BinSignTransm

- 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 47. 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 47:** Test of RTC with I/O
10.17 Basic IED functions

10.17.1 Parameter setting group handling SETGRPS

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

10.17.1.1 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
3. Connect the appropriate dc voltage to the corresponding binary input of the IED and observe the information presented on the local HMI.
   The displayed information must always correspond to the activated input.
4. Check that the corresponding output indicates the active group.
   Operating procedures for the PC aided methods of changing the active setting groups are described in the corresponding PCM600 documents and instructions for the operators within the SCS are included in the SCS documentation.

10.17.1.2 Completing the test

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

10.18 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.
11.1 Overview

Before starting this process, all individual devices that are involved in the fault clearance process of the protected object must have been individually tested and must be set in operation. The circuit breaker must be ready for an open-close-open cycle.

The directional test is performed when the protected object is energized and a certain amount of load current is available. It is also necessary to know the flow of the load current (import or export, i.e. forward or reverse) by help of the indication from an external instrument (energy-meter, or SCADA information).

The design of the test procedure depends on the type of protection function to be tested. Some items that can be used as guidelines are the following.

11.2 Testing the directionality of the distance protection

The test is performed by looking at the information given by the directional function ZDRDIR or ZDMRDIR.

Procedure:

1. Make sure that all control and protection functions that belong to the object that are going to be energized have been tested and are set to be in operation
2. Make sure that the primary load current fulfills the following conditions (by using an external equipment):
   - The magnitude of the primary load current must be higher than the minimum operating current set for the directional elements in the IED. In case of default settings this means:
     - load current > 5% of base current
     - Otherwise the settings $I_{MinOpPG}$ and $I_{MinOpPP}$ for ZDRDIR or ZDMRDIR are available under the HMI menu: **Main menu/Settings/IED Settings/Impedance protection/DirectionalImpedance**

   The primary load impedance must have an angle (PHI) between the setting angles for the directional lines. In case of default settings this means:
• for forward (exported) load: -15 deg < PHI < 115 deg
• for reverse (imported) load: 165 deg < PHI < 295 deg

The settings for forward load: -ArgDir < PHI < ArgNegRes and the settings for reverse load: 180 deg - ArgDir < PHI < 180 deg + ArgNegRes included in the directional functions ZDRDIR or ZDMRDIR are available under the HMI menu:

- **Main menu/Settings/IED Settings/Impedance protection/DirectionalImpedance**

3. The directionality of the load current is shown by the directional function ZDRDIR or ZDMRDIR and it is available under the HMI menu: **Main menu/Test/Function status/Impedance protection/DirectionalImpedance**

If the load current flows in forward (exporting) direction there will be shown:

- L1Dir = forward
- L2Dir = forward
- L3Dir = forward

If the load current flows in the reverse direction (importing) there will be shown:

- L1Dir = reverse
- L2Dir = reverse
- L3Dir = reverse

Compare this result with the information given by the external equipment, it must be the same. If the direction of the three phases is not the same, this is a sign of incorrect connection of the voltage or current transformers serving the distance protection function. It is also possible that there is a wrong setting for the earthing point for one or more of the CTs serving distance protection (the setting name is: CTStarPoint).

If the directional function shows forward when it should show reverse (or vice-versa) for all the three phases, this probably means a wrong connection of CTs and/or VTs serving the distance protection, or it can mean a wrong setting of earthing point (the setting name is: CTStarPoint) for all the three CTs, or it could mean a wrong setting for the pre-processing blocks (3PhaseAnalogGroup) connected to the CTs/VTs and serving the distance protection (verify that no wrong negation has been set; the setting name is: Negation).

If the directional function shows “No direction” for all the three phases it can mean that the load current is below the minimum operating current or that the load impedance has an angle which is outside the above given valid angles for determining forward or reverse direction.

If the directional function shows “No direction” for only some of the three phases, this probably means a wrong CTs/VTs connection.

4. The measured impedance information is available under the same menu. These values are not affected by the minimum operating current setting and the measured values are shown any time the load current is higher than 3% of the nominal current of the line:
The measured impedance information can still be used to determine the direction of the load. A positive resistance measured in all phases indicates a forward (exporting) resistive load (active power), while a negative sign indicates a reverse (importing) resistive load (active power). Usually it is enough to look at the resistive values to get information of the load direction, that must anyway be compared with the indication given by external equipment measuring the same power flow.
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, ABB's recommendation is as follows:

Every second to third year
• Visual inspection of all equipment.
• Removal of dust on ventilation louvres and IEDs if necessary.
• Periodic maintenance test for protection IEDs of object where no redundant protections are provided.

Every four to six years
• Periodic maintenance test for protection IEDs of objects with redundant protection system.

First maintenance test should always be carried out after the first half year of service.

When protection IEDs are combined with built-in control, the test interval can be increased drastically, up to for instance 15 years, because the IED continuously reads service values, operates the breakers, and so on.

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.

ABB 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.
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

Table 37: Signals from the General menu in the diagnostics tree.

<table>
<thead>
<tr>
<th>Indicated result</th>
<th>Possible reason</th>
<th>Proposed action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal fail Off</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>Internal fail On</td>
<td>A failure has occurred.</td>
<td>Check the rest of the indicated results to find the fault.</td>
</tr>
<tr>
<td>Internal warning Off</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>Internal warning On</td>
<td>A warning has been issued.</td>
<td>Check the rest of the indicated results to find the fault.</td>
</tr>
<tr>
<td>Time synch Ready</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>Time synch Fail</td>
<td>No time synchronization.</td>
<td>Check the synchronization source for problems. If the problem persists, contact your ABB representative for service.</td>
</tr>
<tr>
<td>Real time clock Ready</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>Real time clock Fail</td>
<td>The real time clock has been reset.</td>
<td>Set the clock.</td>
</tr>
<tr>
<td>ADC-module OK</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
</tbody>
</table>

Table continues on next page
### 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 38.

<table>
<thead>
<tr>
<th>HMI Signal Name</th>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INT Fail</td>
<td>OFF / ON</td>
<td>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</td>
</tr>
<tr>
<td>INT Warning</td>
<td>OFF / ON</td>
<td>This signal will be active if one or more of the following internal signals are active: INT--RTCERROR, INT--IEC61850ERROR, INT--TIMESYNCHERROR</td>
</tr>
<tr>
<td>ADMnn</td>
<td>READY / FAIL</td>
<td>Analog input module n failed. Signal activation will reset the IED</td>
</tr>
<tr>
<td>BIMnn</td>
<td>READY / FAIL</td>
<td>BIM error. Binary input module Error status. Signal activation will reset the IED</td>
</tr>
<tr>
<td>BOMn</td>
<td>READY / FAIL</td>
<td>BOM error. Binary output module Error status.</td>
</tr>
<tr>
<td>IOMn</td>
<td>READY / FAIL</td>
<td>IOM-error. Input/Output Module Error status.</td>
</tr>
<tr>
<td>HMI Signal Name</td>
<td>Status</td>
<td>Description</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>MIMn</td>
<td>READY/FAIL</td>
<td>mA input module MIM1 failed. Signal activation will reset the IED</td>
</tr>
<tr>
<td>RTC</td>
<td>READY/FAIL</td>
<td>This signal will be active when there is a hardware error with the real time clock.</td>
</tr>
<tr>
<td>Time Sync</td>
<td>READY/FAIL</td>
<td>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.</td>
</tr>
<tr>
<td>Application</td>
<td>READY/FAIL</td>
<td>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.</td>
</tr>
<tr>
<td>RTE</td>
<td>READY/FAIL</td>
<td>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.</td>
</tr>
<tr>
<td>IEC61850</td>
<td>READY/FAIL</td>
<td>This signal will be active if the IEC61850 stack did not succeed in some actions like reading IEC61850 configuration, startup etc.</td>
</tr>
<tr>
<td>LMD</td>
<td>READY/FAIL</td>
<td>LON network interface, MIP/DPS, is in an unrecoverable error state.</td>
</tr>
<tr>
<td>LDCMxxx</td>
<td>READY/FAIL</td>
<td>Line Differential Communication Error status</td>
</tr>
<tr>
<td>OEM</td>
<td>READY/FAIL</td>
<td>Optical Ethernet Module error status.</td>
</tr>
</tbody>
</table>

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 38. Loss of time synchronization can be considered as a warning only. The IED has full functionality without time synchronization.

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>
<thead>
<tr>
<th>Event message:</th>
<th>Description</th>
<th>Generating signal:</th>
</tr>
</thead>
<tbody>
<tr>
<td>INT--FAIL</td>
<td>Off</td>
<td>INT--FAIL (reset event)</td>
</tr>
<tr>
<td>INT--FAIL</td>
<td></td>
<td>INT--FAIL (set event)</td>
</tr>
<tr>
<td>INT--WARNING</td>
<td>Off</td>
<td>INT--WARNING (reset event)</td>
</tr>
<tr>
<td>INT--WARNING</td>
<td></td>
<td>INT--WARNING (set event)</td>
</tr>
<tr>
<td>IOn--Error</td>
<td>Off</td>
<td>IOn--Error (reset event)</td>
</tr>
<tr>
<td>IOn--Error</td>
<td></td>
<td>IOn--Error (set event)</td>
</tr>
<tr>
<td>ADMn-Error</td>
<td>Off</td>
<td>ADMn-Error (reset event)</td>
</tr>
<tr>
<td>ADMn-Error</td>
<td></td>
<td>ADMn-Error (set event)</td>
</tr>
<tr>
<td>MIM1-Error</td>
<td>Off</td>
<td>MIM1-Error (reset event)</td>
</tr>
<tr>
<td>MIM1-Error</td>
<td></td>
<td>MIM1-Error (set event)</td>
</tr>
<tr>
<td>INT--RTC</td>
<td>Off</td>
<td>INT--RTC (reset event)</td>
</tr>
<tr>
<td>INT--RTC</td>
<td></td>
<td>INT--RTC (set event)</td>
</tr>
<tr>
<td>INT--TSYNC</td>
<td>Off</td>
<td>INT--TSYNC (reset event)</td>
</tr>
<tr>
<td>INT--TSYNC</td>
<td></td>
<td>INT--TSYNC (set event)</td>
</tr>
<tr>
<td>INT--SETCHGD</td>
<td></td>
<td>INT--TSYNC (set event)</td>
</tr>
<tr>
<td>DRPC-CLEARED</td>
<td></td>
<td>INT--TSYNC (set event)</td>
</tr>
</tbody>
</table>

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.

13.3 Repair instruction

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

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

An alternative is to open the IED and send only the faulty circuit board to ABB for repair. When a printed circuit board is sent to ABB, it must always be placed in a metallic, ESD-proof, protection bag. The user can also purchase separate replacement modules.

Strictly follow the company and country safety regulations.

Most electronic components are sensitive to electrostatic discharge and latent damage may occur. Please observe usual procedures for handling electronics and also use an ESD wrist strap. A semi-conducting layer must be placed on the workbench and connected to 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 ABB Logistic Center. Please contact the local ABB representative to get more details.

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

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating current</td>
</tr>
<tr>
<td>ACC</td>
<td>Actual channel</td>
</tr>
<tr>
<td>ACT</td>
<td>Application configuration tool within PCM600</td>
</tr>
<tr>
<td>A/D converter</td>
<td>Analog-to-digital converter</td>
</tr>
<tr>
<td>ADBS</td>
<td>Amplitude deadband supervision</td>
</tr>
<tr>
<td>ADM</td>
<td>Analog digital conversion module, with time synchronization</td>
</tr>
<tr>
<td>AI</td>
<td>Analog input</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>AR</td>
<td>Autoreclosing</td>
</tr>
<tr>
<td>ASCT</td>
<td>Auxiliary summation current transformer</td>
</tr>
<tr>
<td>ASD</td>
<td>Adaptive signal detection</td>
</tr>
<tr>
<td>ASDU</td>
<td>Application service data unit</td>
</tr>
<tr>
<td>AWG</td>
<td>American Wire Gauge standard</td>
</tr>
<tr>
<td>BBP</td>
<td>Busbar protection</td>
</tr>
<tr>
<td>BFOC/2,5</td>
<td>Bayonet fibre optic connector</td>
</tr>
<tr>
<td>BFP</td>
<td>Breaker failure protection</td>
</tr>
<tr>
<td>BI</td>
<td>Binary input</td>
</tr>
<tr>
<td>BIM</td>
<td>Binary input module</td>
</tr>
<tr>
<td>BOM</td>
<td>Binary output module</td>
</tr>
<tr>
<td>BOS</td>
<td>Binary outputs status</td>
</tr>
<tr>
<td>BR</td>
<td>External bistable relay</td>
</tr>
<tr>
<td>BS</td>
<td>British Standards</td>
</tr>
<tr>
<td>BSR</td>
<td>Binary signal transfer function, receiver blocks</td>
</tr>
<tr>
<td>BST</td>
<td>Binary signal transfer function, transmit blocks</td>
</tr>
<tr>
<td>C37.94</td>
<td>IEEE/ANSI protocol used when sending binary signals between IEDs</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network. ISO standard (ISO 11898) for serial communication</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td>CB</td>
<td>Circuit breaker</td>
</tr>
<tr>
<td>CBM</td>
<td>Combined backplane module</td>
</tr>
<tr>
<td>CCM</td>
<td>CAN carrier module</td>
</tr>
<tr>
<td>CCVT</td>
<td>Capacitive Coupled Voltage Transformer</td>
</tr>
<tr>
<td>Class C</td>
<td>Protection Current Transformer class as per IEEE/ ANSI</td>
</tr>
<tr>
<td>CMPPS</td>
<td>Combined megapulses per second</td>
</tr>
<tr>
<td>CMT</td>
<td>Communication Management tool in PCM600</td>
</tr>
<tr>
<td>CO cycle</td>
<td>Close-open cycle</td>
</tr>
<tr>
<td>Codirectional</td>
<td>Way of transmitting G.703 over a balanced line. Involves two twisted pairs making it possible to transmit information in both directions</td>
</tr>
<tr>
<td>COM</td>
<td>Command</td>
</tr>
<tr>
<td>COMTRADE</td>
<td>Standard Common Format for Transient Data Exchange format for Disturbance recorder according to IEEE/ANSI C37.111, 1999 / IEC60255-24</td>
</tr>
<tr>
<td>Contra-directional</td>
<td>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</td>
</tr>
<tr>
<td>COT</td>
<td>Cause of transmission</td>
</tr>
<tr>
<td>CPU</td>
<td>Central processing unit</td>
</tr>
<tr>
<td>CR</td>
<td>Carrier receive</td>
</tr>
<tr>
<td>CRC</td>
<td>Cyclic redundancy check</td>
</tr>
<tr>
<td>CROB</td>
<td>Control relay output block</td>
</tr>
<tr>
<td>CS</td>
<td>Carrier send</td>
</tr>
<tr>
<td>CT</td>
<td>Current transformer</td>
</tr>
<tr>
<td>CU</td>
<td>Communication unit</td>
</tr>
<tr>
<td>CVT or CCVT</td>
<td>Capacitive voltage transformer</td>
</tr>
<tr>
<td>DAR</td>
<td>Delayed autoreclosing</td>
</tr>
<tr>
<td>DARPA</td>
<td>Defense Advanced Research Projects Agency (The US developer of the TCP/IP protocol etc.)</td>
</tr>
<tr>
<td>DBDL</td>
<td>Dead bus dead line</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>DBLL</td>
<td>Dead bus live line</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>DFC</td>
<td>Data flow control</td>
</tr>
<tr>
<td>DFT</td>
<td>Discrete Fourier transform</td>
</tr>
<tr>
<td>DHCP</td>
<td>Dynamic Host Configuration Protocol</td>
</tr>
<tr>
<td>DIP-switch</td>
<td>Small switch mounted on a printed circuit board</td>
</tr>
<tr>
<td>DI</td>
<td>Digital input</td>
</tr>
<tr>
<td>DLLB</td>
<td>Dead line live bus</td>
</tr>
<tr>
<td>DNP</td>
<td>Distributed Network Protocol as per IEEE Std 1815-2012</td>
</tr>
<tr>
<td>DR</td>
<td>Disturbance recorder</td>
</tr>
<tr>
<td>DRAM</td>
<td>Dynamic random access memory</td>
</tr>
<tr>
<td>DRH</td>
<td>Disturbance report handler</td>
</tr>
<tr>
<td>DSP</td>
<td>Digital signal processor</td>
</tr>
<tr>
<td>DTT</td>
<td>Direct transfer trip scheme</td>
</tr>
<tr>
<td>EHV network</td>
<td>Extra high voltage network</td>
</tr>
<tr>
<td>EIA</td>
<td>Electronic Industries Association</td>
</tr>
<tr>
<td>EMC</td>
<td>Electromagnetic compatibility</td>
</tr>
<tr>
<td>EMF</td>
<td>Electromotive force</td>
</tr>
<tr>
<td>EMI</td>
<td>Electromagnetic interference</td>
</tr>
<tr>
<td>EnFP</td>
<td>End fault protection</td>
</tr>
<tr>
<td>EPA</td>
<td>Enhanced performance architecture</td>
</tr>
<tr>
<td>ESD</td>
<td>Electrostatic discharge</td>
</tr>
<tr>
<td>F-SMA</td>
<td>Type of optical fibre connector</td>
</tr>
<tr>
<td>FAN</td>
<td>Fault number</td>
</tr>
<tr>
<td>FCB</td>
<td>Flow control bit; Frame count bit</td>
</tr>
<tr>
<td>FOX 20</td>
<td>Modular 20 channel telecommunication system for speech, data and protection signals</td>
</tr>
<tr>
<td>FOX 512/515</td>
<td>Access multiplexer</td>
</tr>
<tr>
<td>FOX 6Plus</td>
<td>Compact time-division multiplexer for the transmission of up to seven duplex channels of digital data over optical fibers</td>
</tr>
<tr>
<td>FUN</td>
<td>Function type</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>G.703</td>
<td>Electrical and functional description for digital lines used by local telephone companies. Can be transported over balanced and unbalanced lines.</td>
</tr>
<tr>
<td>GCM</td>
<td>Communication interface module with carrier of GPS receiver module.</td>
</tr>
<tr>
<td>GDE</td>
<td>Graphical display editor within PCM600.</td>
</tr>
<tr>
<td>GI</td>
<td>General interrogation command.</td>
</tr>
<tr>
<td>GIS</td>
<td>Gas-insulated switchgear.</td>
</tr>
<tr>
<td>GOOSE</td>
<td>Generic object-oriented substation event.</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning system.</td>
</tr>
<tr>
<td>GSAL</td>
<td>Generic security application.</td>
</tr>
<tr>
<td>GTM</td>
<td>GPS Time Module.</td>
</tr>
<tr>
<td>HDLC</td>
<td>High-level data link control, protocol based on the HDLC standard.</td>
</tr>
<tr>
<td>HFBR</td>
<td>Plastic fiber connector.</td>
</tr>
<tr>
<td>HMI</td>
<td>Human-machine interface.</td>
</tr>
<tr>
<td>HSAR</td>
<td>High speed autoreclosing.</td>
</tr>
<tr>
<td>HV</td>
<td>High-voltage</td>
</tr>
<tr>
<td>HVDC</td>
<td>High-voltage direct current.</td>
</tr>
<tr>
<td>IDBS</td>
<td>Integrating deadband supervision.</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrical Committee.</td>
</tr>
<tr>
<td>IEC 60044-6</td>
<td>IEC Standard, Instrument transformers – Part 6: Requirements for protective current transformers for transient performance</td>
</tr>
<tr>
<td>IEC 60870-5-103</td>
<td>Communication standard for protection equipment. A serial master/slave protocol for point-to-point communication</td>
</tr>
<tr>
<td>IEC 61850</td>
<td>Substation automation communication standard.</td>
</tr>
<tr>
<td>IEC 61850–8–1</td>
<td>Communication protocol standard</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers.</td>
</tr>
<tr>
<td>IEEE 802.12</td>
<td>A network technology standard that provides 100 Mbits/s on twisted-pair or optical fiber cable</td>
</tr>
<tr>
<td>IEEE P1386.1</td>
<td>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).</td>
</tr>
</tbody>
</table>
IEEE 1686  Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities

IED  Intelligent electronic device

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

LDCM  Line differential communication module

LDD  Local detection device

LED  Light-emitting diode
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNT</td>
<td>LON network tool</td>
</tr>
<tr>
<td>LON</td>
<td>Local operating network</td>
</tr>
<tr>
<td>MCB</td>
<td>Miniature circuit breaker</td>
</tr>
<tr>
<td>MCM</td>
<td>Mezzanine carrier module</td>
</tr>
<tr>
<td>MIM</td>
<td>Milli-ampere module</td>
</tr>
<tr>
<td>MPM</td>
<td>Main processing module</td>
</tr>
<tr>
<td>MVAL</td>
<td>Value of measurement</td>
</tr>
<tr>
<td>MVB</td>
<td>Multifunction vehicle bus. Standardized serial bus originally developed for use in trains.</td>
</tr>
<tr>
<td>NCC</td>
<td>National Control Centre</td>
</tr>
<tr>
<td>NOF</td>
<td>Number of grid faults</td>
</tr>
<tr>
<td>NUM</td>
<td>Numerical module</td>
</tr>
<tr>
<td>OCO cycle</td>
<td>Open-close-open cycle</td>
</tr>
<tr>
<td>OCP</td>
<td>Overcurrent protection</td>
</tr>
<tr>
<td>OEM</td>
<td>Optical Ethernet module</td>
</tr>
<tr>
<td>OLTC</td>
<td>On-load tap changer</td>
</tr>
<tr>
<td>OTEV</td>
<td>Disturbance data recording initiated by other event than start/pick-up</td>
</tr>
<tr>
<td>OV</td>
<td>Overvoltage</td>
</tr>
<tr>
<td>Overreach</td>
<td>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.</td>
</tr>
<tr>
<td>PCI</td>
<td>Peripheral component interconnect, a local data bus</td>
</tr>
<tr>
<td>PCM</td>
<td>Pulse code modulation</td>
</tr>
<tr>
<td>PCM600</td>
<td>Protection and control IED manager</td>
</tr>
<tr>
<td>PC-MIP</td>
<td>Mezzanine card standard</td>
</tr>
<tr>
<td>PMC</td>
<td>PCI Mezzanine card</td>
</tr>
<tr>
<td>POR</td>
<td>Permissive overreach</td>
</tr>
<tr>
<td>POTT</td>
<td>Permissive overreach transfer trip</td>
</tr>
<tr>
<td>Process bus</td>
<td>Bus or LAN used at the process level, that is, in near proximity to the measured and/or controlled components</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
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</tr>
<tr>
<td>PSM</td>
<td>Power supply module</td>
</tr>
<tr>
<td>PST</td>
<td>Parameter setting tool within PCM600</td>
</tr>
<tr>
<td>PT ratio</td>
<td>Potential transformer or voltage transformer ratio</td>
</tr>
<tr>
<td>PUTF</td>
<td>Permissive underreach transfer trip</td>
</tr>
<tr>
<td>RASC</td>
<td>Synchrocheck relay, COMBIFLEX</td>
</tr>
<tr>
<td>RCA</td>
<td>Relay characteristic angle</td>
</tr>
<tr>
<td>RISC</td>
<td>Reduced instruction set computer</td>
</tr>
<tr>
<td>RMS value</td>
<td>Root mean square value</td>
</tr>
<tr>
<td>RS422</td>
<td>A balanced serial interface for the transmission of digital data in point-to-point connections</td>
</tr>
<tr>
<td>RS485</td>
<td>Serial link according to EIA standard RS485</td>
</tr>
<tr>
<td>RTC</td>
<td>Real-time clock</td>
</tr>
<tr>
<td>RTU</td>
<td>Remote terminal unit</td>
</tr>
<tr>
<td>SA</td>
<td>Substation Automation</td>
</tr>
<tr>
<td>SBO</td>
<td>Select-before-operate</td>
</tr>
<tr>
<td>SC</td>
<td>Switch or push button to close</td>
</tr>
<tr>
<td>SCL</td>
<td>Short circuit location</td>
</tr>
<tr>
<td>SCS</td>
<td>Station control system</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervision, control and data acquisition</td>
</tr>
<tr>
<td>SCT</td>
<td>System configuration tool according to standard IEC 61850</td>
</tr>
<tr>
<td>SDU</td>
<td>Service data unit</td>
</tr>
<tr>
<td>SLM</td>
<td>Serial communication module.</td>
</tr>
<tr>
<td>SMA connector</td>
<td>Subminiature version A, A threaded connector with constant impedance.</td>
</tr>
<tr>
<td>SMT</td>
<td>Signal matrix tool within PCM600</td>
</tr>
<tr>
<td>SMS</td>
<td>Station monitoring system</td>
</tr>
<tr>
<td>SNTP</td>
<td>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.</td>
</tr>
<tr>
<td>SOF</td>
<td>Status of fault</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
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</tr>
<tr>
<td>SPA</td>
<td>Strömberg Protection Acquisition (SPA), a serial master/slave protocol for point-to-point communication</td>
</tr>
<tr>
<td>SRY</td>
<td>Switch for CB ready condition</td>
</tr>
<tr>
<td>ST</td>
<td>Switch or push button to trip</td>
</tr>
<tr>
<td>Starpoint</td>
<td>Neutral/Wye point of transformer or generator</td>
</tr>
<tr>
<td>SVC</td>
<td>Static VAr compensation</td>
</tr>
<tr>
<td>TC</td>
<td>Trip coil</td>
</tr>
<tr>
<td>TCS</td>
<td>Trip circuit supervision</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission control protocol. The most common transport layer protocol used on Ethernet and the Internet.</td>
</tr>
<tr>
<td>TCP/IP</td>
<td>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.</td>
</tr>
<tr>
<td>TEF</td>
<td>Time delayed ground-fault protection function</td>
</tr>
<tr>
<td>TM</td>
<td>Transmit (disturbance data)</td>
</tr>
<tr>
<td>TNC connector</td>
<td>Threaded Neill-Concelman, a threaded constant impedance version of a BNC connector</td>
</tr>
<tr>
<td>TP</td>
<td>Trip (recorded fault)</td>
</tr>
<tr>
<td>TPZ, TPY, TPX, TPS</td>
<td>Current transformer class according to IEC</td>
</tr>
<tr>
<td>TRM</td>
<td>Transformer Module. This module transforms currents and voltages taken from the process into levels suitable for further signal processing.</td>
</tr>
<tr>
<td>TYP</td>
<td>Type identification</td>
</tr>
<tr>
<td>UMT</td>
<td>User management tool</td>
</tr>
<tr>
<td>Underreach</td>
<td>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.</td>
</tr>
<tr>
<td>UTC</td>
<td>Coordinated Universal Time. A coordinated time scale, maintained by the Bureau International des Poids et Mesures</td>
</tr>
</tbody>
</table>
(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

**3I₀**  
Three times zero-sequence current. Often referred to as the residual or the ground-fault current

**3V₀**  
Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage
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