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Title: BS EN IEC 60255-167 Measuring relays and protection equipment

Part 167: Functional requirements for directional overcurrent protection

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

PROJECT NUMBER: IEC 60255-167 ED1	
DATE OF CIRCULATION: 2023-11-17	CLOSING DATE FOR COMMENTS: 2024-02-09
SUPERSEDES DOCUMENTS: 95/527/RR	

IEC TC 95 : MEASURING RELAYS AND PROTECTION EQUIPMENT	
SECRETARIAT: France	SECRETARY: Mr Thierry BARDOU
OF INTEREST TO THE FOLLOWING COMMITTEES: TC 8, TC 57	PROPOSED HORIZONTAL STANDARD: ☐ Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.
FUNCTIONS CONCERNED: ☐ EMC ☐ ENVIRONMENT ☐ QUALITY ASSURANCE ☐ SAFETY	

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Recipients of this document are invited to submit, with their comments, notification of any local regulations or technical reasons that may exist and should be considered should this proposal proceed, recognizing that failure to address such requirements could result in the need for new or existing "In Some Countries" clauses. (See [AC/22/2007](#) or [NEW GUIDANCE DOC](#)).

TITLE:
Measuring relays and protection equipment – Part 167: Functional requirements for directional overcurrent protection

NOTE FROM TC/SC OFFICERS:

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

MEASURING RELAYS AND PROTECTION EQUIPMENT –**Part 167: Functional requirements for directional overcurrent protection**

FOREWORD

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IEC 60255-167 has been prepared by IEC technical committee 95: Measuring relays and protection equipment. It is an International Standard.

This standard, together with IEC 60255-132, cancels and replaces the standard IEC 60255-12 published in 1980. This standard constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Covered directional overcurrent protection function, a combination of directional characteristic and overcurrent characteristic, other than the function measuring displacement angle (direction) only.
- b) Defined polarizing quantity for direction discrimination, which is not limited to voltage.
- c) Specified in detail the characteristic and the performance of the function and corresponding test methodologies.

d) Considered digitally interfaced protection function.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
XX/XX/FDIS	XX/XX/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at <http://www.iec.ch/standardsdev/publications>.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The National Committees are requested to note that for this document the stability date is 20XX.

THIS TEXT IS INCLUDED FOR THE INFORMATION OF THE NATIONAL COMMITTEES AND WILL BE DELETED AT THE PUBLICATION STAGE.

MEASURING RELAYS AND PROTECTION EQUIPMENT –

Part 167: Functional requirements for directional overcurrent protection

1 Scope

This part of IEC 60255 specifies the minimum requirements for functional and performance evaluation of a.c. directional overcurrent protection functions, which will operate at a desired value of a.c. overcurrent flowing in a predetermined direction with relevant phasor as direction reference. Such an a.c. directional overcurrent protection function is a combination of directional characteristic and overcurrent characteristic, and the latter is specified in IEC 60255-151. This document also defines how to document and publish performance test results.

The document covers single-phase, three-phase, positive-sequence, negative-sequence, zero-sequence, residual, or neutral directional overcurrent protection functions with more than one input energizing quantity including electric current(s) and voltage(s) either hardwired from instrument transformers or as data over communication ports using an appropriate data communication protocol. This document also covers the directional overcurrent protection function using the wattmetric part of residual current as characteristic quantity. Specification of the protection function, measurement characteristics, directionality, start, and operate time delay characteristics are addressed. Annex A provides some commonly used operating characteristics.

The test methodologies for verifying performance characteristics and accuracy are included in this document. The document identifies factors that influence the accuracy under steady state conditions and performance characteristics during dynamic conditions.

The directional overcurrent protection functions covered by this standard correspond to those listed in Table 1.

Table 1 – Directional overcurrent protection designations

Protection function	IEEE/ANSI C37.2 Function Numbers	IEC 61850-7-4 Logical Nodes
Single-phase directional overcurrent protection Three-phase directional overcurrent protection Positive-sequence directional overcurrent protection Negative-sequence directional overcurrent protection	67	PTOC RDIR+PTOC
Zero-sequence directional overcurrent protection Residual directional overcurrent protection Neutral directional overcurrent protection	67N	PTOC RDIR+PTOC PSDE ^a
Directional overcurrent protection function using the wattmetric part of residual current as characteristic quantity ^b	67N	PSDE ^a
^a This LN is used for directional earth fault handling in resonant earthed (neutral) system and isolated neutral system. ^b For resonant earthed (neutral) system, this function is often called wattmetric directional earth fault protection. There are several solutions for wattmetric directional earth fault. In this standard, only those directional overcurrent protection functions using wattmetric part of the residual current as characteristic quantity are covered.		

This document does not specify the functional description of additional features often associated with directional overcurrent protection functions such as voltage transformer

supervision (VTS), current transformer supervision (CTS). Only their influence on the directional overcurrent protection function is covered in this document.

This document does not cover directional overcurrent protection based on other characteristic quantities than an a.c. current phasor, such as incremental quantities, d.c. current etc.

The general requirements for measuring relays and protection equipment are defined in IEC 60255-1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60255-1, *Measuring relays and protection equipment – Part 1: Common requirements*

IEC 60255-151:2009, *Measuring relays and protection equipment – Part 151: Functional requirements for over/under current protection*

IEC TS 60255-216-1:202x, *Measuring Relays and Protection Equipment – Part 216-1: Digital Interface - Guidelines for Requirements and Tests for Protection Functions using digital communication as input and output*

IEC TR 61000-1-8:2019, *Electromagnetic compatibility - Part 1-8: Phase angles of harmonic current emissions and voltages in the public supply networks - Future expectations*

IEC 61000-2-2:2002+AMD1:2017 CSV (Ed 2.1 2017), *Electromagnetic compatibility (EMC) - Part 2-2: Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*

IEC 61000-2-4:2002, *Electromagnetic compatibility (EMC) - Part 2-4: Environment - Compatibility levels in industrial plants for low-frequency conducted disturbances.*

IEC 61000-2-12:2003, *Electromagnetic compatibility (EMC) - Part 2-12: Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems*

IEC 61850-7-1:2011+AMD1:2020 CSV (Ed 2.1 2020), *Communication networks and systems for power utility automation - Part 7-1: Basic communication structure - Principles and models*

IEC 61850-7-2:2010+AMD1:2020 CSV (Ed 2.1 2020), *Communication networks and systems for power utility automation - Part 7-2: Basic information and communication structure - Abstract communication service interface (ACSI)*

IEC 61850-7-3:2010+AMD1:2020 CSV (Ed 2.1 2020), *Communication networks and systems for power utility automation - Part 7-3: Basic communication structure - Common data classes*

IEC 61850-7-4:2010+AMD1:2020 CSV (Ed 2.1 2020), *Communication networks and systems for power utility automation - Part 7-4: Basic communication structure - Compatible logical node classes and data object classes*

IEC TR 61850-7-6:2019, *Communication networks and systems for power utility automation - Part 7-6: Guideline for definition of Basic Application Profiles (BAPs) using IEC 61850*

IEC 61850-9-2:2011+AMD1:2020 CSV (Ed 2.1 2020), *Communication networks and systems for power utility automation - Part 9-2: Specific communication service mapping (SCSM) - Sampled values over ISO/IEC 8802-3*

IEC/IEEE 61850-9-3:2016, *Communication networks and systems for power utility automation - Part 9-3: Precision time protocol profile for power utility automation*

IEC 61869-9:2016, *Instrument transformers - Part 9: Digital interface for instrument transformers*

IEEE 519-2022, *IEEE Standard for Harmonic Control in Electric Power Systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

a.c. directional overcurrent protection

protection intended to operate when the a.c. current flowing in a predetermined direction is in excess of a predetermined value

3.2

characteristic quantity

electric quantity, or one of its parameters, the name of which characterizes a measuring relay or protection equipment and the values of which are the subject of accuracy requirements

EXAMPLE

- Current for an overcurrent or an undercurrent relay;
- Frequency for a frequency relay, the input energizing quantity of which can be a voltage;
- Power for a power relay, the input energizing quantities of which are current and voltage.

[SOURCE: IEC 60050-447:2020, 447-07-01]

3.3

polarizing quantity

input energizing quantity that provides a reference to determine power flow direction, fault location, etc. in a power system

[SOURCE: IEC 60050-447:2020, 447-07-11]

3.4

displacement angle

phase difference angle

φ

under sinusoidal conditions, phase difference between the voltage applied to a linear two terminal element or two-terminal circuit and the electric current in the element or circuit

[SOURCE: IEC 60050-131:2002/AMD5:2021, 131-11-48, modified – Remove Note 1 to entry]

3.5

characteristic angle, <of a directional overcurrent protection>

maximum sensitivity angle, <of a directional overcurrent protection>

φ_{MSA}

the phase angle that is used to declare the directional characteristic of a directional overcurrent protection, by which the polarizing quantity shall be adjusted such that the directional detector gives maximum sensitivity in the operate zone when the current is in phase with it

Note 1 to entry: For electromechanical relays with rotating disc or cup mechanisms, a directional overcurrent protection operates with maximum torque under characteristic angle, so characteristic angle is also called as the Maximum Torque Angle (MTA).

3.6

reset ratio

ratio of a reset value to an operate value

[SOURCE: IEC 60050-447:2020, 447-07-06]

3.7

reset hysteresis

absolute value of the difference between a reset value and an operate value

[SOURCE: IEC 60050-447:2020, 447-07-13]

3.8

block, <for a protection function> verb

to suspend all the outputs while the internal processing is still going on

3.9

non-nominal data object

a data object whose quality attribute is different from "good" as defined in Table 26 of IEC 61850-7-2:2010+AMD1:2020 CSV (Ed 2.1 2020)

Note 1 to entry: This means that the quality attribute of the data object (DO) is "questionable", "reserved" or "invalid" as defined in Table 26 of IEC 61850-7-2:2010+AMD1:2020 CSV (Ed 2.1 2020).

3.10

missing sampled value

sampled value expected by a subscribing function which is received out of sequence or not received in a specified time delay

Note 1 to entry: The criteria for a Sample Value to be considered as missing are defined in Subclause 8.4.6.11 of IEC TS 60255-216-1:202x.

[SOURCE: IEC TS 60255-216-1:202x, 3.9]

3.11

time multiplier setting

TMS

setting which describes an adjustable factor that may be provided by a relay manufacturer which is applicable to the theoretical curve of time versus characteristic quantity

Note 1 to entry: Its purpose is to allow adjustment of the relay operating times. This adjustable TMS factor is usually expressed in "per unit". The preferred reference setting of TMS for declaration of relay characteristic is 1,0.

[SOURCE: IEC 60255-151:2009, 3.10]

3.12**setting value (start value) of the characteristic quantity** **G_s**

reference value used for the definition of the theoretical curve of time versus characteristic quantity

[SOURCE: IEC 60255-151:2009, 3.3]

3.13**critical impulse time, <of a measuring relay or protection equipment>**

for a measuring relay or protection equipment in reset condition, the longest duration a specified change in the input energizing quantity(ies), which will cause it to operate, can be applied without switching

[SOURCE: IEC 60050-447:2020, 447-05-09]

3.14**overshoot time**

difference between the operate time of a measuring relay or protection equipment at the specified value of the characteristic quantity and the critical impulse time

[SOURCE: IEC 60050-447:2020, 447-05-12]

3.15**transient overreach**

measure of the effect of the d.c. component of a waveform on the start signal of the functional element

Note 1 to entry: Generally, this d.c. component will result in the relay reaching further than the setting should permit, or specifically in the terms of an overcurrent relay, starting at a value of a.c. current below the set threshold.

[SOURCE: IEC 60255-151:2009, 3.13]

4 Specification of the function**4.1 General**

An example of the directional overcurrent protection function with its inputs, outputs, measuring element, time delay characteristics and functional logic is shown in Figure 1. The manufacturer shall provide the functional block diagram of the specific implementation.

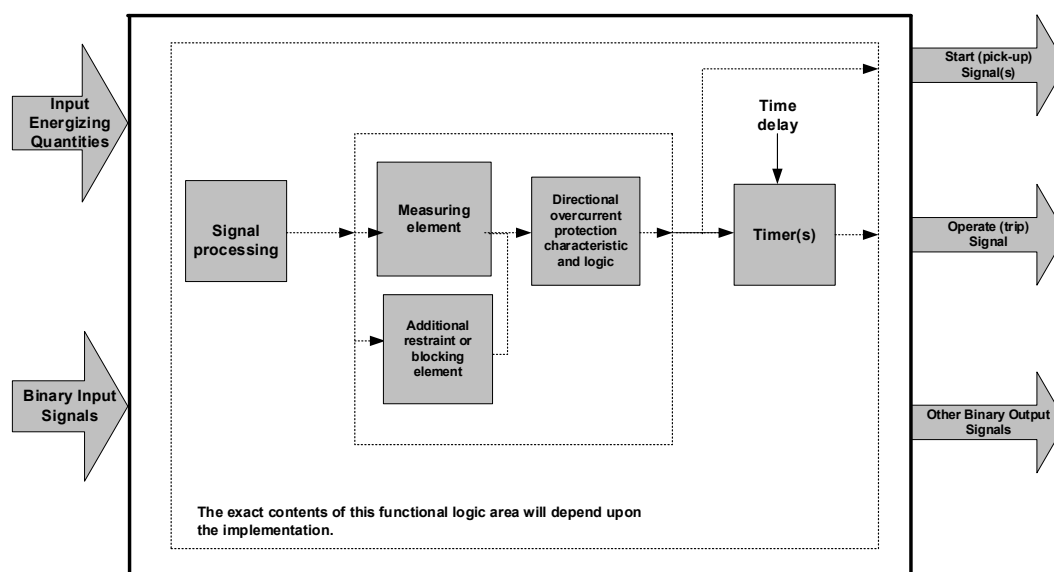


Figure 1 – Simplified protection functional block diagram

4.2 Input energizing quantities, characteristic quantity and polarizing quantity

4.2.1 Input energizing quantities

The protection function documentation shall state the type of input energizing quantities used by the protection function. For example:

- single or three-phase current(s): I_{L1}, I_{L2}, I_{L3} ;
- residual current (I_{res}) or neutral current (I_{neu});
- single or three phase-to-earth voltage(s): U_{L1}, U_{L2}, U_{L3} ;
- multiple phase-to-phase voltage(s): U_{L1L2}, U_{L3L2} ;
- residual voltage: U_{res} .

Ratings and relevant requirements of input energizing quantities are specified in IEC 60255-1.

4.2.2 Characteristic quantity

The manufacturer shall specify to the extent required for proper application and testing which quantities are used for the operation of the directional overcurrent protection elements. Examples of characteristic quantities are:

- phase current(s): I_{L1}, I_{L2}, I_{L3} ;
- positive sequence current: I_1 ;
- negative sequence current: I_2 ;
- zero sequence current (I_0), residual current (I_{res}), or neutral current (I_{neu});
- wattmetric part of the residual current: $I_{res} \cdot \cos(\varphi)$;
- any combination of currents as defined by the manufacturer.

The type of measurement of the energizing quantity shall be stated. Examples are:

- RMS value of the current;
- RMS value of the fundamental component of the current.

4.2.3 Polarizing quantity

Different polarizing quantity may be used according to the design and/or user's configuration (settings). If applicable, the manufacturer shall describe the characteristic for each kind of polarizing quantity and give recommendation for selection according to the application. Examples of polarizing quantities are:

- phase-to-earth voltage(s): U_{L1}, U_{L2}, U_{L3} ;
- phase-to-phase voltage(s): $U_{L1L2}, \dots$;
- positive sequence voltage: U_1 ;
- negative sequence voltage: U_2 ;
- zero sequence voltage (U_0), or residual voltage (U_{res});
- any combination of voltages as defined by the manufacturer;
- memorized quantities of the above ones.

NOTE A current different from the characteristic quantity can be taken as polarizing quantity for direction discrimination as well. For example, in a solidly earthed (neutral) system, during an earth fault, a current will flow through the earthed neutral of the power transformer, which can be used as reference for comparison against the currents flowing in feeders to determinate the fault direction.

4.2.4 Connection

Input energizing quantities can be presented to the directional overcurrent protection either hardwired from instrument transformers or as data received over communication ports using an appropriate data communication protocol, such as IEC 61850-9-2 or, more specifically, IEC 61869-9, which is a profile of IEC 61850-9-2.

When instrument transformers are used, any constraints regarding the accuracy class (e.g. class P or class M CT secondary winding), their connection (star or delta), earthing of the secondary windings and all relevant settings shall be specified by the manufacturer. The manufacturer shall describe the assumed reference direction for forward and reverse direction discrimination.

NOTE Correct connection of the instrument transformers is essential for the correct operation of the directional overcurrent protection. Although in some relays, one can change the polarity of current input by setting or configuration, miswiring (therefore incorrect polarity) should be avoided.

When the input energizing quantity is a data packet received via a communication port(s) using a suitable communication protocol (such as IEC 61869-9, a profile of IEC 61850-9-2), the technical data, the functional description and all relevant settings shall be specified by the manufacturer. See C.2.1 for further information.

4.3 Binary input signals

If any binary input signals (externally or internally driven) are used, their influence on the directional overcurrent protection function shall be clearly described on the functional logic diagram. An additional textual description may also be provided if this can further clarify the functionality of the input signals and their intended usage.

Binary input signals to this function may emanate from a number of different sources. For example:

- traditionally wired to physical inputs (typically optically isolated);
- via a communication port from external devices (e.g., using IEC 61850 GOOSE signals, see C.2.2);
- via internal logical connections from other functional elements within the relay;
- via internal logic within the directional overcurrent protection element.

The method of receiving the signal is largely irrelevant except to conform to operational requirements.

Definitions, ratings and standards for binary input signals are specified in IEC 60255-1.

4.4 Functional logic

4.4.1 Operate characteristics

4.4.1.1 General

Directional overcurrent protection will operate if its characteristic quantity falls into the predetermined direction and increases to reach the operate value for a duration longer than the required duration.

4.4.1.2 Direction discrimination and overcurrent threshold

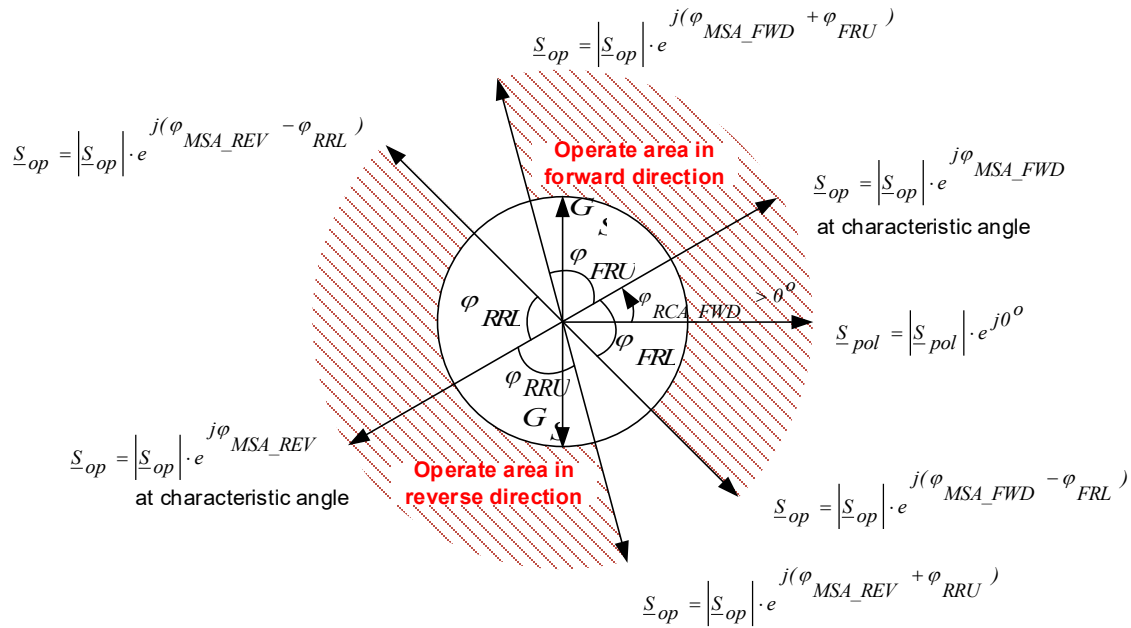
Table 2 specifies two typical types of operate characteristics in the form of formulas. TYPE II is applicable to the directional overcurrent protection function using the wattmetric part of residual current as characteristic quantity and TYPE I is applicable to the other directional overcurrent protection functions.

Table 2 – Operate characteristics of directional overcurrent protection

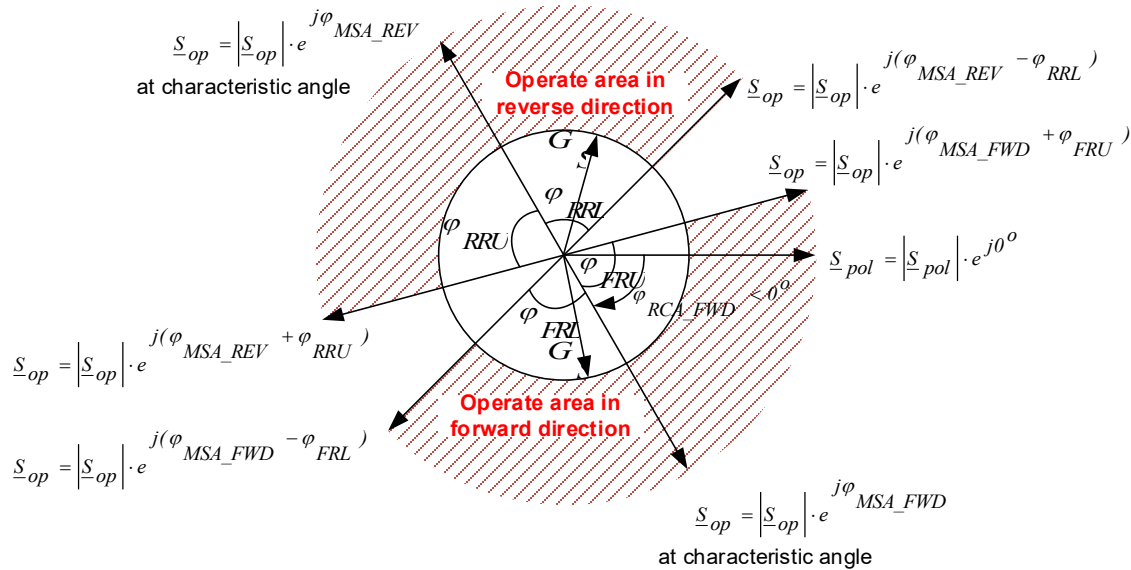
Characteristic type	Direction discrimination		Overcurrent threshold
	Forward direction	Reverse direction	
TYPE I	$-\varphi_{FRL} < \varphi_{op} - \varphi_{MSA} < \varphi_{FRU}$	$-\varphi_{RRL} < \varphi_{op} - \varphi_{MSA} < \varphi_{RRU}$	$ S_{op} > G_S$
TYPE II	$-\varphi_{FRL} < \varphi_{op} - \varphi_{MSA} < \varphi_{FRU}$	$-\varphi_{RRL} < \varphi_{op} - \varphi_{MSA} < \varphi_{RRU}$	$ S_{op} * \cos(\varphi_{op} - \varphi_{RCA}) > G_S$
Key S_{op} : amplitude of characteristic quantity; G_S : setting value (start value) of the characteristic quantity; φ_{op} : phase angle of characteristic quantity with reference to polarizing quantity; φ_{MSA} : characteristic angle (maximum sensitivity angle); φ_{FRL} : lower limit of phase angle range of characteristic quantity in forward direction; φ_{FRU} : upper limit of phase angle range of characteristic quantity in forward direction; φ_{RRL} : lower limit of phase angle range of characteristic quantity in reverse direction; φ_{RRU} : upper limit of phase angle range of characteristic quantity in reverse direction. NOTE Generally $\varphi_{MSA} = 180^\circ$ for Type II characteristic, well other characteristic angles are possible, e.g. -90° to detect capacitive current in isolated neutral system, See Figure A.2.			

The characteristic angle φ_{MSA} and φ_{FRL} , φ_{FRU} , φ_{RRL} , φ_{RRU} may be either fixed or settable independently. For Type I characteristic, typically $\varphi_{FRL} = \varphi_{FRU} = 90^\circ$, $\varphi_{RRL} = \varphi_{RRU} = 90^\circ$, but it is possible that $\varphi_{FRL} \neq \varphi_{FRU}$, $\varphi_{RRL} \neq \varphi_{RRU}$, and/or $\varphi_{FRL} + \varphi_{FRU} < 180^\circ$, $\varphi_{RRL} + \varphi_{RRU} < 180^\circ$.

Figure 2 and Figure 3 show examples of the two types of operate characteristics in current phasor plane. In Figure 2, to be generic, it is demonstrated that $\varphi_{FRL} + \varphi_{FRU} < 180^\circ$, $\varphi_{RRL} + \varphi_{RRU} < 180^\circ$. In Figure 3, $\varphi_{MSA} = 180^\circ$ is assumed for Type II characteristic.



(a) The characteristic quantity of forward direction element leads the polarizing quantity ($\varphi_{MSA_FWD} > 0^\circ$)



(b) The characteristic quantity of forward direction element lags the polarizing quantity ($\varphi_{MSA_FWD} < 0^\circ$)

Key

$\underline{S}_{op}$ phasor of characteristic quantity;

$\underline{S}_{pol}$ phasor of polarizing quantity;

G_s setting value (start value) of the characteristic quantity;

φ_{MSA_FWD} characteristic angle for forward direction element;

φ_{MSA_REV} characteristic angle for reverse direction element;

φ_{FRL} lower limit of phase angle range of characteristic quantity in forward direction;

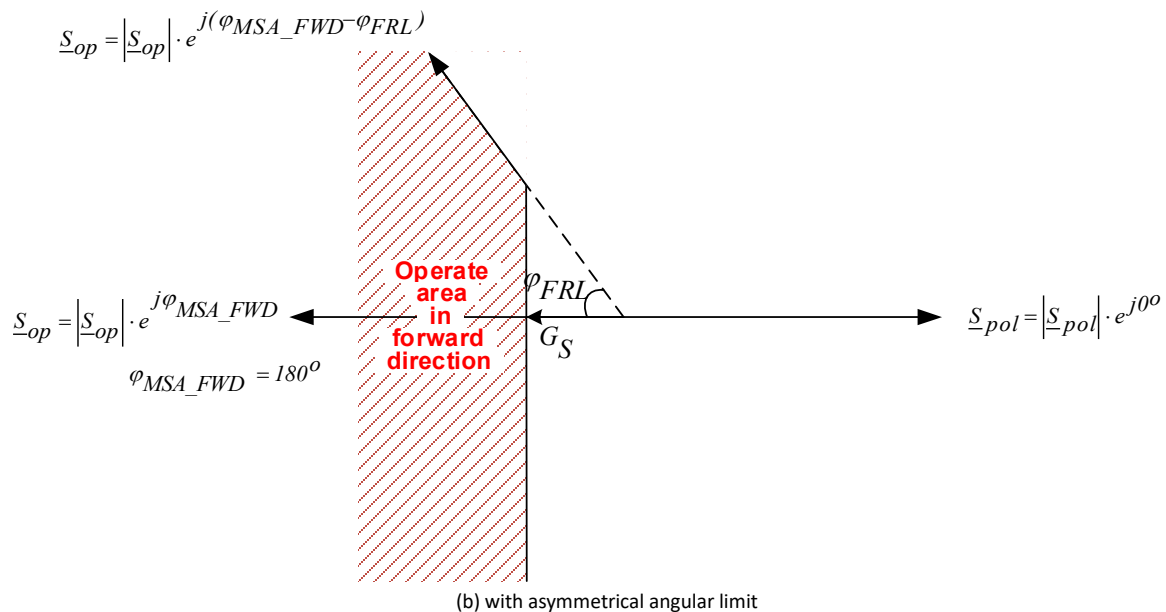
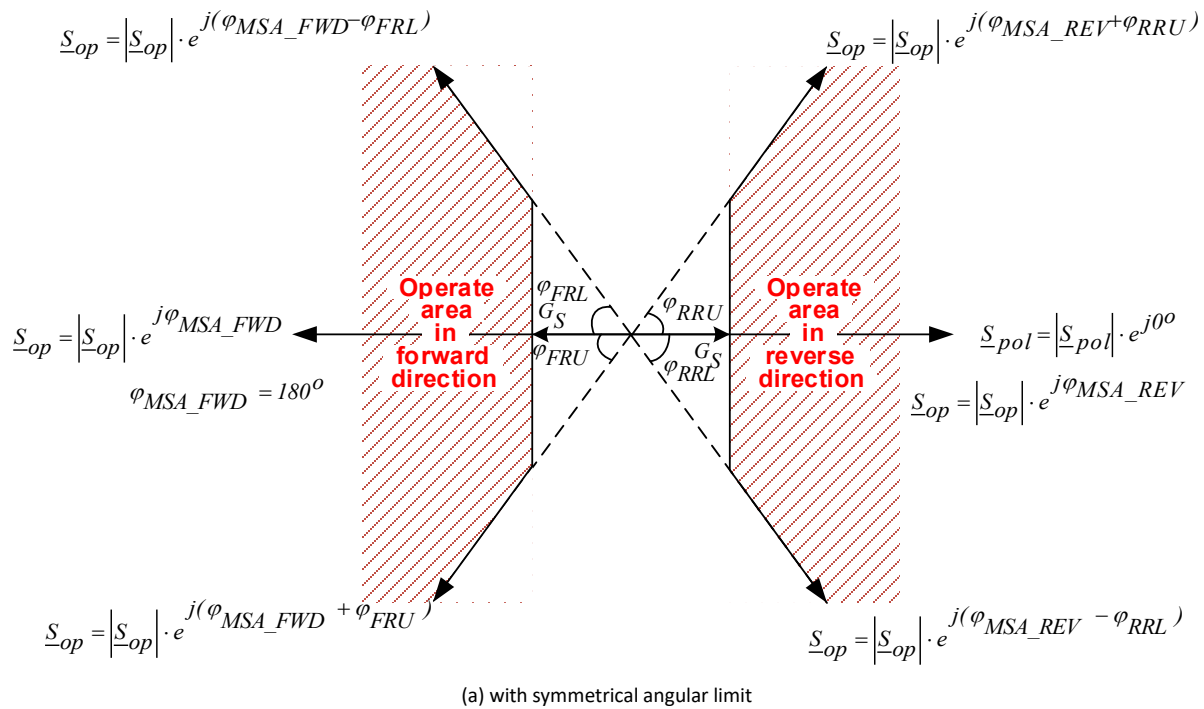
φ_{FRU} upper limit of phase angle range of characteristic quantity in forward direction;

φ_{RRL} lower limit of phase angle range of characteristic quantity in reverse direction;

φ_{RRU} upper limit of phase angle range of characteristic quantity in reverse direction.



Operate area

**Key**

$\underline{S}_{op}$ phasor of characteristic quantity;

$\underline{S}_{pol}$ phasor of polarizing quantity;

G_S setting value (start value) of the characteristic quantity;

φ_{MSA_FWD} characteristic angle for forward direction element;

φ_{MSA_REV} characteristic angle for reverse direction element;

φ_{FRL} lower limit of phase angle range of characteristic quantity in forward direction;

φ_{FRU} upper limit of phase angle range of characteristic quantity in forward direction;

φ_{RRL} lower limit of phase angle range of characteristic quantity in reverse direction;

φ_{RRU} upper limit of phase angle range of characteristic quantity in reverse direction



operate area

NOTE Generally $\varphi_{MSA} = 180^\circ$ for forward direction element with Type II characteristic, well other characteristic angles are possible, e.g. -90° to detect capacitive current in isolated neutral system, See Figure A.2.

If $\varphi_{FRL} = \varphi_{FRU}$, $\varphi_{RRL} = \varphi_{RRL}$, the characteristic quantity at characteristic angle is the centreline of operate area (in line with the bisector of the angle formed by directional lines).

In certain circumstances, overcurrent threshold is fulfilled but neither forward direction nor reverse direction can be discriminated (unknown direction). The manufacturer shall declare the response of the protection function in this case, together with all relevant settings and their meanings, as well as the usage of the settings.

4.4.1.3 Time characteristic

The time characteristic defines the operate time which is the duration between the instant when the characteristic quantity falls into the predetermined direction together with its value crosses the operate value and the instant when the protection function operates.

The relationship between operate time and characteristic quantity may be expressed by means of a characteristic curve. The shape of this curve shall be declared by the manufacturer by a formula (preferred) or by graphical means.

This standard specifies two types of characteristics, which are defined in Subclause 4.4.1.2 and 4.4.1.3 of IEC 60255-151:2009 respectively:

- Independent time characteristic (i.e. definite time delay);
- Dependent time characteristic (i.e. inverse time delay).

Independent time characteristic is applicable to both TYPE I operate characteristic and TYPE II operate characteristic. Dependent time characteristic is applicable to TYPE I operate characteristic only. There are six curves denoted as A, B, C, D, E and F, as defined in Annex A of IEC 60255-151:2009. The manufacturer shall declare which of these curves are implemented.

NOTE Dependent time characteristic (i.e. inverse time delay), in which the operate time is inversely proportional to the applied fault current, is not necessary for TYPE II operate characteristic, which is adopted to handle earth fault in resonant earthed (neutral) system, where earth fault is not an emergent event.

4.4.2 Reset characteristics

To allow users to determine the behaviour of the protection function in the event of repetitive intermittent faults or for faults which may occur in rapid succession, the protection function reset characteristics shall be defined by the manufacturer.

When either direction discrimination or overcurrent threshold does not meet the operate criteria listed in Table 2, then a reset process starts. Different reset characteristics may be used depending upon the settings on the function and whether the element has completed operation or not. The recommended reset characteristics are defined in Subclause 4.4.2 of IEC 60255-151:2009. These reset options can apply to both dependent and independent time protection functions.

4.5 Binary output signals

4.5.1 General

Binary output signals from this function may be available in a number of different forms. For example:

- traditionally wired from physical relay output contacts;
- via a communication port to external devices (e.g. using IEC 61850 GOOSE signals, see C.2.2);
- via internal logical connections to other functional elements within the relay;
- via internal logical connections within the directional overcurrent protection element.

4.5.2 Start (pickup) signals

The start signal is the output of measuring and threshold elements, with or without any additional verification of valid operate conditions but generally without any intentional time delay.

NOTE Start signal of a directional overcurrent protection applied for earth fault handling in resonant earthed (neutral) system and isolated neutral system can have a settable time delay. For more information, see the logical node of sensitive directional earth fault (PSDE) defined in 6.11.17 of IEC 61850-7-4:2010+AMD1:2020 CSV.

In the context of directional overcurrent protection, the start signal occurs when the measured current is determined by measuring and threshold element to fall into the predetermined direction and to be beyond the value required for operation on the operate characteristic.

As an umbrella term, start signal can include the following individual signals:

- general start signal;
- general direction signal – forward, reverse, both or unknown;
- phase-segregated start signals;
- phase-segregated direction signals – forward, reverse or unknown;
- zero-sequence, residual, or neutral protection start signal;
- zero-sequence, residual, or neutral protection direction signal – forward, reverse or unknown.

NOTE For a multi-phase a.c. directional overcurrent protection function, if all the three individual phase elements show different directions, the general direction signal will indicate both forward and reverse direction. For more information, see directional protection indication information (ACD) defined in 7.3.7 of IEC 61850-7-3:2010+AMD1:2020 CSV.

The manufacturer shall specify to the extent required for proper application and testing the information about the start signals, including the characteristic and logic used for the starting element, required setting parameters, meaning and usage of settings, and output signals asserted by the function.

If a start signal is not provided, the manufacturer shall give information on how to carry out the tests related to the start signal as defined in Clause 6.

4.5.3 Operate (trip) signals

The operate(trip) signal is the output of measuring and threshold elements, after completion of any additional verification algorithms to confirm valid operate conditions and completion of any intentional operating time delay. In the case of instantaneous elements, this signal may occur at the same time as the start signal (if provided).

Each operate (trip) signal may associate with forward or reverse directional overcurrent protection function fixedly, or in a configurable way, according to the user's settings.

4.5.4 Other output signals

If any other binary output signals are available for use, their method of operation shall be clearly shown on the functional logic diagram provided by the manufacturer. Additional textual description may also be provided in the product documentation if this can further clarify the functionality of the output signal and its intended usage.

4.6 Additional influencing functions and conditions

4.6.1 General

The following conditions may affect the behaviour of the directional overcurrent protection function. These conditions can be detected by additional function elements which then interact with the directional overcurrent protection relay through external inputs or signals from internal

functional elements in predefined ways, e.g. block directional overcurrent protection when loss of voltage. The manufacturer shall describe the behaviour of the directional overcurrent protection function during the following conditions.

4.6.2 Input energizing quantity failure

Loss of one or several input energizing quantities without an equivalent loss of respective primary voltage or current signal(s) is called input energizing quantity failure. This event can cause directional overcurrent protection function to malfunction, so such an event shall be therefore detected and handled correctly.

For relays with analogue inputs, input energizing quantity failure detection can be implemented internally to the directional overcurrent protection relay by voltage transformer supervision (VTS) and current transformer supervision (CTS), or it can be an external device in which case the input energizing quantity failure signal is transmitted by energizing a relay binary input signal or via communication between the input energizing quantity failure detection relay and the directional overcurrent protection relay.

When the input energizing quantity is a data packet received via a communication port(s) using a suitable communication protocol (such as IEC 61869-9, a profile of IEC 61850-9-2), relevant standards may apply on input energizing quantity failure detection, which shall be declared by the manufacturer. See C.2.1 for further information.

When an input energizing quantity failure happens, an alarm may be issued by the function. Particularly, when loss of voltage signal happens, the directional overcurrent protection function which takes voltage as polarizing quantity may be blocked, shift to an alternative polarizing quantity, or convert to a non-directional overcurrent protection function for a moment according to the user's configuration (settings).

The manufacturer shall declare the behaviour of the directional overcurrent protection function under an input energizing quantity failure and, if any special techniques are used to prevent maloperation, details of any settings relevant to its use shall be provided along with guidance on its usage.

4.6.3 Failure of binary input signal received via a communication port

When the binary input signals are received via a communication port from external devices (e.g. using IEC 61850 GOOSE signals), relevant standards may apply on binary input signal failure detection, which shall be declared by the manufacturer.

The manufacturer shall declare the behaviour of the directional overcurrent protection function in the event of failure of binary input signal and, if any special techniques are used to prevent maloperation, details of any settings relevant to its use shall be provided along with guidance on its usage.

See C.2.2 for further information.

5 Performance specification

5.1 General

Since this document specifies the minimum requirements for directional overcurrent protection, only the performance specifications appropriate to meet these minimum requirements are considered and presented here. The document also defines how the performance related to these minimum requirements shall be documented by the manufacturer.

5.2 Effective and operating ranges

Table 3 shows, with an example, how effective range and operating range shall be declared by the manufacturer. According to the technology employed for the acquisition and the processing of the analogue signals, the range can differ from Table 3, where the values are given as an example to indicate the format of the data. The effective and operating range shall be declared by the manufacturer and the data shall be published in accordance with the format given by Table 3. The behaviour of the directional overcurrent protection outside the effective range shall be declared by the manufacturer.

Table 3 – Example of effective and operating ranges of directional overcurrent protection

Quantity	Effective range	Operating range
Current	0,5 % to 1 000 % of rated current	0,2 % to 4 000 % of rated current
Voltage	5 % to 150 % of rated voltage	2 % to 200 % of rated voltage
Frequency deviation ^a	-5 % to +5 % of nominal frequency	-10 % to +10 % of nominal frequency
	47,5 Hz to 52,5 Hz	45,0 Hz to 55,0 Hz
	57,0 Hz to 63,0 Hz	54,0 Hz to 66,0 Hz
^a For applications where the system frequency is constant, the effective and operating ranges shall be declared as relative values. For applications where the system frequency is not constant, e.g. generators, variable frequency drives, the ranges shall be declared in absolute values (Hz). Additional frequency ranges may be declared if frequency tracking is available.		

For protection function with digital inputs, see C.3.1 for further information.

5.3 Basic characteristic accuracy

5.3.1 General

The purpose of 5.3 is to provide a measure of the basic accuracy under steady state conditions. The test methods that shall be used for this assessment are described in 6.2 and the manufacturer shall declare the specific method used.

5.3.2 Accuracy related to the characteristic quantity and direction determination

The manufacturer shall declare the accuracy related to the characteristic quantity and to the determination of the direction as well as a range of setting values over which it is applicable, following the relevant tests specified respectively in 6.2.1 for the TYPE I operate characteristic and 6.2.2 for the TYPE II operate characteristic. The manufacturer shall also declare the behaviour of the function over the declared operating range. Particularly, the manufacturer shall declare the performance of the element under high fault current conditions (at thermal short-time withstand limit such as current = 100 × rated current). In addition, for dependent time electromechanical relays, the minimum operating value G_T for which the function is guaranteed to operate shall not be more than 1,3 times the setting value G_S .

The accuracy related to the characteristic quantity shall be declared with a relative value with respect to the setting value, together with a fixed maximum absolute error (when this may exceed the percentage value), whichever is greater. The accuracy related to the direction determination shall be declared with a fixed maximum absolute error. For example:

- Accuracy of overcurrent threshold, $\pm 0.5\%$ or $\pm 0.1A$, whichever is greater;
- Accuracy related to the direction determination, $\pm 2^\circ$.

The reset ratio or reset hysteresis of the characteristic quantity and direction determination shall be declared by the manufacturer. For example:

- Overcurrent threshold, reset ratio = 85%;
- Overcurrent threshold, reset hysteresis = 5 mA;

- Overcurrent threshold, reset hysteresis = 5% of G_s ;
- reset hysteresis of direction determination = 5°.

For a protection function with digital input, see C.3.2.

5.3.3 Start time and operate time delay setting

The maximum and average of start time shall be published by the manufacturer as a result of relevant tests specified in Subclause 6.2.3.

The accuracy of the operate time delay setting shall be published by the manufacturer in the way as defined in Subclause 5.2 of IEC 60255-151:2009 as a result of relevant tests specified in Subclause 6.2.3.

The manufacturer shall declare if the internal measurement time of the characteristic quantity and the output contact operation time is included in the operate time delay setting or if it is in addition to the operate time delay setting.

For digitally interfaced protection functions, see C.3.3.

5.3.4 Reset time

The reset time shall be published by the manufacturer in the way as defined in Subclause 5.3 of IEC 60255-151:2009 as a result of relevant tests specified in Subclause 6.2.4.

The manufacturer shall declare if compensation of the internal measurement time is included in the reset time setting or if it is in addition to the reset time setting.

5.4 Performance with load harmonics

Non-linear load conditions or nearby presence of a converter create the presence of harmonics superimposed on the fundamental component of the voltages and currents measured by the a.c. directional overcurrent protection function.

Performance with load harmonics is influenced by several factors, such as filtering circuit and/or filtering algorithm, calculation of characteristic quantity and polarizing quantity, directional discrimination, etc.

The manufacturer shall declare the behaviour of single-phase, three-phase, positive-sequence, and negative-sequence directional overcurrent protection functions when superimposed harmonics are present on the load, according to the tests described in 6.3.

5.5 Behaviour during voltage outside of the effective range but inside the operating range

When voltage signal is used as polarizing quantity for direction determination, it is important to understand the behaviour of the directional overcurrent protection functions when the voltage is outside of the effective range but inside the operating range. Manufacturers shall declare the behaviour of the directional overcurrent protection functions when the voltage is outside of the effective range but inside the operating range, according to the tests described in Subclause 6.4.

Particularly, behaviour of single-phase, three-phase and positive-sequence directional overcurrent protection functions under close-in three-phase fault (all three phase voltages are zero) shall be declared by the manufacturer.

NOTE According to the design, for close-in three-phase fault, the directional overcurrent protection function can use memorized voltage phasor(s) for direction determination.

5.6 Behaviour during frequency outside of the effective range but inside the operating range

In system emergency conditions, system black start conditions or generator stop conditions, it is important to understand the behaviour of the directional overcurrent protection functions when the frequency is outside of the effective range but inside the operating range. Manufacturers shall declare the behaviour of the directional overcurrent protection functions when the frequency is outside of the effective range but inside the operating range, according to the tests described in Subclause 6.5.

5.7 Overshoot time

The manufacturer shall declare the overshoot time according to the tests described in Subclause 6.6.

5.8 Response to time varying value of the characteristic quantity

To ensure proper coordination with dependent time relays, the relay performance under time varying fault current conditions (characteristic quantity varies with time) shall be tested. The manufacturer shall declare any additional errors according to the tests described in Subclause 6.7. In all cases, the additional error shall be less than 15 %.

5.9 Transient overreach

For independent time single-phase, three-phase, positive-sequence or negative-sequence directional overcurrent protection, the manufacturer shall declare transient overreach (See 3.15) as a percentage error of setting value (G_s) based the tests described in Subclause 6.8, i.e. the effect of applying waveforms with maximum d.c. offset associated with systems having a primary time constant as shown in Table 4.

Table 4 – Primary time constant for transient overreach

X/R	Primary time constant at 50 Hz	Primary time constant at 60 Hz
≈120	380 ms	320 ms
≈40	130 ms	110 ms
≈10	30 ms	30 ms

NOTE Transient overreach are not applicable to zero-sequence, residual or neutral directional overcurrent protection and wattmetric directional earth fault protection which are usually with a long time delay, as long time delayed directional overcurrent protection are not be influenced by d.c. offset. Furthermore, time constant in earth fault loop is quite different for system with different neutral point treatment.

5.10 Performance under abnormal SV and GOOSE

See 6.8.3 and C.3.4.

6 Functional tests

6.1 General

6.1.1 Purpose of the tests

This clause gives a detailed description of the tests to be performed to verify the function performance specification described in Clause 5. These tests are a mandatory part of the type-tests for the protection function. These tests are not intended for field commissioning or routine tests to prove any performance of the directional overcurrent protection function for a real application.

Detailed description of the test conditions and how test results shall be published in the manufacturer's documentation are provided. This will allow the comparison of technical

requirements of the user with the protection function specifications given in the manufacturer's documentation.

These tests shall be designed in such a way as to exercise all aspects of hardware and firmware (if applicable) of the directional overcurrent protection relay. This means that injection of input energizing quantities shall be at the interface to the relay, either directly into current and voltage input terminals, or an equivalent signal at the appropriate interface. Similarly, operation shall be taken from output contacts wherever possible or equivalent signals at an appropriate interface. If for any reason it is not possible to measure the results from signal input to output, the point of application of the input energizing quantities and the signal interface used for measurement shall be declared by the manufacturer.

The test method in this chapter is applicable to directional overcurrent protection functions with analogue inputs, as well as those with digital inputs unless otherwise specified.

6.1.2 Injection of input energizing quantities

In order to determine the accuracy of the a.c. directional overcurrent protection function under steady state conditions, the injected input energizing quantities shall be, as required, sinusoidal and of fixed frequency unless otherwise specified (e.g. performance test with load harmonics). Amplitude and phase angles are changed according to test requirements. Unless otherwise specified, tests are performed for all nominal frequencies, all rated voltages, and all rated currents of the directional overcurrent protection function.

NOTE For the tests under off-nominal frequencies, only one rated voltage and one rated current are selected, as specified in the corresponding test requirements.

Depending on test requirements for individual test described in Clause 6, the significant test points of frequency and voltage shall be chosen from Table 5.

Table 5 – Significant test points of frequency and voltage

	Lower limit of operating range	Lower limit of effective range	Nominal value	Upper limit of effective range	Upper limit of operating range
Frequency	$f_{\min (op)}$	$f_{\min (eff)}$	f_r	$f_{\max (eff)}$	$f_{\max (op)}$
Voltage	$V_{\min (op)}$	$V_{\min (eff)}$	V_r	$V_{\max (eff)}$	$V_{\max (op)}$
NOTE Rated voltage (V_r) for residual voltage input can be selected as the actual value of residual voltage on secondary side will be when a close-in single phase-to-earth fault with zero fault resistance happens under the condition that phase-to-neutral voltages of all the three phases are at their rated value.					

The effective range and operating range are described in Subclause 5.2.

For relays with analogue inputs where the settings are in primary values, one or two current transformer ratios (depending on the number of rated secondary values being supported, e.g. 1A and 5A) and one voltage transformer ratio may be selected for performing the tests.

For relays with SV inputs, normal SV stream shall be injected as required unless otherwise specified. See C.4 for further information.

For three-phase, positive-sequence, or negative-sequence directional overcurrent protection functions with three phase-to-earth voltage inputs and three phase current inputs, input energizing quantities shown in Formula (1) and Formula (2) apply.

$$\begin{cases} U_{L1}(t) = k_{UL1} * \sqrt{2} * V_r * \cos(2\pi ft + \varphi_{L1}) \\ U_{L2}(t) = k_{UL2} * \sqrt{2} * V_r * \cos(2\pi ft + \varphi_{L2}) \\ U_{L3}(t) = k_{UL3} * \sqrt{2} * V_r * \cos(2\pi ft + \varphi_{L3}) \end{cases} \quad (1)$$

$$\begin{cases} I_{L1}(t) = k_{IL1} * \sqrt{2} * I_r * \cos(2\pi ft + \varphi_{L1} - \varphi_{IL1}) \\ I_{L2}(t) = k_{IL2} * \sqrt{2} * I_r * \cos(2\pi ft + \varphi_{L2} - \varphi_{IL2}) \\ I_{L3}(t) = k_{IL3} * \sqrt{2} * I_r * \cos(2\pi ft + \varphi_{L3} - \varphi_{IL3}) \end{cases} \quad (2)$$

552 Where,

- 553 – U_{L1}, U_{L2}, U_{L3} are phase-to-earth voltage inputs;
- 554 – I_{L1}, I_{L2}, I_{L3} are phase current inputs;
- 555 – V_r is rated value of phase-to-earth voltage;
- 556 – I_r is rated value of phase current;
- 557 – $k_{UL1}, k_{UL2}, k_{UL3}$ are voltage input amplitude factors;
- 558 – $k_{IL1}, k_{IL2}, k_{IL3}$ are current input amplitude factors;
- 559 – $\varphi_{L1}, \varphi_{L2}, \varphi_{L3}$ are phase angles of phase-to-earth voltage inputs;
- 560 – $\varphi_{IL1}, \varphi_{IL2}, \varphi_{IL3}$ are displacement angles, i.e. phase angle of phase current input lagging
- 561 behind corresponding phase-to-earth voltage input.

562 For single-phase directional overcurrent protection functions with single phase current input
563 and single or three phase-to-earth voltage input(s), relevant input energizing quantities shown
564 in Formula (1) and Formula (2) apply.

565 Particularly, for zero-sequence or residual directional overcurrent protection function with three
566 phase-to-earth voltage inputs (from which zero sequence voltage or residual voltage is derived)
567 and three phase current inputs (from which zero sequence current or residual current is derived),
568 input energizing quantities shown in Formula (1) and Formula (2) apply.

569 NOTE Residual current equals to sum of the phase currents, which is three times of zero sequence current. Residual
570 voltage equals to sum of the phase-to-earth voltages, which is three times of zero-sequence voltage.

571 For residual, or neutral directional overcurrent protection function with single voltage input
572 (residual voltage) and single current input (residual current or neutral current), input energizing
573 quantities shown in Formula (3) and Formula (4) apply.

$$U_{res}(t) = k_{Ures} * \sqrt{2} * V_r * \cos(2\pi ft + \varphi_{Ures}) \quad (3)$$

$$\begin{cases} I_{res}(t) = k_{Ires} * \sqrt{2} * I_r * \cos(2\pi ft + \varphi_{Ires}) \\ I_{neu}(t) = k_{Ineu} * \sqrt{2} * I_r * \cos(2\pi ft + \varphi_{Ineu}) \end{cases} \quad (4)$$

574 Where,

- 575 – U_{res} is residual voltage input;
- 576 – I_{res} is residual current input, and I_{neu} is neutral current input;
- 577 – k_{Ures} is amplitude factor of voltage input;
- 578 – k_{Ires} is amplitude factor of residual current input, and k_{Ineu} is amplitude factor of neutral
- 579 current input;
- 580 – φ_{Ures} is phase angle of residual voltage input;
- 581 – φ_{Ires} is phase angle of residual current input, and φ_{Ineu} is phase angle of neutral current
- 582 input.

583 NOTE Rated voltage (V_r) for residual voltage input may be selected as the actual value of residual voltage on
584 secondary side will be when a close-in single phase-to-earth fault with zero fault resistance happens under the
585 condition that phase-to-neutral voltages of all the three phases are at their rated value.

586 For zero-sequence or residual directional overcurrent protection function with single voltage
587 input (residual voltage) and three phase current inputs (from which either zero sequence current

or residual current is derived), input energizing quantities shown in Formula (2) and Formula (3) apply.

For residual, or neutral directional overcurrent protection function with three phase-to-earth voltage inputs (from which either zero sequence voltage or residual voltage is derived) and single current input (residual current or neutral current), input energizing quantities shown in Formula (1) and Formula (4) apply.

Parameters of input energizing quantities under normal condition or different fault types in systems with different earthing modes are shown in Table 6. If applicable, fault type L1E, L2E, L3E, L1L2, L2L3, L3L1 and L1L2L3 shall be injected. These injections may not be realistic from the power system protection point of view, but they are very helpful for evaluating the inherent characteristic accuracy of the function.

Table 6 – Parameters of input energizing quantities under normal condition and different close-in fault types in systems with different earthing modes

Normal condition or fault type	Three voltage inputs and three current inputs Formula (1), (2)	Single voltage input (residual voltage) and single current input (residual or neutral current) Formula (3), (4)	Three voltage inputs and single current input (residual or neutral current) Formula (1), (4)	Single voltage input (residual voltage) and three phase current inputs Formula (2), (3)
Normal condition ^a	$k_{UL1} = k_{UL2} = k_{UL3} \neq 0$ $k_{IL1} = k_{IL2} = k_{IL3} = 0$ $\varphi_{L2} = \varphi_{L1} - 120^\circ$ $\varphi_{L3} = \varphi_{L1} + 120^\circ$	$k_{Ures} = 0$ $k_{Ires} = 0$ or $k_{Ineu} = 0$	$k_{UL1} = k_{UL2} = k_{UL3} \neq 0$ $k_{Ires} = 0$ or $k_{Ineu} = 0$ $\varphi_{L2} = \varphi_{L1} - 120^\circ$ $\varphi_{L3} = \varphi_{L1} + 120^\circ$	$k_{Ures} = 0$ $k_{IL1} = k_{IL2} = k_{IL3} = 0$
L1L2L3 close-in fault	$k_{UL1} = k_{UL2} = k_{UL3} = 0$ $k_{IL1} = k_{IL2} = k_{IL3} \neq 0$ $\varphi_{L2} = \varphi_{L1} - 120^\circ$ $\varphi_{L3} = \varphi_{L1} + 120^\circ$ $\varphi_{IL1} = \varphi_{IL3} = \varphi_{IL2}$	N.A.	N.A.	N.A.
L1E close-in fault in solidly earthed (neutral) system, impedance earthed (neutral) system ^b	$k_{UL1} = 0; k_{UL2} = k_{UL3} \neq 0$ $k_{IL1} \neq 0; k_{IL2} = k_{IL3} = 0$ $\varphi_{L2} = \varphi_{L1} - 120^\circ$ $\varphi_{L3} = \varphi_{L1} + 120^\circ$ φ_{IL1} as required.	$k_{Ures} \neq 0$ $k_{Ires} \neq 0$ or $k_{Ineu} \neq 0$ $\varphi_{Ures} - \varphi_{Ires} = -180^\circ + \varphi$ or, $\varphi_{Ures} - \varphi_{Ineu} = -180^\circ + \varphi$ φ as required.	$k_{UL1} = 0; k_{UL2} = k_{UL3} \neq 0$ $k_{Ires} \neq 0$ or $k_{Ineu} \neq 0$ $\varphi_{L2} = \varphi_{L1} - 120^\circ$ $\varphi_{L3} = \varphi_{L1} + 120^\circ$ $\varphi_{Ires} = \varphi_{L1} - \varphi$ or, $\varphi_{Ineu} = \varphi_{L1} - \varphi$ φ as required.	$k_{Ures} \neq 0$ $k_{IL1} \neq 0; k_{IL2} = k_{IL3} = 0$ $\varphi_{Ures} = \varphi_{L1} - 180^\circ$ φ_{IL1} as required.
L1E close-in fault in isolated neutral system, resonant earthed (neutral) system ^{b, d}	N.A.	$k_{Ures} \neq 0$ $k_{Ires} \neq 0$ $\varphi_{Ures} - \varphi_{Ires} = -180^\circ + \varphi$ φ as required.	$k_{UL1} = 0; k_{UL2} = k_{UL3} \neq 0$ $k_{Ires} \neq 0$ $\varphi_{L2} = \varphi_{L1} - 150^\circ$ $\varphi_{L3} = \varphi_{L1} + 150^\circ$ $\varphi_{Ires} = \varphi_{L1} - \varphi$ φ as required.	N.A.
L2L3 close-in fault ^c	$k_{UL1} = 2 * k_{UL2} = 2 * k_{UL3}$ $k_{IL1} = 0; k_{IL2} = k_{IL3} \neq 0$ $\varphi_{L2} = \varphi_{L1} - 180^\circ$ $\varphi_{L3} = \varphi_{L1} + 180^\circ$ $\varphi_{IL2} = \varphi_{IL3} - 180^\circ$	N.A.	N.A.	N.A.

^a Under normal condition, depending on the test requirements of the specific test in Clause 6, three voltage inputs can be equal to, higher than or lower than the rated value.

^b Parameters for fault type L2E and L3E are omitted, which can be easily obtained accordingly in the same way as that for L1E.

^c Parameters for fault type L1L2 and L3L1 are omitted, which can be easily obtained accordingly in the same way as that for L2L3.

^d In isolated neutral system, only residual current input is applicable, there is no neutral current input.

6.1.3 Monitor of binary outputs

6.1.3.1 Physical hard wired binary outputs

When monitored, the assertion of the start signal (if provided) or operate(trip) signal shall be affirmed (considered as valid) only if there is no chattering of the signal with several transitions high–low–high during the injection of the step.

NOTE Generally, the inherent output contact chatter is less than 4ms, a period of 5ms is sufficient to affirm the assertion of the monitored signal.

An example of valid assertion of a signal is shown in **Figure 4**.

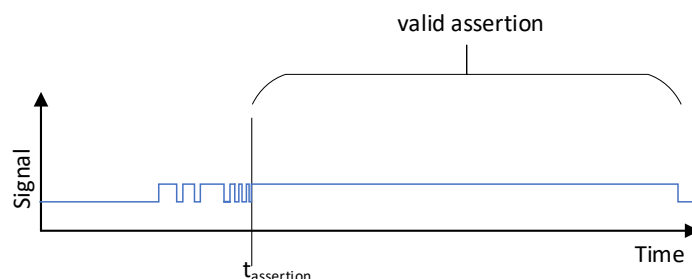


Figure 4 – Example of valid assertion of a signal

For the tests in which start signal shall be monitored, if start signal is not available, then operate(trip) signal with minimum operate time shall be monitored instead.

6.1.3.2 Digital binary outputs

For digital binary outputs, such as IEC 61850 GOOSE, no chattering at all shall be present in the transition of the start signal or operate(trip) signal, in order to be considered valid. In case start signal is not available, then an operate(trip) signal with the minimum time delay shall be used instead.

6.1.4 Test Settings and configuration

In the following subclauses, the test settings to be used are expressed in a percentage of the available range, with 0 % representing the minimum available setting and 100 % representing the maximum available setting. Similarly, 50 % would represent the mid-point of the available setting range. The actual setting to be used can be calculated using the following formula:

$$S_{AV} = (S_{MAX} - S_{MIN}) * X \% + S_{MIN} \quad (5)$$

Where,

- S_{AV} is the actual setting value to be used in the test;
- S_{MAX} is the maximum available setting value;
- S_{MIN} is the minimum available setting value;
- $X \%$ is the test point percentage value expressed in the test methodology.

Sufficient test points should be used to assess the performance over the entire setting range of the protection function.

Depending upon the technology of the protection function being tested, it may be possible to reduce the number of test points in line with the limited range and step-size of available settings. However, the test points listed should be used or the nearest available setting should be used if the exact value cannot be achieved.

Additional checks shall be performed at maximum setting value selected of the characteristic quantity to ensure that the operation occurs for a current value near the short-time thermal withstand limit (such as $100 \times$ rated current) applied to the relay.

6.1.5 Test methods and procedures

The proposed test methods are to be preferred. If a protection algorithm does not allow the use of the proposed approach, the manufacturer shall propose and describe an alternative test procedure and present the results in the format given in this standard.

For successive test shots, before each test state is injected, a normal state shall be injected for at least 5 times of the reset time, or 200 ms, whichever is longer.

The test procedures in Clause 6 are given as an example and the order of the sequence may vary. Some of the tests described in the following subclauses may be merged to optimize the test process.

6.2 Basic performance test

6.2.1 Direction discrimination and overcurrent threshold test of TYPE I

6.2.1.1 Accuracy of characteristic quantity

6.2.1.1.1 General

The purpose of these tests is to determine the accuracy and the reset ratio or reset hysteresis of the setting value (G_S) as described in 5.3.2. These tests are applied only to TYPE I operate characteristic as shown in Figure 2.

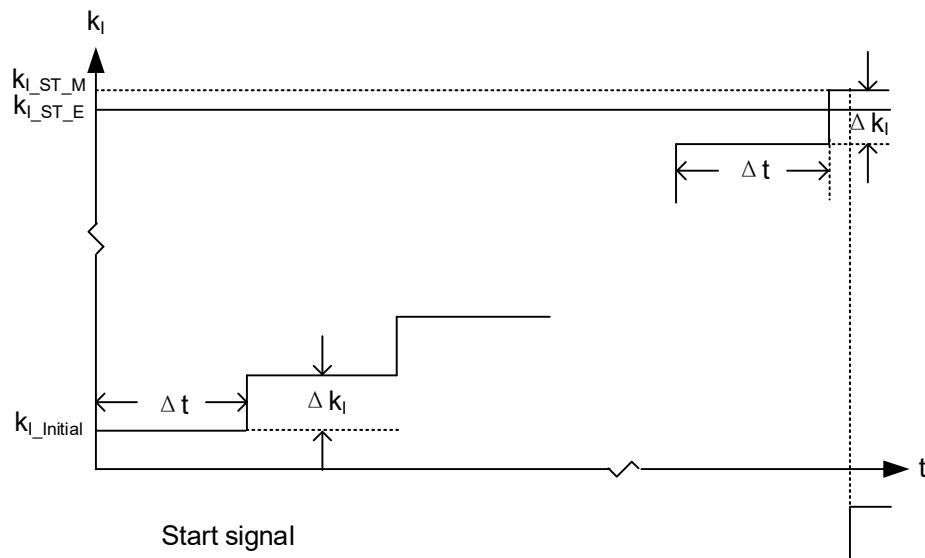
All nominal frequencies shall be covered, and the test frequency values corresponding to each nominal frequency shall be: nominal value (f_r), lower limit of effective range ($f_{\min(eff)}$), upper limit of effective range ($f_{\max(eff)}$). For the tests under nominal frequency, all the rated currents and all the rated voltages shall be covered, and the test voltage values corresponding to each rated voltage shall be: rated value (V_r), lower limit of effective range ($V_{\min(eff)}$), upper limit of effective range ($V_{\max(eff)}$). For the tests under off-nominal frequencies, one rated current and one rated voltage may be selected, and the test voltage value corresponding to the selected rated voltage shall be: rated value (V_r). The test phase angle of characteristic quantity (φ_{op}) shall be: φ_{MSA} . Phase angle of current input(s) shall be kept unchanged during the ramp.

For the tests under nominal frequency, at least 3 setting values of the characteristic quantity shall be covered: 0 %; 50 %; 100 %. For the tests under off-nominal frequencies, at least one setting value of the characteristic quantity shall be covered: 0 %. For settings related to direction determination, if applicable, the default ones (Case 1 in Table 7) or that suggested by the manufacturer for the most typical applications shall apply. Minimum time delay setting for operate shall apply for this test: 0 %. If intentional delay on reset is adopted, minimum time delay setting for reset shall apply: 0 %.

The proposed test methods based on pseudo continuous ramp are to be preferred. However, a ramp of shots (pulse ramp) or a search algorithm with shots like a binary search described in Annex B may be used as well.

6.2.1.1.2 Accuracy of setting (start) threshold

A pseudo-continuous current ramp may be applied, as shown in Figure 5.

**Key**

k_I , amplitude factor of current input, expressed in per cent.

t , time, expressed in millisecond.

$k_{I_Initial}$, amplitude factor of initial current.

$k_{I_ST_E}$, expected value of k_I for the assertion of the start signal.

$k_{I_ST_M}$, measured value of k_I for the assertion of the start signal.

Δk_I , amplitude factor of current ramp step.

Δt , duration of ramp step.

Figure 5 – Pseudo-continuous current ramp for operate characteristic test

If applicable, the following fault types shall be covered: L1E, L2E, L3E, L1L2, L2L3, L3L1. When ramp starts, the voltage input(s) shall be changed suddenly from normal condition to corresponding faulty condition as shown in Table 6, and then remain unchanged during the ramp.

The expected value of k_I for the assertion of the start signal is:

$$k_{I_ST_E} = \frac{G_S}{I_r} \quad (6)$$

The ramp starts at the initial current, which is defined by $k_{I_Initial}$ as expressed as:

$$k_{I_Initial} = k_{I_ST_E} * (1 - k_\sigma * \sigma\%) \quad (7)$$

Where, $\sigma\%$ is the declared accuracy of setting (start) threshold, and k_σ is the multiplier coefficient to be applied to $\sigma\%$ to ensure correct detection of the threshold. k_σ will be chosen such that $k_\sigma \geq 2$.

Each step of the current ramp shall have an increase of:

$$\Delta k_I \leq 10\% * \sigma\% * k_{I_ST_E} \quad (8)$$

Each step of the current ramp shall have a duration of:

$$\Delta t = \text{MAX}(200 \text{ ms}; 5 \text{ times the maximum expected start time}) \quad (9)$$

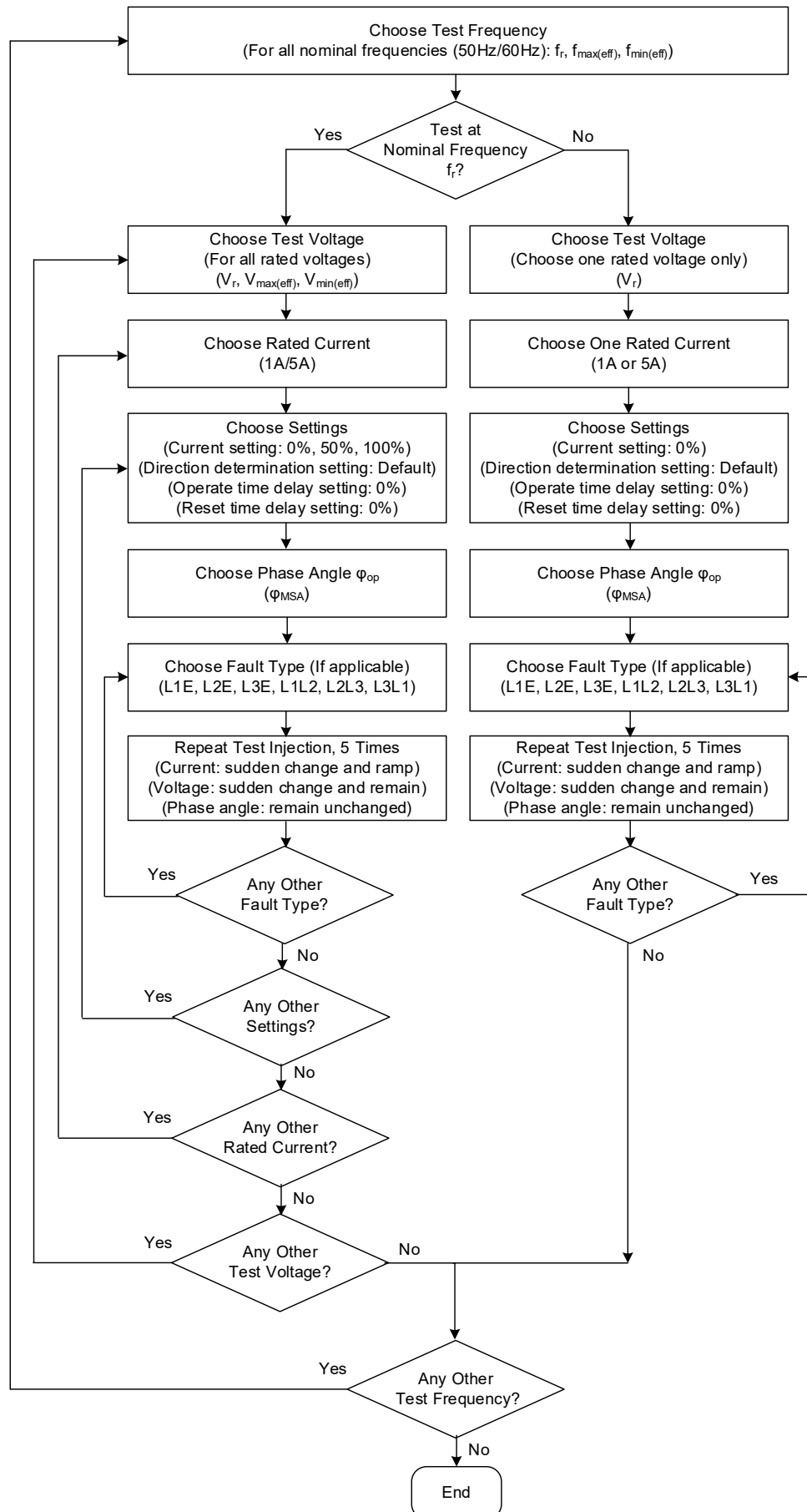
During the transition between successive current steps, the injected signals shall be continuous without step change in their phase angles.

686 The ramp may be interrupted after the assertion of the start signal, resulting in the value of k_I
687 for the assertion of the start signal, $k_{I_ST_M}$.

688 Each test shall be repeated 5 times. The values thus determined of all the tests shall be within
689 the declared accuracy:

$$\left| \frac{k_{I_ST_M} - k_{I_ST_E}}{k_{I_ST_E}} \right| \leq \sigma \% \quad (10)$$

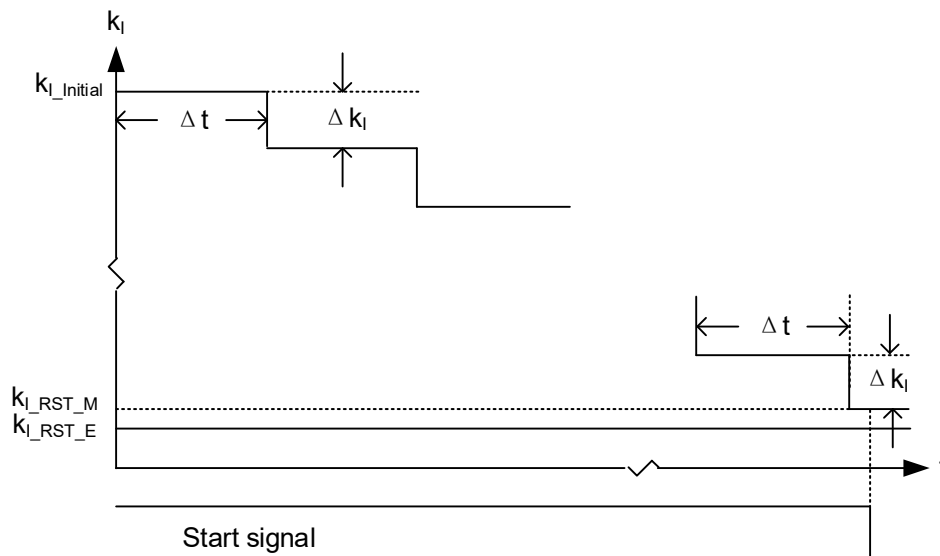
690 Test signal may be injected according to the example test sequence described by the flowchart
691 shown in Figure 6. However, the repetition sequence in Figure 6 may be changed, and other
692 test sequences may be used.



6.2.1.1.3 Reset ratio or reset hysteresis of characteristic quantity

The tests described in this Subclause are performed to verify the reset characteristic of characteristic quantity described in 4.4.2. If the test methodology is not feasible, the manufacturer shall propose and describe an alternative test procedure.

A pseudo-continuous current ramp may be applied, as shown in Figure 7.



Key

k_I , amplitude factor of current input, expressed in per cent.

t , time, expressed in millisecond.

$k_{I_Initial}$, amplitude factor of initial current.

$k_{I_RST_E}$, expected value of k_I for the deassertion of the start signal.

$k_{I_RST_M}$, measured value of k_I for the deassertion of the start signal.

Δk_I , amplitude factor of current ramp step.

Δt , duration of ramp step.

Figure 7 – Pseudo-continuous current ramp for reset characteristic test

If applicable, the following fault types shall be covered: L1E, L2E, L3E, L1L2, L2L3, L3L1. When ramp starts, the voltage input(s) shall be changed suddenly from normal condition to corresponding faulty condition as shown in Table 6, and then remain unchanged during the ramp.

The expected value of k_I for the deassertion of the start signal is:

$$k_{I_RST_E} = \begin{cases} \frac{G_S * k_{RST}}{I_r} & \text{when reset accuracy is declared in reset ratio.} \\ \frac{G_S - H_{RST}}{I_r} & \text{when reset accuracy is declared in reset hysteresis.} \end{cases} \quad (11)$$

Where, k_{RST} is reset ratio specified by the manufacturer, $k_{RST} < 1$; H_{RST} is reset hysteresis.

The ramp starts at the initial current, which is defined by $k_{I_Initial}$:

$$k_{I_Initial} = \frac{G_S}{I_r} * (1 + k_\sigma * \sigma\%) \quad (12)$$