

INTERNATIONAL STANDARD

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**Measuring relays and protection equipment –
Part 121: Functional requirements for distance protection**

**Relais de mesure et dispositifs de protection –
Partie 121: Exigences fonctionnelles pour protection de distance**



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Part 121: Functional requirements for distance protection**

**Relais de mesure et dispositifs de protection –
Partie 121: Exigences fonctionnelles pour protection de distance**

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MEASURING RELAYS AND PROTECTION EQUIPMENT –**Part 121: Functional requirements for distance protection**

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This standard cancels and replaces IEC 60255-16.

The text of this standard is based on the following documents:

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95/319/FDIS	95/321/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60255 series, published under the general title *Measuring relays and protection equipment*, can be found on the IEC website.

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MEASURING RELAYS AND PROTECTION EQUIPMENT –

Part 121: Functional requirements for distance protection

1 Scope

This part of IEC 60255 specifies minimum requirements for functional and performance evaluation of distance protection function typically used in, but not limited to, line applications for effectively earthed, three-phase power systems. This standard also defines how to document and publish performance tests.

This standard covers distance protection function whose operating characteristic can be defined on an impedance plane and includes specification of the protection function, measurement characteristics, phase selection, directionality, starting and time delay characteristics.

The test methodologies for verifying performance characteristics and accuracy are included in this standard. The standard defines the influencing factors that affect the accuracy under steady state conditions and performance characteristics during dynamic conditions. It also includes the instrument transformer requirements for the protection function.

The distance protection functions covered by this standard are as follows:

	IEEE/ANSI C37.2 Function numbers	IEC 61850-7-4 Logical nodes
Phase distance protection	21	PDIS
Earth (ground) distance protection	21G	PDIS

This standard does not specify the functional description of additional features often associated with digital distance relays such as power swing blocking (PSB), out of step tripping (OST), voltage transformer (VT) supervision, switch onto fault (SOTF), trip on reclose (TOR), the logic for cross country faults in not effectively earthed networks, and trip conversion logic. Only their influence on the distance protection function is covered in this standard. The protection of series-compensated lines is beyond the scope of this standard.

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

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at <<http://www.electropedia.org>>)

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

IEC 61850 (all parts), *Communication networks and systems for power utility automation*

IEC 61869-2:2012, *Instrument transformers – Part 2: Additional requirements for current transformers*

IEC 61869-5:2011, *Instrument transformers – Part 5: Additional requirements for capacitor voltage transformers*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-444, IEC 60050-447, IEC 60050-448, as well as the following apply.

3.1

distance protection

non-unit protection whose operation and selectivity depend on local measurement of electrical quantities from which the equivalent distance to the fault is evaluated by comparing with zone settings

[SOURCE: IEC 60050-448:1995, 448.14.01]

3.2

zones of non-unit protection

zones of protection (US)

reaches of the measuring elements of non-unit protection, generally distance protection, in a power system

Note 1 to entry: These non-unit protections, generally distance protection, often have two, three or even more zones available. These are usually arranged such that the shortest zone corresponds to an impedance slightly smaller than the impedance of the protected section, and is normally instantaneous in operation. Zones with longer reach settings are normally time-delayed to obtain selectivity.

[SOURCE: IEC 60050-448:1995, 448.14.02]

3.3

operating range

range for which the measuring relay under specified conditions is able to perform its intended function(s) according to the specified requirements

Note 1 to entry: When accuracy requirements have to be met, see effective range (IEC 60050-447:2010, 447.07.08).

[SOURCE: IEC 60050-447:2010, 447.03.16]

3.4

effective range

part of the operating range of an input energizing quantity or characteristic quantity within which the accuracy requirements are met

[SOURCE: IEC 60050-447:2010, 447.07.08]

3.5

characteristic quantity

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

[SOURCE: IEC 60050-447:2010, 447.07.01]

3.6

operate time

duration of the time interval between the instant when the characteristic quantity of a measuring relay in reset condition is changed, under specified conditions, and the instant when the relay operates

[SOURCE: IEC 60050-447:2010, 447.05.05]

3.7

disengaging time

duration of the time interval between the instant a specified change is made in the value of the input energizing quantity which will cause the relay to disengage and instant it disengages

Note 1 to entry: The disengaging time is a parameter that is more commonly denoted with the word “reset time”.

[SOURCE: IEC 60050-447:2010, 447.05.10]

3.8

source impedance ratio

SIR

at a given measurement location, commonly at one end of a line, the ratio of the power system source impedance to the impedance of the protected zone

Note 1 to entry: This note applies to the French language only.

[SOURCE: IEC 60050-448:1995, 448.14.14]

4 Specification of the function

4.1 General

A block diagram of the distance protection function is shown in Figure 1. The main elements are:

- starting/fault detection,
- phase selection,
- directional determination,
- loop impedance calculations,
- distance protection characteristic,
- functional logic.

Distance protection function designs differ among manufacturers, and some of them may have a different architecture than the one shown in Figure 1.

4.2 Input energizing quantities/energizing quantities

The input energizing quantities are the measuring signals, which are voltages and currents in the case of distance protection. Their ratings and relevant standards are specified in IEC 60255-1. Input energizing quantities can be presented to the distance protection functional logic either hardwired from voltage and current transformers or as a data packet over a communication port using an appropriate communication protocol (such as IEC 61850-9-2).

For three-phase distance protection function, the Input energizing quantities shall be specified. As an example:

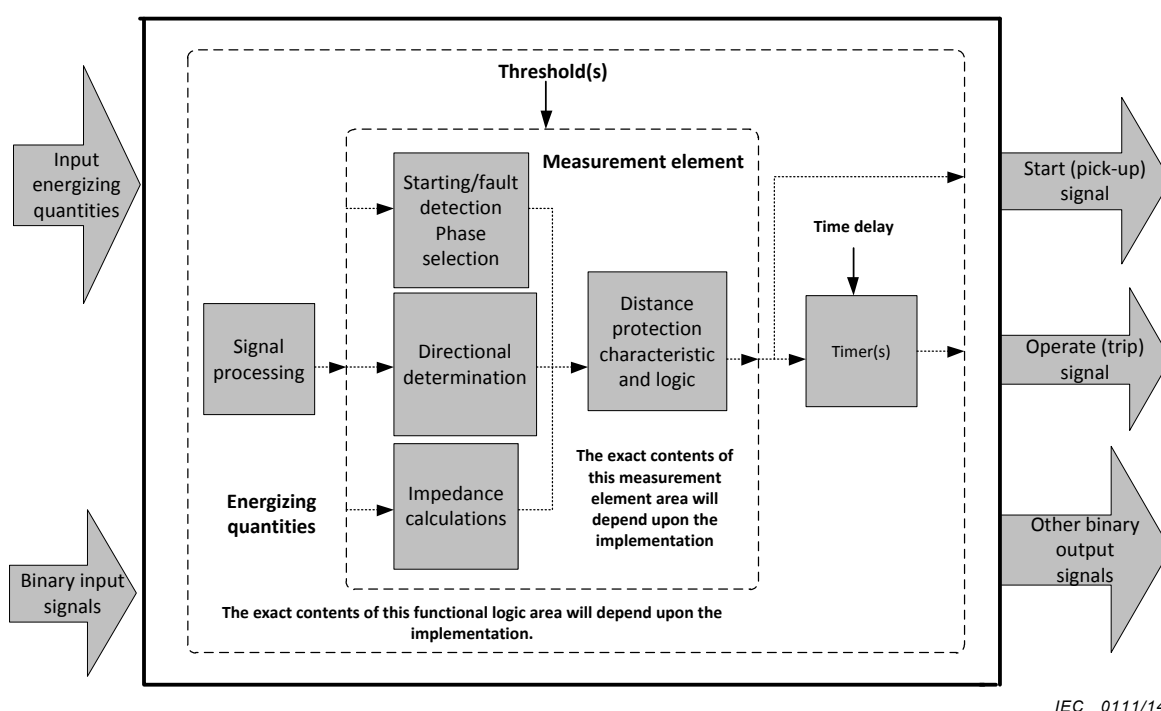
- phase-to-earth voltages: U_{L1} , U_{L2} and U_{L3}

- phase currents: I_{L1} , I_{L2} and I_{L3}

Distance protection functions may have an input for line residual current. In addition the distance protection function may have input from residual current of a parallel line. However, the influence of mutual coupling from a parallel line is not considered in this standard.

The manufacturer shall specify to the extent required for proper application and testing which Energizing quantities are used for the operation of the distance protection elements. For example:

- use of phase to earth or phase-to-phase voltage;
- use of phase and residual (measured or calculated) currents;
- use of derived signals from phase quantities, e.g. negative sequence current, zero sequence voltage, ΔI and/or ΔV detection.



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Figure 1 – Simplified distance protection function block diagram

The distance function may provide the following directional output signals:

- fault in forward direction,
- fault in reverse direction.

Depending on the relay design, directional signals are used internally by the distance elements in different ways. Directional signals are also important for teleprotection schemes.

No general specifications can be given for the directional elements as many different relay designs and architectures are in use. The manufacturer shall describe the principle used for the directional elements, including all required setting parameters, meaning and usage of settings and output signals.

4.3 Binary input signals

If applicable, the manufacturer shall declare and describe binary input signal(s) required for the correct operation of the distance elements with the purpose of demonstrating their effect

on the protection function and response time characteristics. For example: loss of voltage due to fuse failure, any other blocking input, zone extension, etc.

Binary inputs to the relays can be traditionally wired to physical inputs or binary signals coming to the relay over a communication port using a communication protocol or signal from an internal functional element such as loss of voltage due to fuse failure, power swing detection etc. Definitions, ratings and standards for binary input signals are specified in IEC 60255-1.

4.4 Functional logic

4.4.1 Faulted phase identification

The purpose of the faulted phase identification function in distance protection is to provide information about the phases involved in the fault and also if earth is involved (for single phase to earth and phase-phase to earth faults). Faulted phase identification is also important for fault location, teleprotection, single phase tripping and reclosing.

Faulted phase identification may be challenged under some fault conditions including evolving faults, cross-country faults, high fault resistance faults and weak system conditions.

Faulted phase identification may use phase and/ or sequence components of currents, phase and/ or sequence components of voltages, and/ or measured loop impedances as input quantities. No general specifications can be given for the faulted phase identification function as many different relay designs and architectures are in use. Faulted phase identification is required to enable appropriate distance loops and inhibit the other loops in order to maintain dependability and security.

The manufacturer shall describe the principle used for the faulted phase identification and specify all required setting parameters, meaning and usage of settings and output signals asserted by faulted phase identification function.

The distance protection relay shall detect and indicate the appropriate faulted phases and also indicate if earth is involved in the fault (for single phase to earth and phase-phase to earth faults).

4.4.2 Directional signals

The distance function may provide the following directional output signals:

- fault in forward direction,
- fault in reverse direction.

Depending on the relay design, directional signals are used internally by the distance elements in different ways. Directional signals are also important for teleprotection schemes.

No general specifications can be given for the directional elements as many different relay designs and architectures are in use. The manufacturer shall describe the principle used for the directional elements, including all required setting parameters, meaning and usage of settings and output signals.

4.4.3 Distance protection function characteristics

The distance relay shall have a distance measurement function and it shall have an operating characteristic where the relay shall operate inside a characteristic boundary. Several different distance protection operating characteristics are in use. For steady state (static conditions), the operating characteristics are described by geometrical figures and shapes in the complex impedance (R - X) plane (see Annex A for additional information) or by mathematical formulae. It is important to note that these characteristics may dynamically change during transient

fault conditions. No general specifications can be provided for this function as several different relay designs and architectures are in use.

The manufacturer shall declare the operating characteristics in the impedance plane, in graphical form or by mathematical formulae, for phase-to-earth (LN), phase-phase (LL) and 3-phase (LLL) faults in the chosen impedance plane such as ohms/loop or ohms/phase. The operating characteristics shall be referred to the distance protection function impedance setting(s) for a radial feeder with no superimposed load. Annex A provides some commonly used operating characteristics.

The operating criteria for phase selection (or starting elements), if available, shall be declared by the manufacturer. The operating characteristic shall be declared by the manufacturer as a function of the settable parameters, for LN, LL and LLL faults in the chosen impedance plane or by mathematical formulae.

If load encroachment characteristic is available, the manufacturer shall provide its operating characteristic, for LN, LL and LLL faults in the chosen impedance plane or by mathematical formulae, as a function of related settings.

If a directional characteristic is available, the manufacturer shall provide its operating characteristic, for LN, LL and LLL faults in the chosen impedance plane or by mathematical formulae, as a function of related settings.

The manufacturer shall declare all the operating characteristics that influence the protection performance such as minimum enabling current, residual current from a parallel line.

4.4.4 Distance protection zone timers

The behaviour of the timers in time delayed distance protection zones may be different based on the relay design philosophy. In case of evolving faults, the different designs may result in different operate times, when the same evolving fault condition is applied. It is hence necessary to know the behaviour of the distance protection relay during evolving faults in order to ensure selectivity in remote back-up applications. The relay manufacturers shall describe the design philosophy of timers associated with different zones and also, if available, timers associated with different fault types in the same zone.

The informative Annex B shows two particular examples of evolving fault events for time delayed back-up distance protection zones to provide guidance to manufacturers in reporting the information on the design philosophy of zone timers.

4.5 Binary output signals

4.5.1 General

Binary outputs from the relay can be traditionally wired or binary signals coming from the relay over a communication port using a communication protocol. Definitions, ratings and standards for binary output signals are specified in IEC 60255-1.

4.5.2 Start (pickup) signals

The purpose of the start (pickup) signal in a distance protection function is to provide information about the detection of a fault. In some relay designs the start (pickup) signal is used to block or release individual measuring elements. Also, start signals are used for teleprotection schemes.

The starting element may use phase and/or sequence components of currents, phase and/or sequence components of voltages and/or measured loop impedance as input quantities as there are different relay designs and architectures. The manufacturer shall specify to the extent required for proper application and testing the information about the start signals; the

characteristic and logic used for the starting/fault detection element; required setting parameters; meaning and usage of settings; and output signals asserted by the function.

4.5.3 Operate signals

The operate signals are generated by the distance element organized in zones. Numerical distance relays have several distance zones for both phase to earth and phase to phase faults. Each distance zone may provide independent operate signals.

Distance zones combine the signals coming from the starting, phase selection elements, those from distance characteristic/loop impedance calculations, timers in the tripping logic to produce the operate signal.

Operate signals include:

- operate L1,
- operate L2,
- operate L3,
- operate L1, L2, L3.

4.5.4 Other binary output signals

Other binary outputs related to the distance protection function shall be described by the manufacturer.

4.6 Additional influencing functions/conditions

4.6.1 General

The following conditions may affect the behaviour of the distance protection function. These conditions can be detected by additional function elements which then interact with the distance protection relay through external inputs or signals from internal functional elements in pre-defined ways, e.g. blocking distance protection when loss of voltage. The manufacturer shall describe the behaviour of distance protection function during the following conditions.

4.6.2 Inrush current

Inrush current due to power transformer switching might generate unwanted starting or operate signals by the distance protection function.

4.6.3 Switch onto fault/trip on reclose

Switch onto fault condition is defined as a closure of the circuit breaker onto a short circuit condition. Trip on reclose is defined as a special case of a switch onto fault condition where the reclose command is made by auto reclose function.

Switch onto fault and three-phase reclose on to fault conditions are characterised by the absence of pre-fault line voltages when VTs are on the line side of the circuit breaker (CB). When the CB is opened, the distance protection function measures zero line voltages and currents and suddenly, when the CB closes, it measures the fault voltages and currents (line circuit breaker is closed on the permanent fault).

Switch onto fault protection is hence an auxiliary function of the line distance protection. It can be implemented (built-in) in the distance protection function or available as separate function.

4.6.4 Voltage transformer (VT) signal failure (loss of voltage)

Loss of one or several secondary voltages, without equivalent loss of respective primary voltage signal (s), is called VT signal failure. This event can cause distance protection

function to trip instantaneously. The VT signal failure condition is usually detected and the distance protection blocked by the VT signal failure detection function. VT signal failure detection can be implemented internal to the distance protection relay or it can be an external device in which case the blocking is achieved by energizing a relay binary input signal or via communications between the VT signal failure detection relay and the distance relay. The relay may trip if the blocking signal reaches the distance protection function too late.

4.6.5 Power swings

Power swing is defined as a variation in three-phase power flow which occurs when the generator rotor angles are advancing or retarding relative to each other in response to changes in load, line switching, loss of generation, faults, and other system disturbances. When a generator, or group of generators, terminal voltage phase angles go past 180° with respect to the rest of the connected power system the generator or group of generators are in out of step (or pole slip) with the rest of the power system.

A power swing is considered stable if the generators do not slip poles and the system reaches a new state of equilibrium. If the generators are experiencing pole slip condition then the power system is considered as unstable. The impedance trajectory during power swings may encroach the relay characteristics. If the measured impedance trajectory stays in the distance relay zone for sufficient time the relay will issue a trip signal.

4.6.6 Behavior during frequencies outside of the operating range

In system emergency conditions and black start conditions it is important to understand the behaviour of the distance relay when the frequency is outside of the operating range. Manufacturers shall declare the behaviour of the distance relay when the frequency is outside of the operating range.

5 Performance specifications

5.1 General

Since this standard specifies the minimum requirements for distance protection, only the performance specifications appropriate for meeting these minimum requirements are considered and presented here. The standard also defines how the performance related to these minimum requirements shall be documented by the manufacturer. The manufacturer generally performs a much wider set of tests and produces a large amount of data to ensure the performance of its protection device.

5.2 Effective and operating ranges

Table 1 shows, with an example, how effective range and operating range shall be declared by the manufacturer. Depending on the relay technology, the range can differ from the given table, 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 1. The behaviour of the distance protection outside the effective range shall be declared by the manufacturer.

Table 1 – Example of effective and operating ranges of distance protection

Quantity	Effective range	Operating range
Current	20 % to 1 000 % of rated current	20 % to 4 000 % of rated current
Voltage	5 % to 150 % of rated voltage	2 % to 200 % of rated voltage
Frequency deviation	-2 % to +2 % of rated frequency	-5 % to +5 % of rated frequency

5.3 Basic characteristic accuracy under steady state conditions

5.3.1 General

The purpose of this subclause is to provide a measure of the characteristic shape and its inherent accuracy. Test methods that shall be used for this assessment are described in Clause 6 and the manufacturer shall declare the specific method used.

Annex C provides a setting example for a radial feeder. The manufacturer as a minimum shall provide the settings for the equipment in order to fulfil the requirements given in Annex C.

The manufacturer shall declare the basic error of the operating characteristics in the R - X impedance plane within the declared effective range. An example specification of accuracy for a quadrilateral/polygonal characteristic is shown in Figure 2. Similar description can be provided for other characteristics. The basic accuracy is denoted by two parameters ε_R and ε_X . If the ratio between the settings in the X - and R - direction differs significantly from the conditions defined in Clause 6, the error for the quadrilateral/polygonal characteristic may increase. For this reason, the manufacturer may optionally specify a reduced accuracy for these conditions.

NOTE In cases where the limits of the characteristic are not perpendicular to the R - and X -axes, the values ε_R and ε_X are not exactly the errors of the resistive and reactive components. They are however still related to the resistive and reactive components.

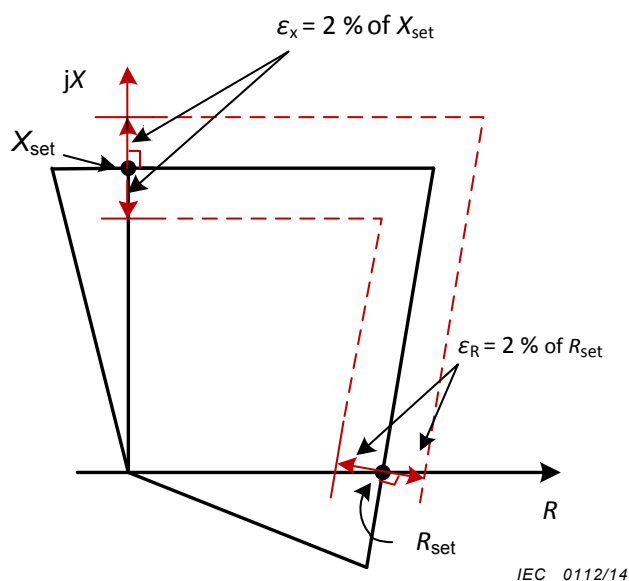


Figure 2 – Basic accuracy specification of an operating characteristic

Figure 3 describes the graphical description of angular accuracy of directional lines (example: forward direction), if available in the device.

5.3.2 Determination of accuracy related to time delay setting

These tests are aimed at determining the accuracy of the timers for time delayed distance protection zones. They are based on monitoring the time difference between the start and operate output signals of the relay.

Details on how these tests are conducted are given in Clause 6.

5.3.3 Disengaging time

For line distance protection applications it may be important to consider the disengaging time of the distance protection zone when the fault current is interrupted. This information has an impact on the time grading of back-up zone, on communication schemes (weak-end infeed, blocking, fault current reversal). The manufacturer shall declare the disengaging time of the protection relay according to the test procedure described in Clause 6.

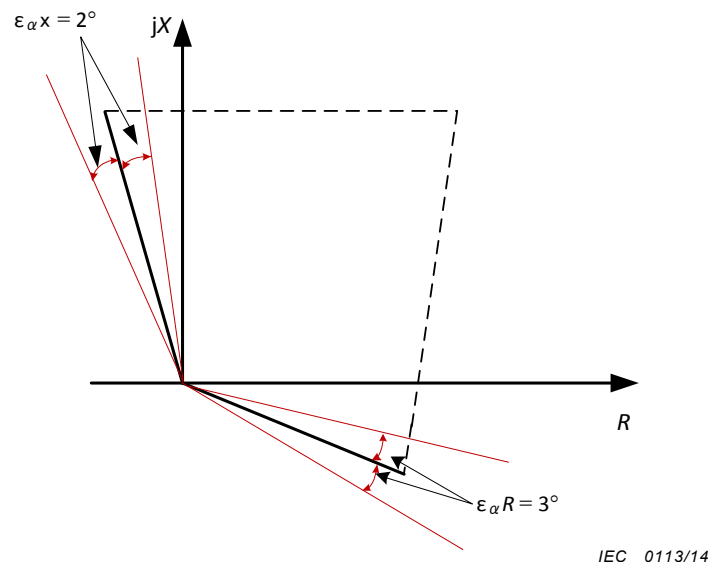


Figure 3 – Basic angular accuracy specifications of directional lines

5.4 Dynamic performance

5.4.1 General

Dynamic performance represents the response of the protection function to various power system conditions (such as electrical faults). Testing to verify the response of the protection relay for dynamic power system conditions usually requires a power system network simulator. Clause 6 provides details of the power system network model for the simulation.

When the relay input signals are simulated with steady state pre-fault conditions, followed by a fault condition (transient and steady state conditions) the test is called a dynamic test. In this case the simulation considers linear CT and VT models. The power system is represented by an R-L circuit and the capacitance is neglected. The response of the distance protection function to the above tests is called dynamic performance. The results of dynamic performance tests are represented in the so called SIR diagrams, where it is possible to see the effect of source impedance ratio on the operate time and on the transient overreach. For the transient overreach itself, a particular test shall be performed in order to be able to compare data from different manufacturers.

In addition, the performance of the distance protection during dynamic fault conditions (such as evolving faults, cross country faults, superimposing of load currents on fault currents during faults with relevant fault resistance, etc.) needs to be declared by the manufacturer.

5.4.2 Transient overreach (TO)

The steady state tests for the basic accuracy of the distance protection characteristic and the SIR (source impedance ratio) diagrams show the effect of steady state and transient errors; in order to allow the user to have comparison among different manufacturers it is beneficial to keep the steady state and transient errors separately, hence a specific test for the measurement of the transient overreach (TO) is provided in this standard.

The transient overreach can be defined as a measure of accuracy of a distance protection element under dynamic fault conditions. These tests aim to detect a fault position where the underreaching and instantaneous zone 1 always operates (*XST*), and a fault position where the same zone 1 never operates (*XNT*), while the distance protection zone 1 settings are kept constant.

The transient overreach is defined as:

$$TO = \frac{XNT - XST}{(XNT + XST)/2} \cdot 100 \%$$

A detailed description on how to perform transient overreach tests is available in Clause 6, where tests are performed considering different source impedance ratios and include the presence of capacitor voltage transformer (CVT) model.

5.4.3 Operate time and transient overreach (SIR diagrams)

Distance protection source impedance ratio (SIR) diagrams provide a description of the operate time of the protection function zone 1, as a function of the fault position and the ratio between equivalent source impedance and the reach of the tested protection zone. The diagrams also provide an indication of the transient overreach, which is the area of the SIR diagram beyond the setting reach of the relay (100 %). The manufacturer shall publish SIR diagrams for one short and for one long line with minimum, mean and maximum operate times shown for LN, LL, LLL and LLN faults. Diagrams shall be published at the rated power system frequencies for which the device is designed and in accordance with IEC 60255-1. Figure 4 gives an example of a SIR diagram. More comprehensive information about test methodology is provided in Clause 6.

5.4.4 Operate time and transient overreach (CVT-SIR diagrams).

To determine the effect of capacitor voltage transformers on the distance protection function operate time and transient overreach, CVT-SIR diagrams are introduced. In this case the network model and test procedures are the same as that of the SIR diagrams and the only addition being the CVT model. It is assumed that the current transformers are dimensioned according to the relay manufacturer's recommendations and hence an ideal current transformer model is used in the simulation.

Distance protection SIR diagrams, when CVT effect is considered are called distance protection CVT-SIR diagrams.

The diagram is published for one short line. Minimum, and maximum operate times are published, for LN, LL, LLL and LLN faults. This means that a total of 12 SIR diagrams will be published for the CVT dynamic performance testing.

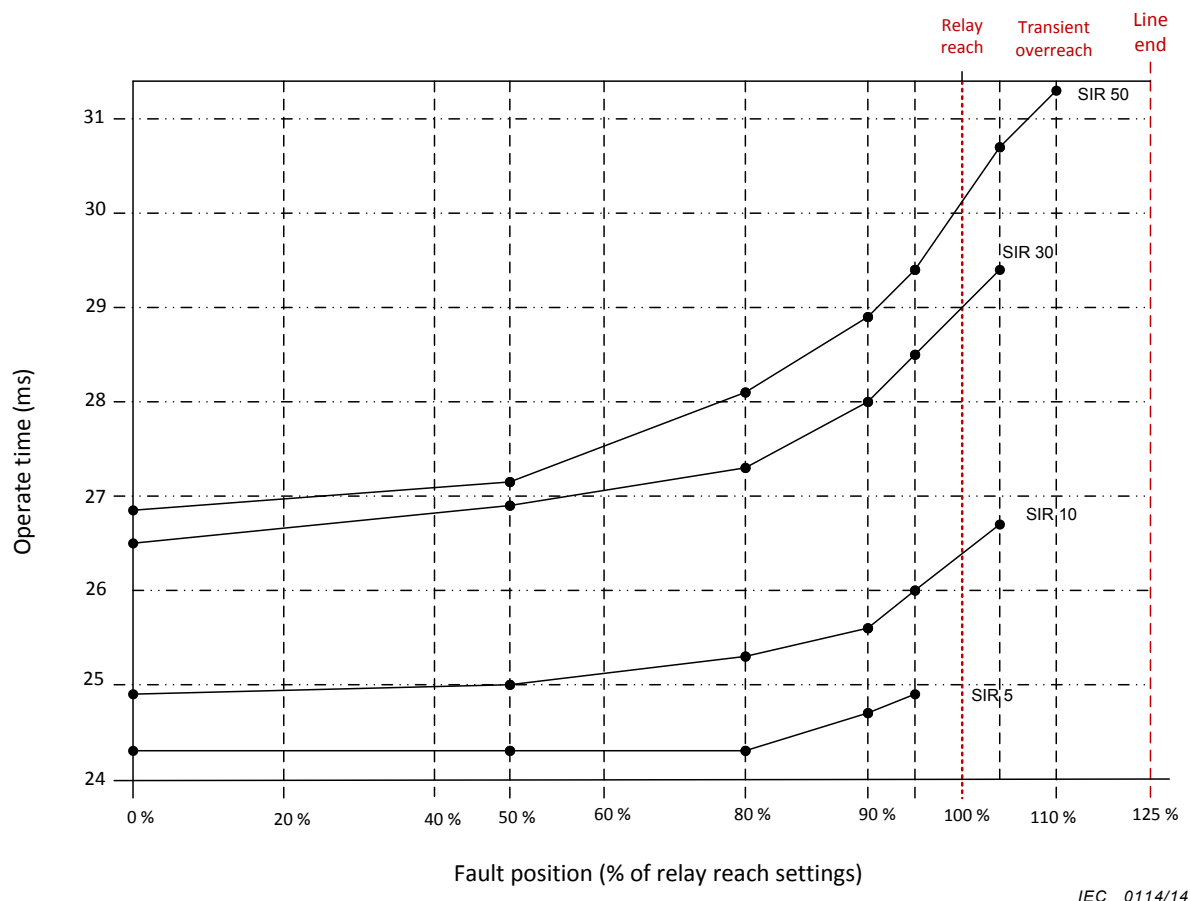
Clause 6 will describe in detail how the CVT-SIR diagrams shall be obtained and how the results shall be published.

5.4.5 Typical operate time

The operate time (trip time) of a distance protection function depends upon a number of factors:

- fault current level,
- distance to fault,
- source impedance ratio (SIR),
- magnitude and time constant of DC component,
- type of fault.

The typical operate time (median operate time as defined in Clause 6) shall be published by the manufacturer which is a statistical representation of different operate times registered during the dynamic tests performed for the SIR diagrams. The manufacturer shall provide the median operate time of these tests as a statistical indicator of typical operate time. In addition, a graphical representation of the complete set of tests shall be provided with the mean, mode and median values indicated.



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Figure 4 – SIR diagram – Short line average operate time

The typical operate time shall be published at the rated power system frequencies for which the device is designed and in accordance with IEC 60255-1.

More comprehensive information about test methodology is provided in Clause 6. Detailed description of the statistical terminology is provided in Annex D.

5.5 Performance with harmonics

5.5.1 General

Non-linear load conditions or nearby presence of a HVDC network create the presence of harmonics superimposed on the fundamental frequency of the voltages and currents measured by the distance protection relay. The presence of harmonics on a steady state load can be simulated by steady state injection, and may affect the basic accuracy of the distance protection relay, while the effect of harmonics during power system faults may result in delayed operation of the relay or additional transient overreach.

In order to determine the effect of harmonics on relay operate time and overreach, a transient power system simulation is necessary.

5.5.2 Steady-state harmonics tests

The purpose of this subclause is to provide a measure of the inherent accuracy of the distance protection characteristic close to the load area (resistive reach) when a steady state harmonic component is superimposed on the fundamental frequency component.

Low steady state accuracy in the presence of harmonics during load conditions may cause the relay to issue unnecessary start indication or unwanted operate signals.

More comprehensive information about test methodology is provided in Clause 6.

5.5.3 Transient LC oscillation tests

These tests are intended to verify the effect of harmonics under fault conditions on the relay operate time and transient overreach. In order to simulate the harmonics during fault conditions a resonant RLC circuit is used. The capacitance is positioned behind the relay point; the inductance and the resistance are represented by the fault impedance. Results of these tests are represented with SIR diagrams which are centred around 100 % of the relay setting (reach) at the fundamental frequency.

A power system network simulator is required to perform these tests. More comprehensive information about test methodology is provided in Clause 6.

5.6 Performance during frequency deviation

5.6.1 General

Purpose of these tests is to verify the relay performance when the frequency of the energizing quantities deviates from the nominal value. The influence of frequency deviation is determined by means of testing accuracy when the frequency of the characteristic quantity is set to the off-nominal values.

5.6.2 Steady state testing during frequency deviation

The steady state characteristic accuracy during frequency deviation is measured in the same way as the tests used for basic characteristic accuracy. For quadrilateral/polygonal characteristic, only two points of the characteristic are considered, one on the reactive reach and one on the resistive reach. For MHO characteristic, only one point is considered and it is the reach along the impedance angle setting.

The accuracy is measured at the effective range values and the operating range values. The characteristic reference graph at the tested frequency will depend on the relay algorithm used to measure the impedance (reactance based or inductance based).

- For the reactance based algorithm (non frequency compensated), the reference graph will be the same as the one used for the nominal frequency.
- For inductance based algorithm (frequency compensated) the reference graph will vary considering the effect of frequency deviation from the nominal value on the inductance setting.

More comprehensive information about test methodology is provided in Clause 6.

5.6.3 Transient testing during frequency deviation

Transient testing during frequency deviation will show how the relay behaves in terms of operate time and transient overreach when the power system frequency deviates from the nominal value.

The tests shall be performed at two different frequencies: $f_{\min}$ and $f_{\max}$, where:

- $f_{\min}$ = 98 % of the rated frequency,
- $f_{\max}$ = 102 % of the rated frequency.

If the effective range is narrower than the specified value, the minimum and maximum frequencies of the effective range shall be used.

Tests similar to the SIR diagrams are performed, and a power system network simulator is required. More comprehensive information about test methodology is provided in Clause 6.

5.7 Double infeed tests

5.7.1 General

The following tests determine the performance of the distance protection function during dynamic system conditions listed below:

- exporting/importing power,
- evolving faults,
- cross-country faults,
- current reversal condition.

A network simulator is required for performing the tests, as in some cases it is necessary to correctly simulate the power network behaviour after the operation of some remote circuit breakers and also after the operation of the tested relay (single phase or three-phase) in order to verify the performance of the relay under test. A real time network simulator may also be used to simulate the above conditions.

The manufacturer shall publish the results of the tests, with reference to the list of events of the protection signals described in 6.6. The tests do not have a definite pass/fail criteria and results are provided so that the user can study them to determine if the performance of the relay will suit a given application.

5.7.2 Single line, double infeed system

High voltage networks are characterized by supplying the fault current from both sides of the faulty line. Phase to earth (LN) and phase-phase-earth (LLN) faults, with a significant fault resistance, together with the superimposed transmitted electric power, create overreaching (exporting power) and underreaching (importing power) phenomena. Additionally for LLN faults the wrong faulty phase (phases) may be indicated by the relay.

More comprehensive information about the list of tests and the test methodology is provided in Clause 6.

5.7.3 Double line, double infeed system

5.7.3.1 General

With double lines (mutual coupling neglected between the two lines), the following cases shall be considered:

- current reversal condition,
- evolving faults,
- cross-country faults.

5.7.3.2 Current reversal

These tests are intended to determine the behaviour of the distance protection function for correctly cleared faults on a parallel line (seen by the relay as reverse fault) under exporting load conditions.

More comprehensive information about the tests is provided in 6.6.

5.7.3.3 Evolving faults

Evolving faults should be recognized and proper multiphase trip command shall be issued by the distance protection function. Faults can evolve from one phase into several phases, at the same fault position, or can evolve from one phase into other phases, at different line locations (example: forward to reverse).

Informative guide for the behaviour of timers in distance protection zones in case of evolving faults is presented in Annex B.

More comprehensive information about the tests is provided in 6.6.

5.7.3.4 Evolving faults (both lines affected)

For parallel overhead lines on the same tower, it is a well-known phenomenon that a fault occurs in one line, on one phase, and then jumps to the parallel line, involving maybe a different phase. In this condition distance protection function might fail in selecting the faulty phases in different zones jeopardizing the auto reclosing scheme.

More comprehensive information about the tests is provided in 6.6.

5.8 Instrument transformer (CT, VT and CVT) requirements

5.8.1 General

Instrument transformer requirements declared by the manufacturer shall include the effects on the distance protection function performance due to:

- capacitor voltage transformer response (if its use is allowed by relay manufacturer),
- current transformer saturation.

Capacitor voltage transformer influence on distance protection function behaviour is considered in SIR diagrams with CVT models.

5.8.2 CT requirements

This clause states how the relay manufacturers shall specify CT requirements for distance relays and the conditions that shall be fulfilled. Annex E provides information about CT saturation and the influence on the performance of distance relays.

For correct operations of distance protection, the CT shall have a minimum saturation voltage. The CT requirements shall be specified as a rated equivalent limiting secondary e.m.f. E_{al} according to IEC 61869-2. The required rated equivalent limiting secondary e.m.f. E_{alreq} depends on the application and on the design of the relay. E_{alreq} is defined as follows:

$$E_{alreq} = \frac{I_f}{I_{pr}} \cdot K_{tot} \cdot I_{sr} (R_{ct} + R_{ba})$$

where

- I_f is the maximum primary CT current for the considered fault case;
- I_{pr} is the CT rated primary current;
- I_{sr} is the CT rated secondary current;
- K_{tot} is the total over-dimensioning factor (including the transient dimensioning factor and the remanence dimensioning factor);
- R_{ct} is the CT secondary winding resistance;
- R_{ba} is the total resistive burden, including the secondary wires and all relays in the circuit.

Distance relay applications require that current transformers shall not saturate for a specific minimum time in order to have correct relay operation for faults. The required saturation free time is dependent on the relay design and can vary for different fault positions. The current transformer shall be over-dimensioned with the K_{tot} factor to guarantee the required saturation free time.

The relay manufacturer shall specify and provide the required K_{tot} factors for all fault positions specified in this document. These requirements shall be applicable to all versions of the relay including 50 Hz /60 Hz and 1 A/5 A.

By means of the required K_{tot} factors a user can calculate the E_{alreq} for the specific application and select a current transformer with a rated equivalent limiting secondary e.m.f. E_{al} that is larger than or equal to the required rated equivalent limiting secondary e.m.f. E_{alreq} . Annex G describes in detail the practical procedure for a user on how to dimension CTs for a distance protection application based on the specified current transformer requirements given by the relay manufacturer.

Basically four main fault positions are relevant for dimensioning the current transformers and shall be considered to specify the current transformer requirements. The fault positions are shown in Figure 5: close-in reverse (fault 1), close-in forward (fault 2), zone 1 underreach (fault 3) and zone 1 overreach (fault 4).

In principle there are three different types of current transformers.

- High remanence current transformer (e.g. class P, TPX). This current transformer has a closed core and can have a high level of remanent flux.
- Low remanence current transformer (e.g. class PR, TPY). This current transformer has small air gaps in the core and the remanent flux is limited to 10 % of the saturation flux (Ψ_{sat} according to IEC 61869-2).
- Non remanence current transformer (e.g. class TPZ). This current transformer has big air gaps in the core and there is no remanent flux.

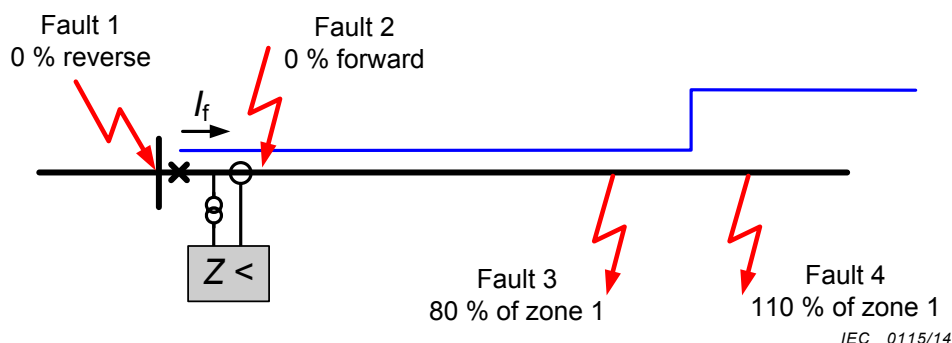


Figure 5 – Fault positions to be considered for specifying the CT requirements

The relay manufacturer shall provide current transformer requirements for the high remanence current transformer type considering zero percent remaining flux. Optionally the

relay manufacturer may also provide current transformer requirements considering remanence. In such cases it is recommended to consider the levels of remanence and remaining flux specified in Table 2. It is more important to consider remanence for the security cases than for the dependability cases as remanence can cause unwanted operation but never cause a failure to operate. When remanence is considered the importance and the priority of the different fault cases are shown in Table 2.

When specifying current transformer requirements, the manufacturer shall consider remanence/remaining flux as follows:

- a) normative/mandatory: remanence/remaining flux is not considered;
- b) option 1: remanence/remaining flux is considered for security cases and for trip on reclose (priority 1, according to Table 2);
- c) option 2: Remanence/remaining flux is considered also for dependability cases (priority 1 and 2, according to Table 2).

In this context, trip on reclose means that a function shall operate in case of fast automatic reclosing on to a fault.

Table 2 – Recommended levels of remanence in the optional cases when remanence is considered

Type of current transformer	Remanence/remaining flux in % of the saturation flux (Ψ_{sat})		
	Fault positions 2 and 3 (Dependability)		Fault positions 1 and 4 (Security)
	Zone measuring function	Trip on reclose	
	Priority 2	Priority 1	Priority 1
High remanence current transformer	75	75	75
Low remanence current transformer	10	60 ^a	60 ^a
Non remanence current transformer	0	0	0
^a Although the maximum level of remanent flux for a low remanence current transformer is stated not to exceed 10 % of the saturation flux 3 min after the interruption of a magnetizing current it is possible to have a much higher level of flux after a high speed reclosing attempt.			

The total over-dimensioning factor shall be specified for the four fault positions that are shown in Figure 5. The conditions and acceptance criteria for the different cases are specified below and the following conditions shall be valid for all four fault positions.

- Fault inception angles in the range that produce maximum DC offset and no DC offset shall be considered. (Maximum DC offset does not give the shortest time to saturation when the time to saturation < 15 ms (50 Hz)/12,5 ms (60 Hz) which is relevant for numerical distance protection.)
- Three-phase faults (L1L2L3) and phase to earth faults (L1N) shall be considered to cover both phase to phase measuring and phase to earth measuring elements. A residual compensation factor $K_N = 1$ shall be used. This means that the zero sequence impedance of the line is four times the positive sequence impedance.

Where:

$$K_N = \frac{Z_0 - Z_1}{3 \cdot Z_1}$$

- A ratio of the resistive and inductive reach of 3 shall be considered if the reach can be set individually for the zone. All settings of the distance relay shall remain the same for all fault cases.

Fault 1: Close-in reverse fault, security case:

$$E_{\text{alreqCrev}} = \frac{I_{\text{fCrev}}}{I_{\text{pr}}} \cdot K_{\text{totCrev}} \cdot I_{\text{sr}} (R_{\text{ct}} + R_{\text{ba}})$$

where

$E_{\text{alreqCrev}}$ is the required rated equivalent limiting secondary e.m.f. for fault 1;

I_{fCrev} is the symmetrical primary fault current through the CT for fault 1;

K_{totCrev} is the necessary total over-dimensioning factor for fault 1.

Criteria and additional conditions:

The distance protection shall not operate for close-in reverse faults. Fault current primary time constant (T_p) up to at least 100 ms shall be considered.

Fault 2: Close-in forward fault, dependability case:

$$E_{\text{alreqCfw}} = \frac{I_{\text{fCfw}}}{I_{\text{pr}}} \cdot K_{\text{totCfw}} \cdot I_{\text{sr}} (R_{\text{ct}} + R_{\text{ba}})$$

where

E_{alreqCfw} is the required rated equivalent limiting secondary e.m.f. for fault 2;

I_{fCfw} is the symmetrical primary fault current through the CT for fault 2;

K_{totCfw} is the necessary total over-dimensioning factor for fault 2.

Criteria and additional conditions:

The CT saturation shall not cause more than 1 cycle of additional time delay for any fault compared with the operate time for the same fault case but with a large current transformer so that no saturation occurs. Fault current primary time constant (T_p) up to at least 200 ms shall be considered.

Fault 3: Zone 1 underreach fault, dependability case:

$$E_{\text{alreqZone1U}} = \frac{I_{\text{fZone1U}}}{I_{\text{pr}}} \cdot K_{\text{totZone1U}} \cdot I_{\text{sr}} (R_{\text{ct}} + R_{\text{ba}})$$

where:

$E_{\text{alreqZone1U}}$ is the required rated equivalent limiting secondary e.m.f. for fault 3;

I_{fZone1U} is the symmetrical primary fault current through the current transformer for fault 3;

$K_{\text{totZone1U}}$ is the necessary total over-dimensioning factor for fault 3.

Criteria and additional conditions:

The CT saturation shall not cause more than 3 cycles of additional time delay for any fault compared with the operate time for the same fault case but with a large current transformer so that no saturation occurs, for faults at 80 % of the zone reach. Fault current primary time constant (T_p) up to at least 100 ms shall be considered.

Fault 4: Zone 1 overreach fault, security case:

$$E_{\text{alreqZone1O}} = \frac{I_{\text{fZone1O}}}{I_{\text{pr}}} \cdot K_{\text{totZone1O}} \cdot I_{\text{sr}} (R_{\text{ct}} + R_{\text{ba}})$$

where

- $E_{\text{alreqZone1O}}$ is the required rated equivalent limiting secondary e.m.f. for fault 4;
 I_{fZone1O} is the symmetrical primary fault current through the current transformer for fault 4;
 $K_{\text{totZone1O}}$ is the necessary total over-dimensioning factor for fault 4.

Criteria and additional conditions:

The distance protection shall not operate for faults at 110 % of the zone reach. Fault current primary time constant (T_p) up to at least 100 ms shall be considered.

The current transformer shall have a rated equivalent limiting secondary e.m.f. E_{al} that is larger than the maximum of the E_{alreq} for the four fault positions. The relay manufacturer shall report all required rated equivalent limiting secondary e.m.f. (E_{alreq}) equations including the corresponding total over-dimensioning factors K_{tot} that are necessary to cover all four fault positions. Normally the requirements for fault 3 and fault 4 can be combined to one requirement. It is also possible to combine requirements for close-in faults and zone 1 faults as long as they cover all four fault positions. However, combination of requirements for all fault positions can result in unnecessarily high CT requirements. Each relay manufacturer may decide to what extent he will combine the requirements for different fault positions.

The K_{tot} factor normally depends on the primary time constant and shall be given for the complete intervals of primary time constants specified in this document. The K_{tot} factors may alternatively be given as a graph/function depending on the primary time constant, as different values valid in subintervals or as one value valid for the complete range of the primary time constant. The manufacturer may decide what is suitable for the specific distance relay.

Annex F provides an informative guide describing an example test procedure to determine CT requirements for distance protection provided by the relay manufacturer.

6 Functional tests**6.1 General**

This clause gives a detailed description of the tests to be performed to verify the relay performance specification described in Clause 5. These tests are not intended for protection relay field commissioning or routine tests. These tests are, as explained in Clause 5, a mandatory part of the type-tests for the protection relay. 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 relay specifications given in the manufacturer's documentation. The test procedures in this clause are given as a sequence of steps in the form of a flowchart. The sequence shown is only as an example and the order of the sequence may vary.

6.2 Rated frequency characteristic accuracy tests**6.2.1 General**

The purpose of these tests is to measure the inherent accuracy of the characteristic shape for all operative zones of the distance function under quasi steady state conditions.

are not intended to prove any performance of the distance protection relay for a real application. The manufacturer shall declare the basic error of the operating characteristics in the R - X plane within the declared effective range of the protection relay. These tests may not be realistic from the power system protection point of view, but they determine the inherent characteristic accuracy of the device. The proposed tests should not be used as criteria for performance evaluation of the relay for a specific protection application.

The proposed test methods are to be preferred. If a particular 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. Tests are performed for all rated frequencies and for all rated currents of the protection relay. A rated voltage of 100 V (phase to phase) shall be selected. If a rated voltage of 100 V is not applicable then a rated voltage which is closest to 100 V shall be selected.

The flowchart shown in Figure 6 describes the test procedure for determining basic characteristic accuracy.

6.2.2 Basic characteristic accuracy under steady state conditions

6.2.2.1 General

Three significant points (A, B, and C) in the secondary effective range are chosen as shown in Figure 7. For each point the distance protection settings (see Annex H) are calculated. For each setting, which will define an impedance characteristic, the characteristic accuracy is checked for 10 test points in the first quadrant. The characteristic error detected with these ten points, will define the accuracy error for the reactive and resistive reaches, called ε_X and ε_R . For MHO characteristic, only one generic accuracy error is defined which is denoted as ε .

From the effective range in the phase-to-earth voltage (U) and current (I) plane as shown in Figure 7, three significant points (A, B and C) are chosen.

- Point A defines testing at constant current ($2 \times I_{\text{rated}}$), with variable (ramping) voltage.
- Point B defines testing at constant current (I_{min}), with variable (ramping) voltage.
- Point C defines testing at constant voltage (U_{min}), with variable (ramping) current.

The reference voltages used for Figures 7 and 8 are phase to earth voltages.

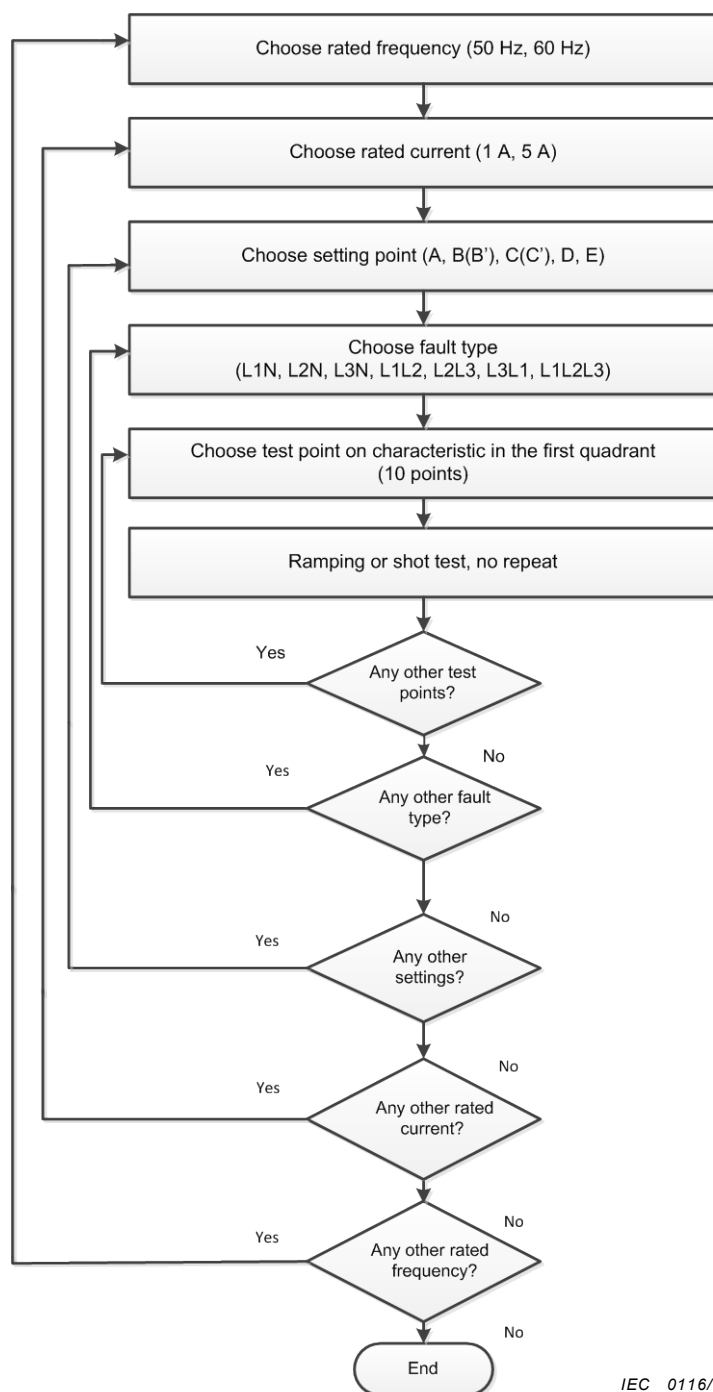


Figure 6 – Test procedure for basic characteristic accuracy

As shown in Figure 7, the setting range of the protection relay may not allow the calculated settings for points B and/or C. In this case points B' and C' will be considered, as shown in Figure 8.

"MAX setting range" and "MIN setting range" in Figures 7, 8, 9, and 10; in cases where the manufacturer guarantees the full accuracy only for a part of the total setting range, the setting limits of this part may be used here. In this case it has however to be indicated clearly by the manufacturer, that setting values outside these limits may lead to reduced accuracy.

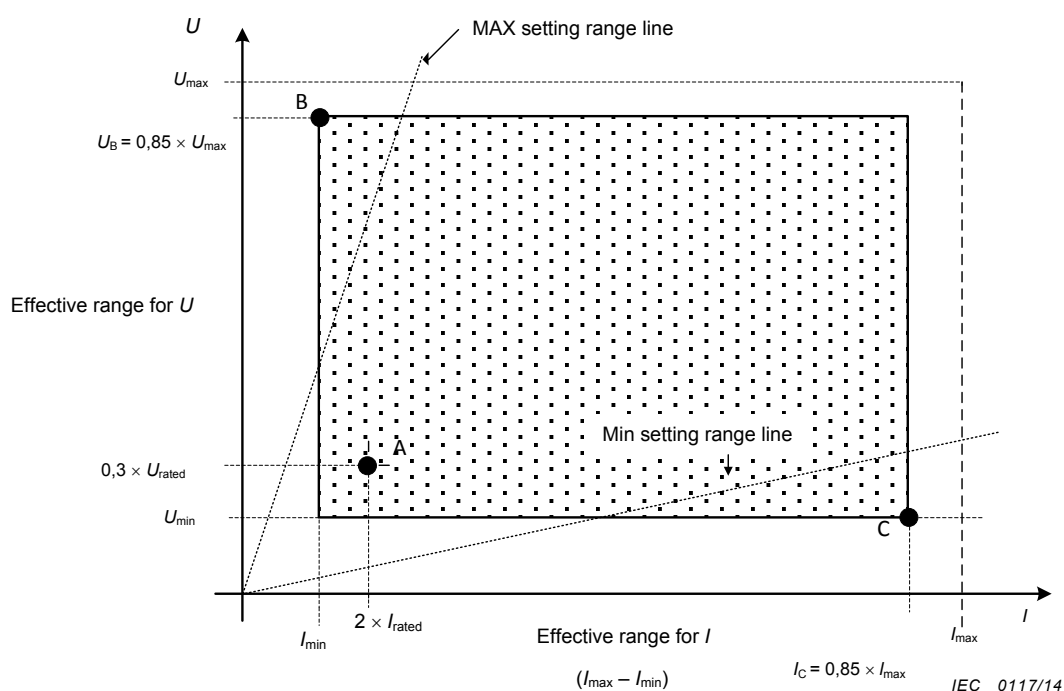


Figure 7 – Calculated test points A, B and C based on the effective range of U and I

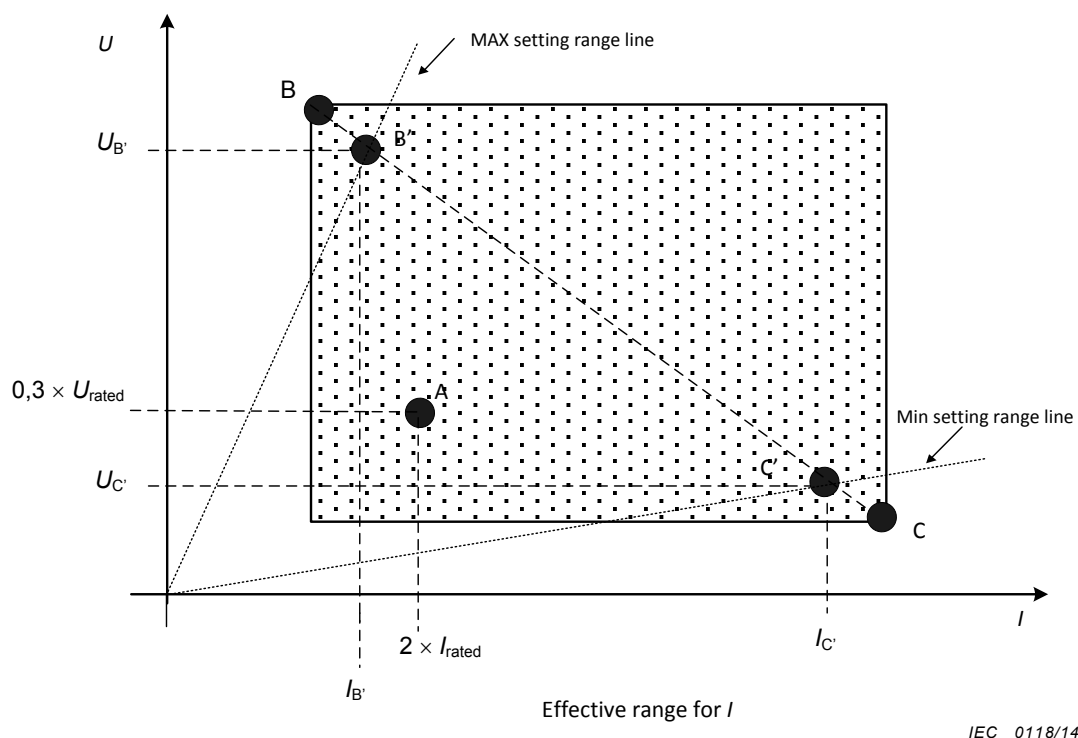


Figure 8 – Modified points B' and C' based on the limited setting range

Additional two test points, D and E, are considered, with the purpose of increasing the number of characteristic tests with different distance protection settings. Point D is located at the midpoint of the segment between A and B. Point E is located at the midpoint of the segment between A and C. If points B' and C' have to be used, points D and E are respectively located in the midpoint of segments AB' and AC'.

The positions of the two added points in the effective range are shown in Figures 9 and 10.

- Point D defines testing at constant current (I_D), with variable (ramping) voltage.
- Point E defines testing at constant current (I_E), with variable (ramping) voltage.

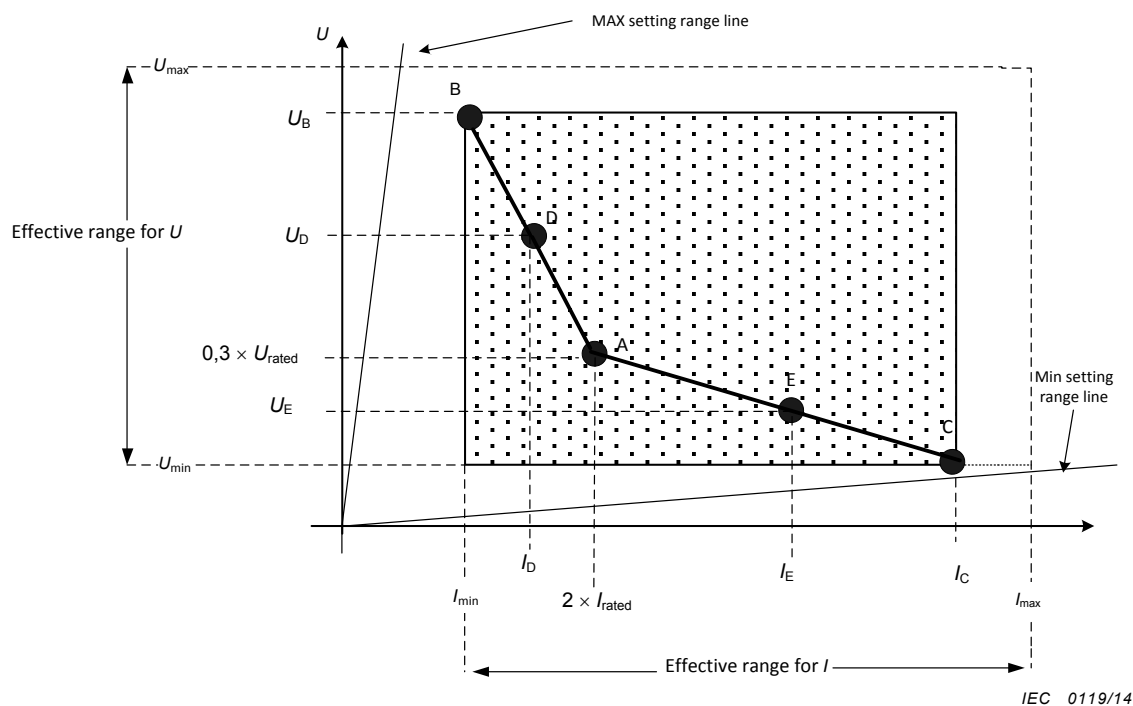


Figure 9 – Position of test points A, B, C, D and E in the effective range of U and I

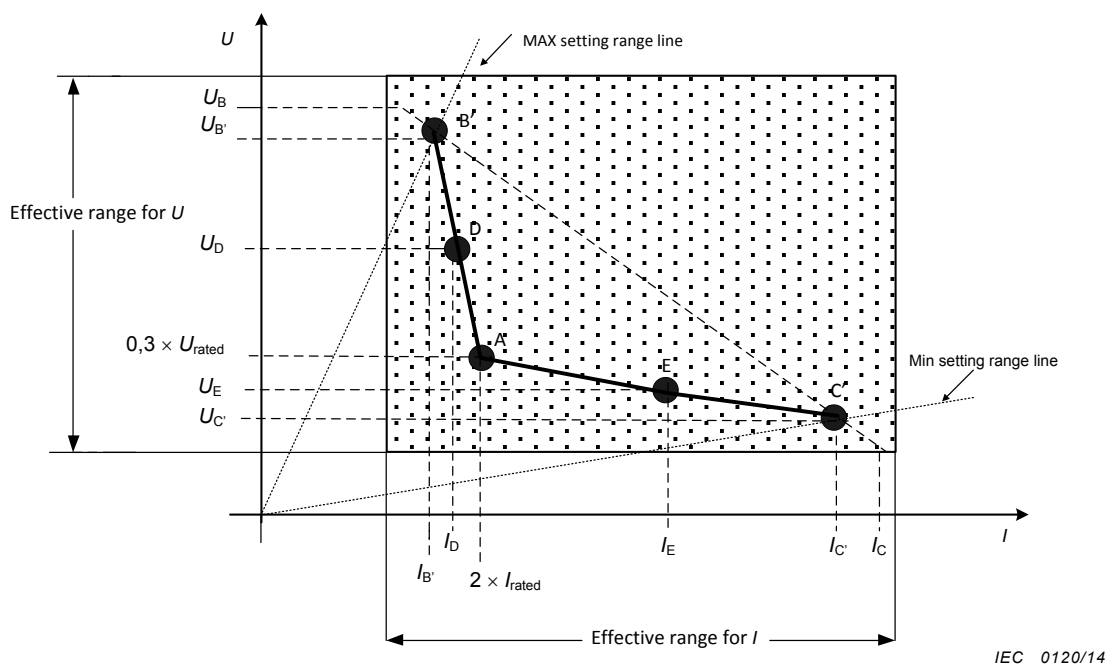


Figure 10 – Position of test points A, B', C', D and E in the effective range of U and I

6.2.2.2 Procedure for testing the generic test point P

6.2.2.2.1 General

In this subclause, the test procedure for testing a generic test point P in the effective range with coordinates U_P and I_P is given.

The relay settings that are defined by the point P are calculated according to the Annex H.

6.2.2.2.2 Characteristic tests

The distance protection function characteristic will be tested for all the following fault types:

L1N, L2N, L3N, L1L2, L2L3, L3L1, L1L2L3

where L1, L2, L3 designate the three phases and N designates the neutral/earth.

Distance protection zones that have a settable direction shall be set and tested in forward direction. The tests will only be done on the first quadrant.

Distance protection zones that can only be active in the reverse direction shall be tested in reverse direction, and the tests will only be done in the third quadrant.

Non directional zones that cannot be set as forward or reverse direction shall be tested only with forward fault injections (1st quadrant).

6.2.2.2.3 Test procedure for quadrilateral/polygonal characteristic

In this description a distance protection function characteristic area in the first quadrant is considered.

Ten test points will be selected, defined by lines starting from origin at angles 0° , 10° , 20° , ..., 90° , as shown in Figure 11.

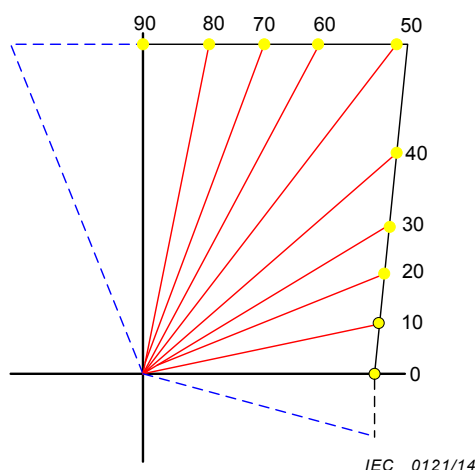


Figure 11 – Quadrilateral characteristic showing ten test points

From each defined test point, a ramp perpendicular to the characteristic will be drawn, as indicated in Figure 12.

If the characteristic has more complex shape additional points may be necessary to verify the accuracy of the characteristic. Depending on the point in the effective range (point A, point B

(or B') and point C (or C')) that has generated the characteristic, a different type of ramps will be requested:

- constant voltage ramp, where the voltage is kept constant and the current is changed as a function of the fault impedance;
- constant current ramp, where the current is kept constant and the voltage is changed as a function of the fault impedance.

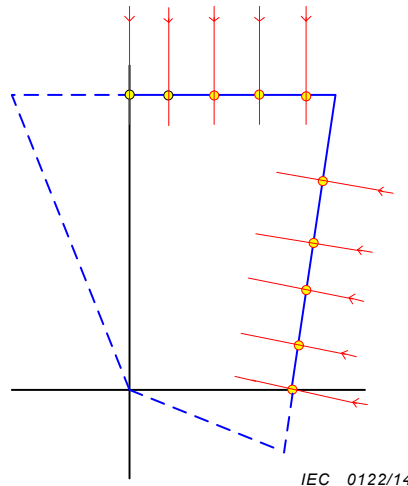


Figure 12 – Quadrilateral characteristic showing test ramps

The pick-up value will be determined at the instant when the distance zone issues the start signal (pick-up signal). The ramp can be a pseudo continuous ramp or a ramp of shots (pulse ramp or any searching algorithm). The ramping methods and the associated voltages and currents to the simulated impedance are described in Annex I. The manufacturer shall declare which ramping method has been used to test the basic accuracy.

Each defined test ramp, will give a measured characteristic operating point. The distances from the measured operating points and the characteristic border are denoted as e_{X1} , e_{X2} , ..., e_{Xn} for reactive border, and e_{R1} , e_{R2} , ..., e_{Rm} for resistive border. The maximum absolute value of e_{Xi} defines the characteristic error, e_X , for the reactive border, and the maximum absolute value of e_{Ri} defines the characteristic error e_R for the resistive border, as shown in Figures 13 and 14. The Figure 13 a) shows a case where positive errors are larger than negative errors. If a negative error will have the largest magnitude then that error will define the accuracy.

Figure 13 a) shows an example where the accuracy limit is defined by errors outside the trip characteristic. Figure 13 b) shows an example where accuracy limits are defined by errors inside the trip characteristic for the reactive border, and outside the trip characteristic for the resistive border. Figure 14 shows the result for a quadrilateral/polygonal characteristic. Note that the points indicated by “set” maybe intended as directly settable or indirectly obtained by the rely zone settings.

Finally, the percentage accuracy is given by the formulae:

$$\varepsilon_X = (e_X / X_{\text{set}}) \times 100$$

$$\varepsilon_R = (e_R / R_{\text{set}}) \times 100$$

where X_{set} and R_{set} are read directly on the plotted graph of the characteristic.

The maximum errors ε_X and ε_R are obtained considering all different fault types (L1N, L2N, L3N, L1L2, L2L3, L3L1 and L1L2L3) and they will be the accuracy errors associated with the generic test point P.

6.2.2.2.4 Test procedure for MHO characteristic

MHO characteristic expansion due to source impedance variation is not considered in these tests.

In this description a distance protection function characteristic area in the first quadrant is considered.

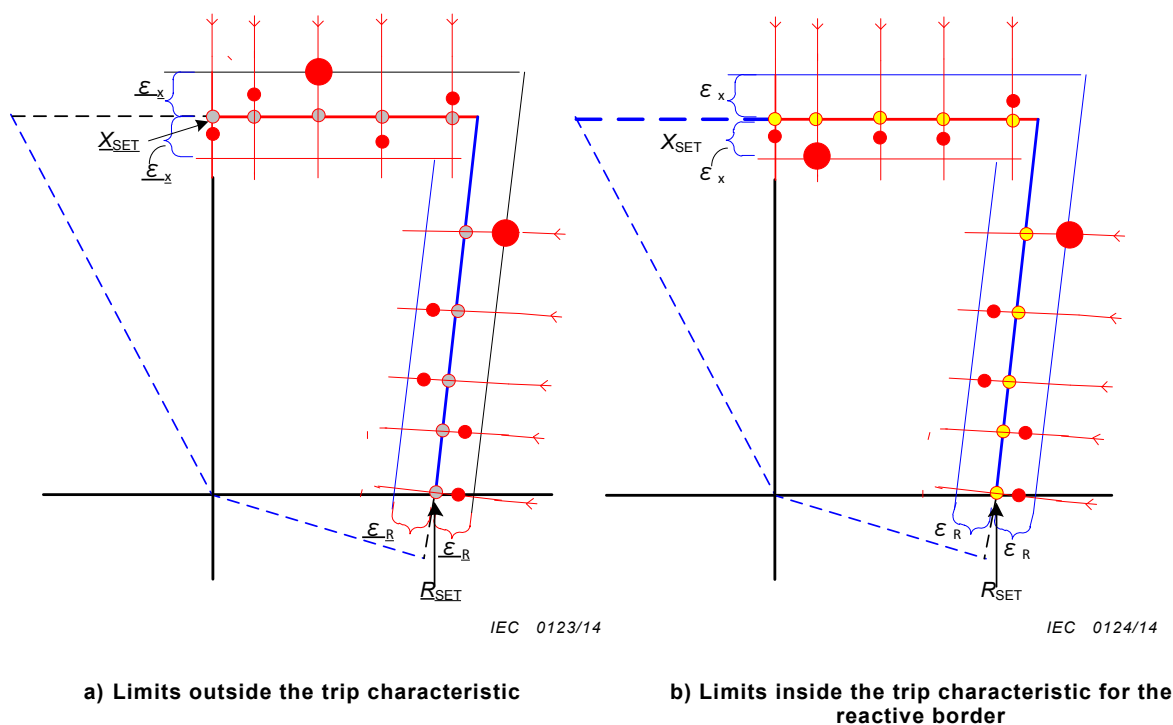


Figure 13 – Quadrilateral characteristic showing accuracy limits

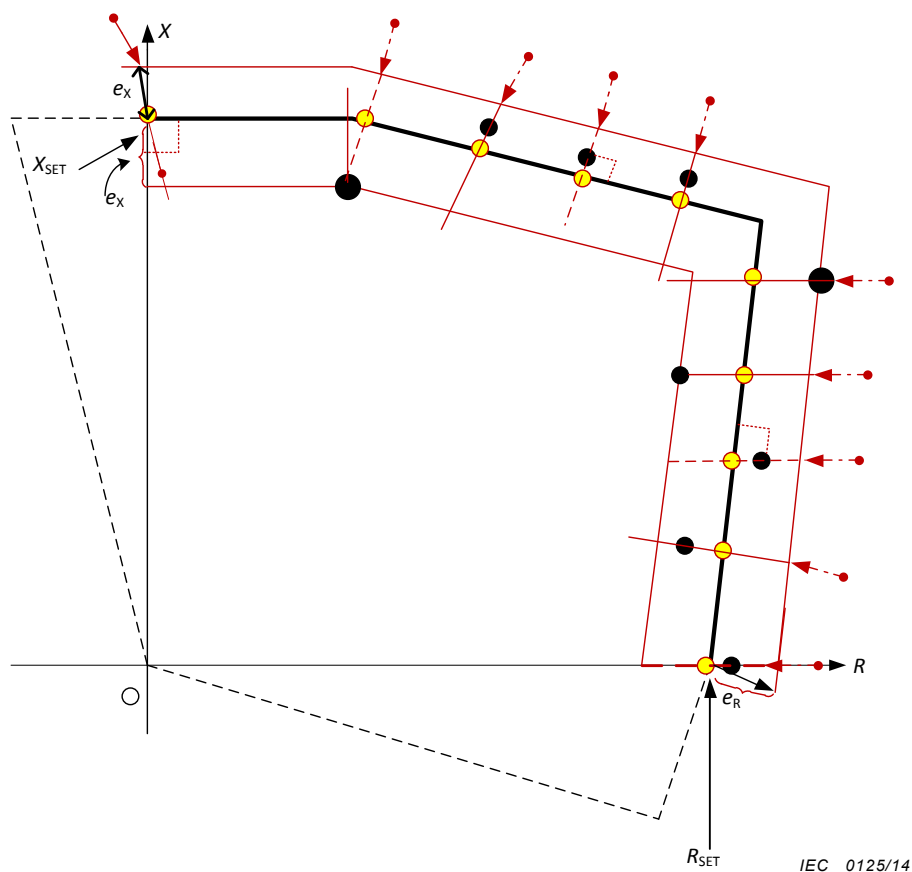


Figure 14 – Quadrilateral/polygonal characteristic showing accuracy limits

Nine test points will be selected, defined by lines starting from origin at angles 10° , 20° , ..., 90° , as shown in Figure 15.

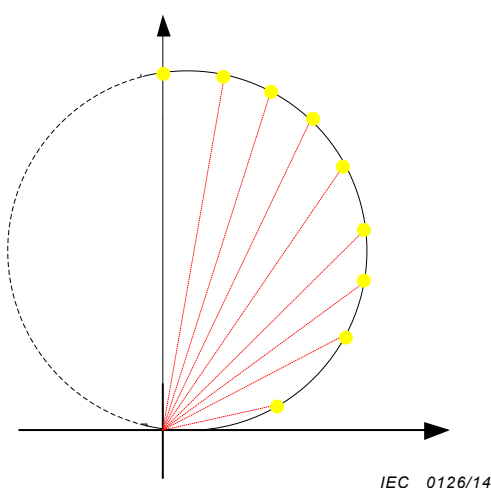


Figure 15 – MHO characteristic showing nine test points

From each defined test point, a ramp perpendicular to the characteristic will be drawn, as indicated in Figure 16.

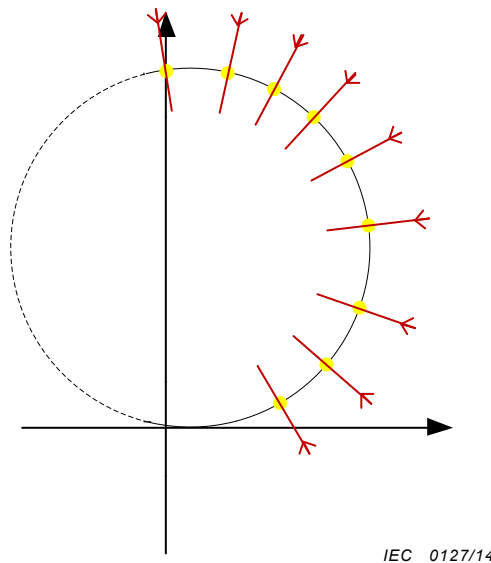


Figure 16 – MHO characteristic showing test ramps

Depending on the point in the effective range (point A, point B (or B') and point C (or C')) that has generated the characteristic, different type of ramps will be requested:

- constant voltage ramp, where the voltage is kept constant and the current is changed as a function of the fault impedance;
- constant current ramp, where the current is kept constant and the voltage is changed as a function of the fault impedance.

The pick-up value will be determined at the instant when the distance zone issues the start signal (pick-up signal). The ramp can be a pseudo continuous ramp or a ramp of shots (pulse ramp or any searching algorithm). The ramping methods and the associated voltages and currents to the simulated impedance are described in Annex I. The manufacturer shall declare which ramping method has been used to test the basic accuracy.

Each defined test ramp, will give a measured characteristic operating point. The distances from the measured operating points and the characteristic border are denoted as $e_1, e_2, \dots, e_n$. The maximum absolute value of e_i defines the characteristic error, e , for the characteristic, as shown in Figure 17.

Figure 17 a) shows an example where the accuracy is determined by one measured point outside the trip characteristic. Figure 17 b) shows a similar example, where the accuracy is determined by a measured point inside the trip characteristic.

Finally, the percentage accuracy is given by the formula:

$$\varepsilon = e / Z_{\text{set}} \times 100$$

where Z_{set} is the Z reach at the line angle of 85° as shown in Figures 17 a) and 17 b).

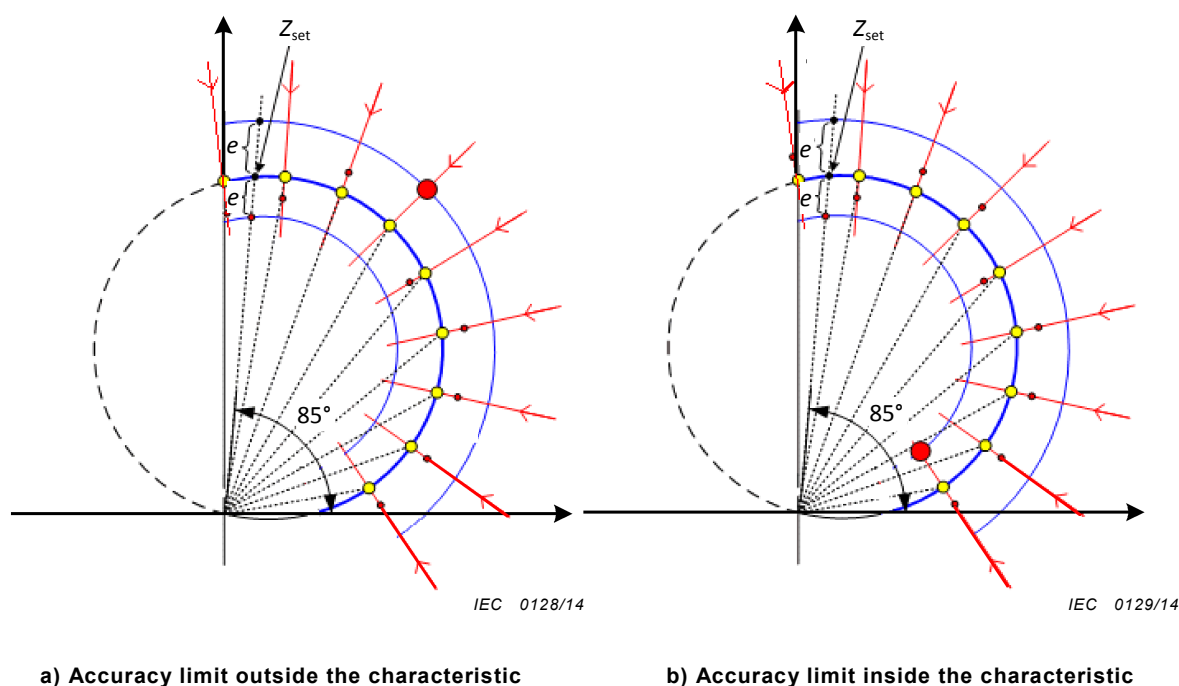


Figure 17 – Accuracy limits for MHO characteristic

The maximum error obtained considering all different fault types will be the accuracy error associated with the generic test point P in the effective range.

6.2.2.3 Test procedure for test point A

Settings calculation

Settings for the distance protection zone are calculated by considering the impedance associated with point A in Figure 9:

$$Z_A = (0,3 \times U_{\text{rated}}) / (2 \times I_{\text{rated}})$$

Protection function settings are calculated using the procedure given for generic test point P, described in Annex H.

Test procedure

The impedance will be injected by keeping the value of the injected current constant at a value of $2 \times I_{\text{rated}}$. The test procedure is as described for the generic point P (Annex I).

Percentage accuracy will be calculated for test point A.

6.2.2.4 Test procedure for test point B (or B')

Settings calculation

Settings for the distance protection zone will be calculated by considering the impedance associated with point B in Figure 9 or point B' in Figure 10.

$Z_B = (U_B) / (I_B)$ or $Z_{B'} = (U_{B'}) / (I_{B'})$ if point B' is chosen because of setting range limitation.

Where U_B is 85 % of the maximum voltage value of the effective range, and $I_{\min}$ is the minimum current value of the effective range of the distance protection.

Protection function settings are calculated using the procedure given for generic test point P (Annex H).

Test procedure

The impedance will be injected by keeping the value of the injected current constant at a value of $I_{\min}$ (or $I_{B'}$). The test procedure is as described for the generic test point P (Annex I).

During ramping if the voltage goes above the effective range of the protection relay then the ramp can be skipped in the test and the next ramp can be considered.

Percentage accuracy will be calculated for test point B (or B').

6.2.2.5 Test procedure for test point C (or C')

Settings calculation

Settings for the distance protection zone are calculated by considering the impedance associated with the test point C in Figure 9 or point C' in Figure 10.

$Z_C = (U_{\min}) / (I_C)$ or $Z_{C'} = (U_{C'}) / (I_{C'})$ if point C' is chosen because of setting range limitation;

where

$U_{\min}$ is the minimum voltage value of the effective range, and

I_C is 85 % of the maximum current value of the effective range of the distance protection.

Protection function settings are calculated using the procedure given for generic test point P (Annex H).

Test procedure

The impedance will be injected by keeping the value of the injected voltage constant at the value of $U_{\min}$ (or $U_{C'}$). The test procedure is as described for the generic point P (Annex I).

It is important to pay attention to the thermal capability of the protection relay, during repeated current injection that is required for ramping tests. It may be necessary to switch off the current after several injection steps and restart the testing after a time delay considering the duty cycle of the injected current to remain below the thermal capability of the relay.

Percentage accuracy will be calculated for test point C (or C').

Because of the practical complexity of this test, it is sufficient to measure the basic accuracy only for the following points:

- pure resistive reach and pure reactive reach points for the quadrilateral/polygonal characteristic, determining ε_R and ε_X ;
- at 85° impedance angle for the MHO characteristic, determining ε .

6.2.2.6 Test procedure for test point D

Settings calculation

Settings for the distance protection zone are calculated by considering the impedance associated with point D in Figure 9.

$$Z_D = (U_D) / (I_D)$$

where U_D and I_D are the coordinates of point D in the effective range of the distance protection.

Protection function settings are calculated using the procedure given for generic test point P (Annex H).

Test procedure

The impedance will be injected by keeping the value of the injected current constant at a value of I_D . The test procedure is as described for the generic test point P (Annex I).

Percentage accuracy will be calculated for the test point D.

6.2.2.7 Test procedure for test point E

Settings calculation

Settings for the distance protection zone will be calculated by considering the impedance associated with point E in Figure 9:

$$Z_E = (U_E) / (I_E)$$

where U_E and I_E are the coordinates of point E in the effective range of the distance protection.

Protection function settings are calculated using the procedure given for generic test point P (Annex H).

Test procedure

The impedance will be injected by keeping the value of the injected current constant at a value of I_E . The test procedure is as described for the generic point P (Annex I).

It is important to pay attention to the thermal capability of the protection relay, during repeated current injections that is required for ramping tests. It may be necessary to switch off the current after several injection steps and restart the testing after a time delay considering the duty cycle of the injected current to remain below the thermal capability of the relay.

Percentage accuracy will be calculated for test point E.

Because of the practical complexity of this test, it is sufficient to measure the basic accuracy only for the following points:

- pure resistive reach and reactive reach points for the quadrilateral/polygonal characteristic, determining ε_R and ε_X ;
- at 85° impedance angle, for the MHO characteristic, determining ε .

6.2.2.8 Reporting of the basic characteristic accuracy

The basic characteristic accuracy values shown in this subclause are only examples and the format of the report is presented here.

For quadrilateral/polygonal characteristic, the format of the test report shall be as shown in Tables 3 and 4.

Table 3 – Basic characteristic accuracy for various points (quadrilateral/polygonal)

Points in the effective range	ε_X	ε_R
Point A	1,9 %	2,1%
Point B	2,4 %	2,6%
Point C	2,3 %	2,4 %
Point D	2,0 %	2,2 %
Point E	2,1 %	2,3 %

From Table 3, the characteristic accuracy shall be published as shown in Table 4.

Table 4 – Overall basic characteristic accuracy (quadrilateral/polygonal)

Basic characteristic accuracy ε_X	$\pm 2,4 \%$ Corresponds to 2,5 % band
Basic characteristic accuracy ε_R	$\pm 2,6 \%$ Corresponds to 5 % band

The reported error in Table 4 is the largest measured error from Table 3.

For MHO characteristic the reported data is only one value and the format of the test report shall be as shown in Table 5.

Table 5 – Basic characteristics accuracy for various points (MHO)

Points in the effective range	ε
Point A	1,9 %
Point B	2,7 %
Point C	2,4 %
Point D	2,0 %
Point E	2,3 %

The basic characteristic accuracy shall be published as shown in Table 6.

Table 6 – Overall basic characteristic accuracy (MHO)

Basic characteristic accuracy ε	$\pm 2,7 \%$ Corresponds to 5 % band
---	---

The reported error in Table 6 is the largest measured error from Table 5.

Tests are performed at the rated voltage (example 100 V), all rated frequencies and all rated currents of the protection relay.

Together with the given tables the manufacturer shall specify the ramping method used for the tests (pseudo-continuous ramp or ramp of shots, as described in Annex I).

6.2.3 Basic directional accuracy under steady state conditions

6.2.3.1 General

Purpose of these tests is to define the angular accuracy of the directional lines for the distance protection device. This test is applicable for any distance protection function with directional supervision.

With reference to basic characteristic accuracy test points in the effective range, only test point A is considered for these tests. Tests are performed at a rated voltage (example 100 V), all rated frequencies and all rated currents of the protection relay. Faults will be injected according to the sequence described by the flowchart in Figure 18.

6.2.3.2 Test point A

Protection function settings

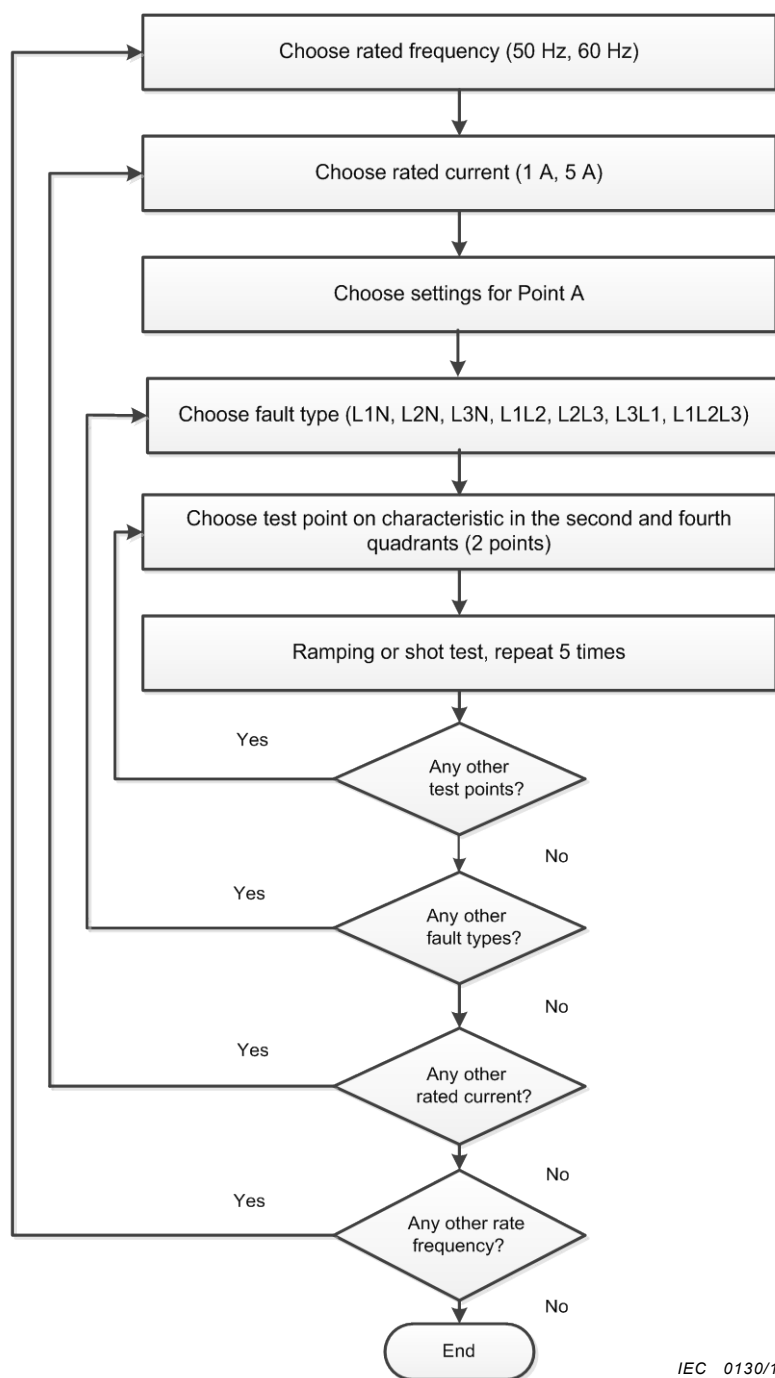
Protection function settings are the same that have been used for the test point A for basic accuracy tests. Additionally, directional line settings are the settings suggested by the relay manufacturer for the most typical application.

Directional characteristic tests

The characteristic of the directional lines will be tested for all of the following fault types:

L1N, L2N, L3N, L1L2, L2L3, L3L1, L1L2L3

Injected quantities representing the above faults are the same as defined for the basic characteristic accuracy tests.



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Figure 18 – Basic directional element accuracy tests

Directional element accuracy tests in the second quadrant

The characteristic line in the second quadrant is tested as shown in Figure 18. The impedance trajectory for this test is circular with the origin of the circle in the R/jX characteristic origin.

The impedance will be injected by keeping the value of the injected current constant at a value of $2 \times I_{\text{rated}}$. The voltage magnitude is selected such that the reactance is 80 % of the setting (X_{set}) along the positive jX axis as shown in Figure 19.

The injected impedance is kept constant in magnitude, and its angle is varied. The angle is varied by steps that are smaller than 10 % of the declared angle accuracy. The ramp can be a pseudo continuous ramp, a ramp of shots (pulse ramp), or a more advanced search algorithm

with shots like a binary search. The start of the impedance ramp is selected as shown in Figure 19. For the test methods ramp of shots (pulse ramp), or a more advanced search algorithm with shots like a binary search, the initial conditions and the reset conditions (between the shots) are rated voltage and zero current.

Each injection will last for a time period longer than 5 times the typical operate time of the protection function (if the typical operate time is 20 ms, then each injection step will be at least 100 ms long).

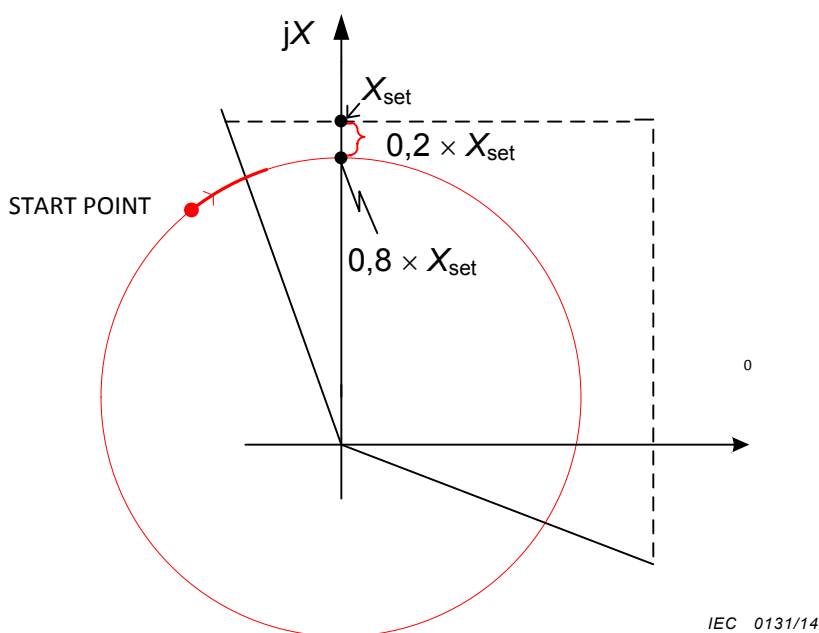


Figure 19 – Directional element accuracy tests in the second quadrant

The injection will stop when the tested distance protection zone issues the start signal. The angle of the injected impedance at the instant of the start signal is reported and the difference between the theoretical angle and the measured angle is the measured error in degrees.

Test results (e_{dir2}) are reported for each fault type as indicated in Figure 20.

The largest absolute error e_{dir2} obtained for all different fault types (L1N, L2N, L3N, L1L2, L2L3, L3L1, L1L2L3) shall be documented and the maximum value from these tests shall be declared as the basic directional accuracy.

Directional element accuracy tests for the fourth quadrant

The characteristic line in the fourth quadrant is tested as shown in Figure 21. The impedance trajectory for this test is circular with the origin of the circle in the R/jX characteristic origin.

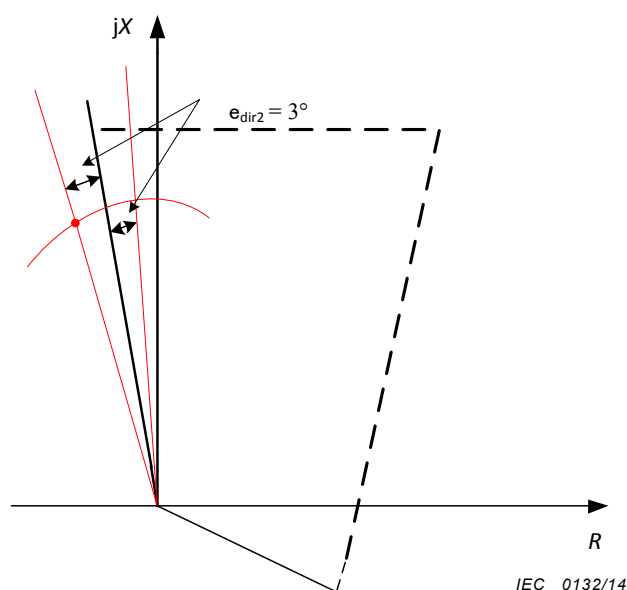


Figure 20 – Directional element accuracy tests in the second quadrant

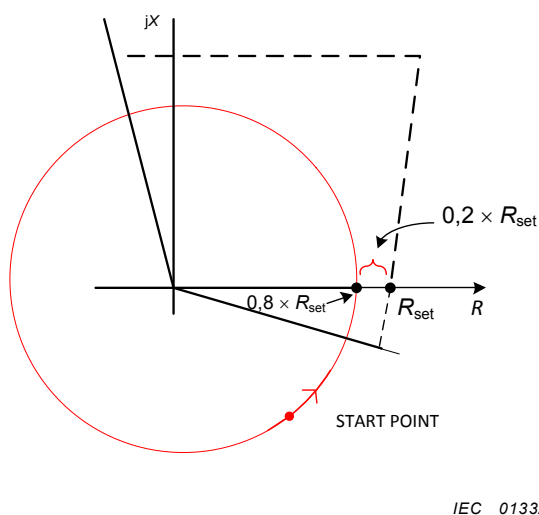


Figure 21 – Directional element accuracy tests in the fourth quadrant

The impedance will be injected by keeping the value of the injected current constant at a value of $2 \times I_{rated}$. The voltage magnitude is selected such that the resistance is 80 % of the setting along the positive R -axis.

The injected impedance is kept constant in magnitude, and its angle is varied. The angle is varied by steps that are smaller than 10 % of the declared angle accuracy. The ramp can be a pseudo continuous ramp, a ramp of shots (pulse ramp), or a more advanced search algorithm with shots like a binary search. The start of the impedance ramp is selected as shown in Figure 21. For the test methods ramp of shots (pulse ramp), or a more advanced search algorithm with shots like a binary search, the initial condition and the reset condition (between the shots) is rated voltage and zero current.

Each injection will last for a time period longer than 5 times the typical operate time of the protection function (if the typical operate time is 20 ms, then each step of injection will be at least 100 ms long).

The injection will stop when the tested distance protection zone issues the start signal. The angle of the injected impedance at the instant of start signal is reported and the difference between the theoretical angle and the measured angle is the measured error in degrees.

Test results for directional accuracy test in the fourth quadrant (e_{dir4}) are published for each fault type as indicated in Figure 22.

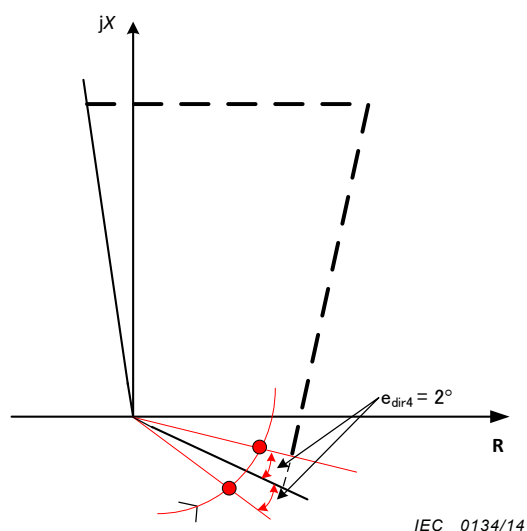


Figure 22 – Directional test accuracy lines in the fourth quadrant

The largest absolute error e_{dir4} obtained from all different fault types (L1N, L2N, L3N, L1L2, L2L3, L3L1 and L1L2L3) shall be documented and the maximum value from these tests shall be declared as the basic directional accuracy.

6.2.3.3 Reporting of the basic directional accuracy

The basic directional accuracy shall be published as a result of the tests described in the previous subclause.

The Table 7 shows the error for each fault type.

Table 7 – Basic directional accuracy for various fault types

Test type	e_{dir2}	e_{dir4}
L1N	2°	1,5°
L2N	1,8°	1,4°
L3N	1,9°	1,5°
L1L2	0,7°	1,2°
L2L3	0,9°	1,1°
L3L1	0,8°	1,0°

Basic directional accuracy shall be published as indicated in Table 8.

Table 8 – Basic directional accuracy $e_{\alpha X}$

Basic directional accuracy e_{dir2}	$\pm 2,0^\circ$
Basic directional accuracy e_{dir4}	$\pm 1,5^\circ$

The reported error in Table 8 is the largest measured error from Table 7.

6.2.4 Determination of accuracy related to time delay setting

In order to determine the time delay accuracy of a distance element, currents and voltages shall be applied to the relay with no DC component and the start and operate output contacts of the element monitored.

Tests shall be conducted for LN, LL, and LLL fault types. At least 2 settings (50 % and 100 % of the time delay setting range) shall be tested.

With reference to basic characteristic accuracy test points in the effective range, only test point A (Figure 7) is considered for these tests.

Protection function settings are derived from the test point A of 6.2.2.

Each test point shall be repeated at least 5 times to ensure the repeatability of results, with the maximum and average value of the 5 attempts being used for the analysis.

The difference between the times recorded for the start output and operate output signals shall be used to determine the time delay.

The initial (pre-fault) test condition shall be with nominal voltage and zero current.

The fault condition shall be simulated based on a fault at 50 % of the impedance setting with no fault resistance.

6.2.5 Determination and reporting of the disengaging time

6.2.5.1 Test procedure

The disengaging time is tested for the three-phase distance protection characteristic that corresponds to the settings associated with test point A ($I = 2 \times I_{\text{rated}}$ and $U = 0,3 \times U_{\text{rated}}$) in the effective range of U (phase-earth) and I .

The minimum operating current of the tested distance protection zone shall be published, and if that value is settable in the relay it shall be set to 15 % of the relay rated current.

The distance protection settings for the zone are calculated according to the procedure explained in Annex H.

A three-phase fault is injected in the relay, and the trip signal from the distance protection is monitored.

The three-phase fault has an impedance angle of 85° and is positioned at 50 % of the zone positive sequence reach setting, as indicated in Figure 23.