



BSI Standards Publication

Requirements for generating plants to be connected in parallel with distribution networks

Part 10: Tests for conformity assessment of generating units

National foreword

This British Standard is the UK implementation of EN 50549-10:2022.

The UK participation in its preparation was entrusted to Technical Committee GEL/8, Systems Aspects for Electrical Energy Supply.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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English Version

Requirements for generating plants to be connected in parallel
with distribution networks - Part 10: Tests for conformity
assessment of generating units

Exigences relatives aux centrales électriques destinées à
être raccordées en parallèle à des réseaux de distribution -
Partie 10: Essais d'évaluation de la conformité des unités
de production

Anforderungen für zum Parallelbetrieb mit einem Verteilnetz
vorgesehene Erzeugungsanlagen - Teil 10:
Prüfanforderungen für die Konformitätsbeurteilung von
Erzeugungseinheiten

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European Committee for Electrotechnical Standardization
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European foreword

This document (EN 50549-10:2022) has been prepared by CLC/TC 8X “System aspects of electrical energy supply”.

The following dates are fixed:

- latest date by which this document has to be (dop) 2023-08-09
implemented at national level by publication of
an identical national standard or by
endorsement
- latest date by which the national standards (dow) 2025-08-09
conflicting with this document have to be
withdrawn

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC shall not be held responsible for identifying any or all such patent rights.

EN 50438:2013 has been superseded by EN 50549-1:2019. However, Annex D of EN 50438:2013 provided requirements on compliance type testing, which is out of the scope of EN 50549-1:2019 resulting in a gap regarding type testing. This document provides requirements for compliance type testing for generating units and closes this gap.

This document has been prepared under a Standardization Request given to CENELEC by the European Commission and the European Free Trade Association.

Any feedback and questions on this document should be directed to the users' national committee. A complete listing of these bodies can be found on the CENELEC website.

1 Scope

The purpose of this document is to provide technical guidance for tests on generating units and interface protection to evaluate their electrical characteristics.

NOTE 1 Mechanical issues are taken into account as far as they influence the electrical characteristics.

The evaluation results are intended to be used to demonstrate conformity of generating units to technical requirements for grid connection. In this context the evaluation results can also be used as part of a certification programme.

NOTE 2 Besides the type test results of the generating unit all additional elements for connection to the grid (e.g. transformer, cabling, multiple units) are considered in the evaluation of the final installation of a generating plant.

The requirements to be evaluated are covered in the following standardization documents:

- EN 50549-1:2019: Requirements for generating plants to be connected in parallel with distribution networks
- Part 1: connection to a LV distribution network - Generating plants up to and including Type B
- EN 50549-2:2019: Requirements for generating plants to be connected in parallel with distribution networks
- Part 2: Connection to a MV distribution network - Generating plants up to and including Type B

If grid connection requirements are dealt with in other documents or for other generating module types, where no specific testing procedure is provided, testing methods of this document can be used if applicable.

This document provides evaluation criteria for the conformity assessment of generating units with respect to the abovementioned standardization documents, based on type testing. However, some requirements are applicable on the generating plant level. The assessment of the conformity to these plant requirements are out of the scope of this document. Nevertheless, this document may be used to show the capabilities of a generating unit to be used in a plant.

As a consequence, it is possible that the conformity assessment of a generating unit does not cover all aspects of the above-mentioned standardization documents, typically when a requirement is evaluated on a plant level. Therefore, the conformity assessment report indicates clearly which clauses of this document are covered and which clauses are not covered.

This document recognizes the existence of specific technical test requirements within several member states that must be complied with.

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.

EN 50549-1:2019, *Requirements for generating plants to be connected in parallel with distribution networks - Part 1: Connection to a LV distribution network - Generating plants up to and including Type B*

EN 50549-2:2019, *Requirements for generating plants to be connected in parallel with distribution networks - Part 2: Connection to a MV distribution network - Generating plants up to and including Type B*

EN IEC 60034 (all parts), *Rotating electrical machines*

EN IEC 60034-4-1, *Rotating electrical machines - Part 4-1: Methods for determining electrically excited synchronous machine quantities from tests*

EN 50524, *Data sheet for photovoltaic inverters*

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

- EN 60255-26, *Measuring relays and protection equipment - Part 26: Electromagnetic compatibility requirements*
- EN 60255-27, *Measuring relays and protection equipment - Part 27: Product safety requirements*
- EN 60255-127, *Measuring relays and protection equipment - Part 127: Functional requirements for over/under voltage protection*
- EN IEC 60255-181:2019, *Measuring relays and protection equipment - Part 181: Functional requirements for frequency protection*
- EN 60730-1:2016¹, *Automatic electrical controls - Part 1: General requirements*
- EN 61000-3-2, *Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*
- EN 61000-3-3, *Electromagnetic compatibility (EMC) - Part 3-3: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*
- EN 61508-3:2010, *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 3: Software requirements*
- EN IEC 61000-3-11, *Electromagnetic compatibility (EMC) - Part 3-11: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current ≤ 75 A and subject to conditional connection*
- EN 61000-3-12, *Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase*
- EN 61000-4-7:2002,² *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*
- EN 61000-4-13:2002,³ *Electromagnetic compatibility (EMC) - Part 4-13: Testing and measurement techniques - Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests*
- EN 61869-2, *Instrument transformers - Part 2: Additional requirements for current transformers*
- EN 61869-3, *Instrument transformers – Part 3: Additional requirements for inductive voltage transformers*
- EN 62116, *Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures*
- EN 62109-2, *Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters*
- EN IEC 61010 (all parts), *Safety requirements for electrical equipment for measurement, control, and laboratory use*
- EN IEC 61326 (all parts), *Electrical equipment for measurement, control and laboratory use - EMC requirements*
- UL 1998:2013, *Standard for Software in Programmable Components*

¹ As amended by EN 60730-1:2016/A1:2019 and EN 60730-1:2016/A2:2022.

² As amended by EN 61000-4-7:2002/A1:2009.

³ As amended by EN 61000-4-13:2002/A1:2009 and EN 61000-4-13:2002/A2:2016.

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 50549-1:2019, EN 50549-2:2019 and the following apply. The terms and definitions given in this clause are structured in the same way as the terms and definitions of EN 50549-1:2019 and EN 50549-2:2019.

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

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

NOTE Terms and definitions are selected to achieve consistency with IEV (cf. www.electropedia.org) and CENELEC terminology, recognizing that terms in COMMISSION REGULATION (EU) 2016/631 can deviate.

3.1.1 General

3.1.1.1

relevant parties

stakeholders having role and responsibility in the different conformity procedures in place within different EU countries

EXAMPLE TSOs, DSOs, certifiers, measuring institutes, manufacturers, etc.

3.1.1.2

manufacturer

organisation, situated at a stated location or stated locations that carries out or controls such stages in the process of bringing a product to the market as manufacture, assessment, verification, handling and storage of a product

Note 1 to entry: A manufacturer has full responsibility for continued compliance of the product until delivery to the customer with the relevant requirements and undertakes all obligations in that connection.

[SOURCE: IECRE Definitions, modified – Limitation until delivery to the customer added.]

3.1.1.3

conformity

fulfilment of a requirement

[SOURCE: IEV 192-01-15]

3.1.1.4

conformity assessment

demonstration that specified requirements relating to a product, process, system, person or body are fulfilled

Note 1 to entry: The subject field of conformity assessment includes activities defined elsewhere in ISO/IEC 17000, such as testing, inspection and certification, as well as the accreditation of conformity assessment bodies.

Note 2 to entry: The expression "object of conformity assessment" or "object" is used in ISO/IEC 17000 to encompass any particular material, product, installation, process, system, person or body to which conformity assessment is applied. A service is covered by the definition of a product (see Note 1 to IEV 902-02-03).

[SOURCE: IEV 902-01-01]

3.1.1.5**conformity evaluation**

systematic examination of the extent to which a product, process or service fulfils specified requirements

[SOURCE: IEC 151-16-14]

3.1.2 Plant, module and unit**3.1.2.1****type test**

conformity test made on one or more items representative of the production

[SOURCE: IEC 151-16-16]

3.1.2.2**measuring equipment**

assembly of measuring instruments intended for specified measurement purposes

[SOURCE: IEC 311-03-05]

3.1.2.3**test equipment**

all equipment that is added to a test setup for the purpose of testing and measuring during the test

Note 1 to entry: This includes among others specific impedances, FRT-container, measurement equipment, grid-simulator as applicable.

3.1.2.4**test set-up**

electrical system where the test is carried out

Note to entry 1: This includes, among others, grid-characteristics at POC, transformers, cables, test equipment as applicable.

3.1.2.5**generating unit under test****GUT**

generating unit subjected to tests

3.1.2.6**equipment under test****EUT**

equipment (products, devices, components and systems) subjected to tests

3.1.2.7**component**

constituent part of a device which cannot be physically divided into smaller parts without losing its particular function

[SOURCE: IEC 151-11-21]

3.1.2.8**primary energy converter**

system that converts any form of primary energy into either electrical or mechanical energy as part of the conversion to AC electricity

EXAMPLE PV generator; fuel driven engines; gas, steam or water turbines; aerodynamic system of a wind turbine.

3.1.2.9

on-load tap-changer load-tap-changer (US) OLTC

device for changing the tapping connections of a winding, suitable for operation while the transformer is energized or on load

[SOURCE: IEC 421-11-01, modified – An abbreviation was added.]

3.1.2.10

software

assembly of programs, procedures, rules, documentation and data, pertaining to the operation of an information processing device or system

EXAMPLE Firmware, operating system, application software.

Note 1 to entry: Software is an intellectual creation that is independent of the medium upon which it is recorded.

Note 2 to entry: Software requires hardware to execute programs, and to store and transmit data.

[SOURCE: IEC 171-01-21]

3.1.3 Power

3.1.3.1

nominal power

P_n

nominal value of a generating unit's active power, which is stated by the manufacturer

3.1.3.2

nominal current

I_n

nominal value of generating unit, either as stated by the manufacturer or which shall be calculated from nominal active power P_n and nominal voltage U_n according to

$$I_n = \frac{P_n}{\sqrt{3}U_n}$$

[SOURCE: IEC 61400-27, ed. 1.0 (2015-02) 3.1.6, modified – Applicable for generating units, manufacturer statement added.]

3.1.3.3

minimum regulating level

minimum active power, as specified by the manufacturer, down to which the generating unit can control active power

Note 1 to entry: In special cases, generating units of non-synchronous generating technology also have a minimum technical power.

Note 2 to entry: The minimum regulating level of a power generating plant is to be determined in a suitable manner based on the minimum regulating levels of the power generating units.

[SOURCE: COMMISSION REGULATION 2016/631 Article 2 (24) modified – RfG definition adopted to the formal terminology structure in CLC standards and two notes have been added.]

3.1.3.4**maximum reactive power** **$Q_{\max \text{ over}}$**

<overexcited> maximum continuous overexcited reactive power, measured in a 10 min average, which a generating unit or the sum of all the generating units in a generating plant can exchange as specified in the connection agreement or as agreed between the DSO and the generating plant operator

Note 1 to entry: In some configurations $Q_{\max}$ is not available for all active power operating points.

3.1.3.5**maximum reactive power** **$Q_{\max \text{ under}}$**

<underexcited> maximum continuous underexcited reactive power, measured in a 10 min average, which a generating unit or the sum of all the generating units in a generating plant can exchange as specified in the connection agreement or as agreed between the DSO and the generating plant operator

Note 1 to entry: In some configurations $Q_{\max}$ is not available for all active power operating points.

3.1.4 Voltage**3.1.4.1****rate of change of frequency****ROCOF**

change of frequency by a given amount per unit of time

Note 1 to entry: A ROCOF relay measures the characteristic quantity and triggers if a given amount of this quantity per unit of time has changed.

3.1.4.2**phase****instantaneous phase** **ϑ**

argument of the cosine function in the representation of a sinusoidal quantity

Note 1 to entry: The term “instantaneous phase” is only used when the independent variable is time.

Note 2 to entry: For the quantity $a(t) = \hat{A} \cos(\omega t + \vartheta_0)$, the phase is $\omega t + \vartheta_0$.

[SOURCE: IEC 103-07-04]

3.1.4.3**phase jump**

abrupt change in the phase of the voltage of an AC electrical network

3.1.5 Circuit theory

3.1.5.1

root-mean-square value

RMS value

quadratic mean

quantity representing the quantities in a finite set or in an interval,

1. for n quantities $x_1, x_2 \dots x_n$, by the positive square root of the mean value of their squares

$$X_q = \left(\frac{1}{n} (x_1^2 + x_2^2 + \dots + x_n^2) \right)^{1/2}$$

2. for a quantity x depending on a variable t , by the positive square root of the mean value of the square of the quantity taken over a given interval $(t_0, t_0 + T)$ of a variable:

$$X_q = \left(\frac{1}{T} \int_{t_0}^{t_0+T} (x(t))^2 dt \right)^{1/2}$$

Note 1 to entry: The root-mean-square value of a periodic quantity is usually taken over an integration interval the range of which is the period multiplied by a natural number.

Note 2 to entry: The root-mean-square value of a quantity is denoted by adding the subscript q to the symbol of the quantity.

Note 3 to entry: The abbreviation RMS was formerly denoted as r.m.s. or rms, but these notations are now deprecated.

[SOURCE: IEC 103-02-02]

3.1.6 Protection

3.1.6.1

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

[SOURCE: IEC 447-07-01]

3.1.6.2

setting value of the characteristic quantity

threshold value of the characteristic quantity at which a measuring relay or protection equipment is required to operate under specified conditions

[SOURCE: IEC 447-07-02]

3.1.6.3

reset value

value of the characteristic quantity at which a measuring relay or protection equipment resets

[SOURCE: IEC 447-02-12]

3.1.7 Control

3.1.7.1

steady state

state of a system at which all state and output variables remain constant in time while all input variables are constant

Note 1 to entry: A state under periodic conditions is often considered as a steady-state.

[SOURCE: IEC 351-45-10, modified, irrelevant note deleted, note of IEC 103-05-01 added]

3.1.7.2

accuracy

degree to which a measurement, calculation, performed function etc. is exact or correct

3.1.7.3

required accuracy

A_r

accuracy required by an assessment criterion

EXAMPLE EN 50549-1:2019 requires a voltage measurement accuracy of 1 % U_n .

3.1.8 Power quality

3.1.8.1

switching current factor

k_i

ratio of the highest current occurring during a switching operation (e.g. starting or connecting current or the highest breaking current under normal operating conditions) to the rated current I_r of the generating unit

Note 1 to entry: For this purpose, the current is to be considered as an RMS value over one period.

Note 2 to entry: If controlled power operation is possible, only the electromechanical switching operation (inrush of inductances and capacities) is observed.

3.1.8.2

flicker coefficient for continuous operation

$c(\psi_k)$

normalized measure of the flicker emission during continuous operation of the generating unit

$$c(\psi_k) = P_{st, fic} \times \frac{S_{k, fic}}{S_n}$$

where

$P_{st, fic}$ is the short-term flicker severity from the wind turbine on the fictitious grid;

S_n is the nominal apparent power of the generating unit;

$S_{k, fic}$ is the short-circuit apparent power of the fictitious grid

[SOURCE: EN IEC 61400-21-1 modified – Definition applied to generating units.]

3.1.8.3**fictitious grid**

representation of an ideal phase-to-neutral voltage source with the instantaneous value $u_0(t)$, in series with a defined grid resistance R and grid inductance L

Note 1 to entry: The fictitious grid is used for the normalization of flicker measurements.

[SOURCE: EN IEC 61400-21-1]

3.2 Symbols and abbreviations

For the purposes of this document, the following symbols and abbreviations apply

3.2.1 Abbreviations

AVR	automatic voltage regulator
CHP	combined heat and power
CT	current transformer
DFIG	doubly fed induction generator
DSO	distribution system operator
EES	electrical energy storage
EHV	extra high voltage
EMC	electromagnetic compatibility
HV	high voltage
IEV	international electrotechnical vocabulary (IEC 60050)
LV	low voltage
MV	medium voltage
OEL	overexcitation limit
OVRT	over voltage ride through
POC	point of connection
PV	photovoltaic
ROCOF	rate of change of frequency
THD	total harmonic distortion
UEL	underexcitation Limit
UVRT	under voltage ride through
VT	voltage transformer

3.2.2 Symbols

A_r	required accuracy
G_R	reset value of the characteristic quantity
G_S	setting value of the characteristic quantity (activation threshold)

k_i	switching current factor
T_{Op}	operate time (equals start time plus time delay setting)
T_{Res}	reset time
T_{Ov}	overshoot time
> / > >	first / second stage of protection function
Δf	frequency step
Δt	time step
ΔU	voltage step

4 Assessment methods and test equipment

4.1 General

In order to prove conformity with the requirements, tests and evaluations shall be performed. All tests shall be conducted as type tests either on a unique generating unit or on an item representative of the production of one type of generating unit. The results of the evaluation are considered valid for the whole production of this type of generating unit manufactured to the same design and operating with the same software as during the type test of the EUT.

For changed software (updates) intended to be used in the product, 4.5 applies.

NOTE 1 This covers changes in software during the test procedure, in production and at field updates.

For the type test different types of assessment methods and tests are considered.

As the reference assessment method, the test on the complete generating unit (4.2.1) is considered. When (a combination of) alternative assessment methods are permitted, this document describes the conditions to be fulfilled.

These conditions are based on e.g.:

- the power rating of the generating unit
- the kind of primary energy source
- the technology of the generating unit
- the type of requirement to be assessed

Due to limitations of available test sites, test equipment and other constraints, it may not be reasonably feasible to perform the full set of tests on the complete generating unit. Hence alternative methods are defined to demonstrate compliance with the requirements.

NOTE 2 The alternatives are always considered as an option. It is always possible to test the complete unit instead of the alternatives proposed.

It is possible to combine different proposed alternatives. Consequently, in this case, all of the conditions relevant for the chosen alternatives shall then be fulfilled.

In the following clauses the characteristics of the reference method and its alternatives are given.

4.2 Assessment methods

4.2.1 Test on complete generating unit

The test on the complete generating unit is defined by all the following conditions:

- Test is performed on an EUT covering the complete generating unit from the primary energy converter up to and including the output stage intended for the connection to the distribution network.
- The nominal frequency of the output of the EUT corresponds to the nominal frequency of the distribution network
- For generating units to be connected to the LV distribution network, the voltage level at the output stage of the EUT shall correspond to the voltage of the LV distribution network.
- For generating units to be connected to the MV distribution network the voltage level at the output stage of the EUT shall either corresponds to the voltage of the MV distribution network or the manufacturer shall declare the output boundary at a different voltage level requiring a transformer in the final installation.

NOTE 1 If the output voltage of the generating unit is not matching with the voltage of the distribution network, all additional elements for connection to the grid (e.g. transformer, cabling) are considered in the final installation of a generating plant.

- The EUT includes all necessary auxiliary equipments which can affect the assessment results; it is not necessary to include all auxiliary equipment.

NOTE 2 Tests in the field with use of specific test equipment other than measurement equipment, e.g. a fault ride through test container, is considered as a complete unit test and not as field measurement (see further).

4.2.2 Test on the electrical generation system

Test on the electrical generation system is defined by all the following conditions:

- Test is performed on a EUT that is limited to the electrical generation system, a subsystem of the generating unit.
- The boundary of the EUT (which does not necessarily include the complete generating unit) is chosen such that there will be no impact on the results of the conducted test. This means that the result is the same as if the test would have been conducted on the complete generating unit. This shall be justified in the test report.
- The characteristics of the source (e.g. PV panel, battery, reciprocating engine, etc) shall be taken into account when defining the boundary of the electric generating system for the assessment of a particular requirement. The boundary can depend on the assessed requirement.
- The boundary of the EUT shall be unambiguously defined and described in the test report.
- The nominal frequency of the output stage of the EUT corresponds to the nominal frequency of the distribution network.
- For generating units to be connected to the LV distribution network, the voltage level at the output stage of the EUT shall be in line with the voltage of the LV distribution network.
- For generating units to be connected to the MV distribution network the output boundaries of the EUT shall be declared by the manufacturer.

NOTE 1 If the output voltage of the generating unit is not matching with the voltage of the distribution network, all additional elements for connection to the grid (e.g. transformer, cabling) are considered in the final installation of a generating plant.

- The primary energy converter is replaced by an alternative energy source emulating the behaviour of that primary source. The alternative primary source should at least emulate the behaviour of the primary source that is relevant for the tests. The correct emulation of the primary source shall be justified in the test report.

NOTE 2 Primary energy converters are subsystems such as mechanical blades, PV generator, fuel driven engines.

- The EUT includes all auxiliary equipment of the electrical generation system.

This test could be considered when a good alternative primary source is available or when the primary source behaviour and its transformation into electrical power do not impact the results of the assessed requirement.

EXAMPLE:

- PV inverter tested on a DC source emulating the characteristics of a PV array
- Fuel cell inverter tested on a DC source emulating the characteristics of the fuel cell
- Wind turbine generator tested with an alternative mechanical source on a test bench
- Battery inverter tested on a battery emulating bi-directional DC source
- Genset tested on a drive test stand emulating a reciprocating engine

4.2.3 Test on the nacelle of a wind turbine

Test on the nacelle of a wind turbine is defined as in EN 61400-21-4. Until publication of EN IEC 61400-21-1 the following shall apply.

- The complete nacelle is placed on the test bench.
- The different components of the wind turbine (e.g. generator, gearbox, hydraulics, main bearing(s) and electrical cabinets) are mounted in the nacelle and in its original positions and structures.
- The wind turbine's power control system is in operation and the load of the different electrical systems is equivalent to site operation.
- All the electrical systems present at site, that will experience the grid event are present and operational.
- If parts of the electrical system are located in the tower section of the turbine, these components can be placed next to the test bench, in its original mechanical structure and frames etc. This is to ensure the correct interfaces and electrical cable lengths as well as electrical noise properties, which is intended to enable valid test results for performance testing.
- All the nacelle control systems are active during testing. The tested wind turbine is operated with its original control system software. For the purpose of the test setup no changes to relevant control software are made.
- A mHiL (mechanical hardware in the loop) controller to emulate wind speed and control the torque of the test bench motor shall ensure correct dynamic response of the turbine and its control systems torque/speed wise so that the response to the electrical tests are representative to real site operation.
- The mHiL operation shall be validated. This may be ensured by performing a number of tests with varying wind speeds / wind speed ramps to compare test bench measurements with site measurements or results derived from validated simulation models.
- If the hub is part of the test setup, and the pitch system of the turbine is operational, a more simplified mHiL control mode can be implemented to achieve the correct operational dynamic response of the turbine during testing. With verified parameters of the rotor characteristic of the tested WTG (wind, pitch angle, RPM,

resulting torque) and an inertia compensation, the dynamic response can be obtained by controlling the prime mover in torque control mode. Therefore, performance testing is also possible in this mode.

- If parts of the electrical system are left out of the tests (yaw and optional pitch) they shall be tested separately in order to validate the performance of the final nacelle design.

EXAMPLE wind turbine generator tested with an alternative mechanical source on a test bench as nacelle test

4.2.4 Test on the primary energy converter

Test on the primary energy converter is defined by all the following conditions:

- The test is conducted on the primary energy converter associated with its controller.
- The evaluated operational capability is referring to the active power only.
- The active power output is controlled on the primary energy converter and its controller, irrespective of the electrical generation system.
- The mechanical power output can be measured.

EXAMPLE active power control on set point and active response to frequency deviation tests conducted on reciprocating engine coupled with a synchronous generator or a gas turbine coupled with a synchronous generator

4.2.5 Test at limited power

The test is defined by all the following conditions:

- Test is conducted on complete generating unit or test on electrical generating system.
- EUT is operated at power levels below its rated and above its minimum power capacity.

EXAMPLE

- Test of the integrated interface protection, while the generating unit is operated at limited power
- Test of the automatic reconnection after tripping

4.2.6 Test on stopped generating unit

The test is defined by all of the following conditions:

- Test on complete generating unit (according to 4.2.1) or test on power generating system (according to 4.2.2)
- EUT is stopped (switched on but not producing energy)

This test may be used if the assessed requirement is not depending on the actual operation of the generating unit.

EXAMPLE

- Test of the interface protection
- Test of the automatic reconnection after tripping

4.2.7 Test on an independent component

The component test on an independent component is defined by all the following conditions:

- The assessed protection functions or operational capabilities are provided by the component.

- The assessed protection functions or operational capabilities are not dependent on other components / systems.

This test may be used if the assessed requirement may be implemented in an independent component and does not rely on other components of the generating unit.

EXAMPLE

- Interface protection relay not embedded in the generating unit
- Independent plant controller implementing control functions not embedded in the generating unit

4.2.8 Simulated input test

The simulated input test is defined by all the following conditions:

- Test on complete generating unit (according to 4.2.1) or Test on electrical generating system (according to 4.2.2).
- A change on a grid parameter (e.g. voltage or frequency) is simulated to the measurement inputs of the control unit or to measurement sensors of the EUT instead of to the terminals of the EUT.
- The simulated grid provides the same properties regarding voltage, frequency and number of phases, the output power of the grid simulator may be reduced as only the measurement shall be provided.
- The signal to be simulated only affects the control of the generating unit and has no electromechanical effect to the generating unit itself. This shall be justified in the report.

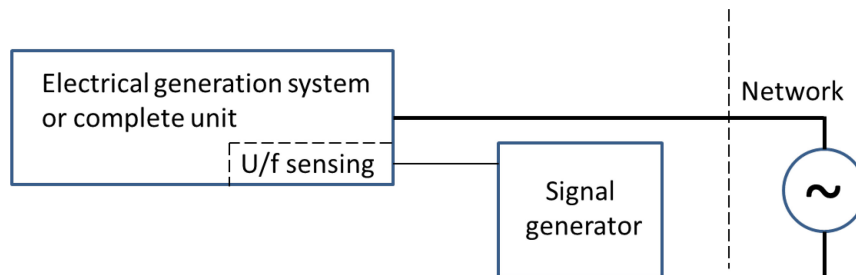


Figure 1 — Test setup n. 2 (test signal generator)

This test may be used if simulated signals can be connected to the generating unit (see Figure 1).

EXAMPLE

- Integrated interface protection system with use of a test terminal
- Active power response to over-frequency
- Voltage related control mode for reactive power $Q(U)$

4.2.9 Test by changing a control parameter

The test by changing a control parameter is defined by all of the following conditions:

- Test on complete generating unit (according to 4.2.1) or test on electrical generating system (according to 4.2.2) or test on a component (according to 4.2.7 and 4.2.13)
- Using an analogue or digital interface or a special human-machine interface
- One or more parameters in the control unit of the EUT are changed

- The signal corresponding to the changed parameter only affects the control of the generating unit and has no electromechanical effect to the generating unit itself. This shall be justified in the report.
- The firmware of the control unit of the generating unit is not changed.

See also Figure 2.

In order to simulate a progressive changing in a grid parameter and the subsequent return of the same to the nominal value, it is possible to modify:

- The reading of the grid parameter measurement of the EUT control system, or
- The threshold parameters and characteristic curve that define the EUT response as a function of the measured grid parameter

NOTE Two options are possible to modify the reading of mains frequency:

- A bias can be added to the measured value of the grid. The bias is increased and decreased according to the procedure. In this option, if real grid fluctuates, additional changes may result.
- The real frequency measured value can be overwritten with the frequency value to be controlled. Fluctuations on the real grid are not relevant anymore.

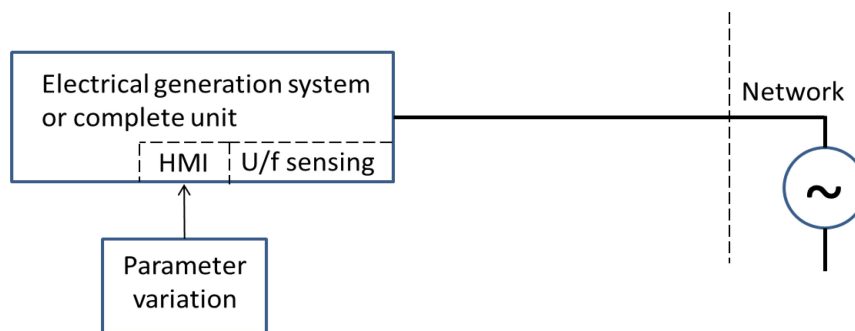


Figure 2 — Test setup n. 3 (change of control parameter)

EXAMPLE

- Changing the grid frequency parameter in the control unit when evaluating power response on frequency deviation
- Changing the $Q(U)$ parameter in the control unit when evaluating voltage related control mode for reactive power $Q(U)$

4.2.10 Field measurements

Field measurements are defined by all following conditions:

- The complete generating unit is operated in normal field conditions according to manufacturer specification.
- Based on natural fluctuations of voltage, frequency and/or the primary energy source or set point, the behaviour of a function is evaluated.
- If applicable, voltage fluctuation may be inserted by changing the position of tap changers (online or offline).

NOTE 1 Tests in the field with use of specific test equipment other than measurement equipment, e.g. a fault ride through test container, is not considered as field measurements but as a complete unit test.

NOTE 2 Normal field conditions means, that no test equipment besides measurement equipment is added to the installation of the generating unit.

EXAMPLE Flicker emission of a wind turbine.

4.2.11 Test by calculation and numerical simulation for generating units of synchronous generating technology

Where valid information is available to conduct calculations or numerical simulations these may be used to provide evidence of conformity for functions that cannot be tested using any of the methods above. The simulation models shall be validated. The model validation process is described in 5.13. A model validated according to alternative procedures described in recognized standards can be adopted if the model shows similar or higher fidelity than the one described in 5.13 and upon agreement with the relevant parties involved in the process of conformity assessment.

Components of the generating unit that are not included in the model according to 5.13 shall be evaluated according to 4.2.13.

NOTE This method is intended to facilitate generating unit tests. The model is not intended to be used in generating plant studies.

4.2.12 Test of the real generating unit control unit in a simulated environment (“Controller-Hardware-in-the-loop” (HIL) test)

Test of the real control unit in a simulated environment is defined by all following conditions:

- The power components of the generating unit, the primary energy source and the distribution grid, are replaced by simulation models running on a real-time computing system.
- The real control unit of the generating unit is connected through analogue, digital and communication interfaces to the virtual representation of the physical system.
- The firmware of the control unit of the generating unit is not changed.

The simulation models need to be validated, based on measured data from tests performed on the complete generating unit or electrical generating system.

The model validation process is currently under consideration. A model validated according to alternative procedures described in other recognized standards can be adopted if the model shows similar or higher fidelity and upon agreement with the relevant parties involved in the conformity procedure.

4.2.13 Evaluation by inspection and test of dependent components

When evaluation by inspection is applied, the following steps need to be conducted and documented in the test report.

- Any component that may be impacted by or impact the assessed protection functions or operational capabilities shall be listed in a list of critical components for this requirement.
- For each of the items in this list of critical components,
 - the assessed protection functions or operational capabilities shall be evaluated, considering the test results according to applicable product standards. Or,
 - if the assessed protection functions or operational capabilities cannot be assessed based on applicable product standards, each of the items in this list of critical components, shall be tested individually according to the procedure of Clause 5.

This method may be used if the assessed requirement may be implemented in or is impacting a system consisting of multiple components and the function or capability of each component can be assessed separately.

EXAMPLES

- Interface protection system: test on interface protection relay and test on interface switch to evaluate interface protection system behaviour.
- Frequency operating range: Examples of critical components regarding the frequency operating range are among others: AC operated drives e.g. for fans, pumps, synchronous and asynchronous generators and motors, electronic drive systems (PLL etc), Transformers, power factor correction devices.
- Active power response to frequency deviation: test on frequency measurement and test on controller and test on response to active power set point of generating unit to evaluate the active power response to frequency derivations.

4.3 Requirements for the measuring equipment

The measuring equipment for performing the tests as defined in this standard usually consists of the following components:

- Signal conditioning
- Data acquisition
- Data processing and storage

Electrical parameters (voltages and currents) are measured directly or via voltage and current transducers- In addition, also further internal and external parameters of the generating unit (e.g. rotational speed, wind speed, internal references) are acquired together with set point signals. All signals are then processed and stored together with timing information (time stamps).

The data are then further processed, including e.g. calculation of RMS values, averages etc.

To ensure the validity of the measurements, the measurement equipment and data acquisition should meet the following minimum requirements related to the sampling rate and measurement uncertainty as provided in Table 1 and Table 2.

Table 1 — Required sampling rates

Test item	Voltages and currents signals	Set points and reference signals	Other signals (e.g. wind speed, rotational speed, battery state of charge etc.)
5.1 Power specification of the generating unit	≥ 3 kHz	≥ 3 kHz	≥ 1 Hz
5.2 Normal operating range	≥ 3 kHz	≥ 3 kHz	≥ 1 Hz
5.3 Immunity to disturbances	≥ 10 kHz	N/A	≥ 1 Hz
5.4 Active response to frequency deviation	≥ 3 kHz	N/A	≥ 1 Hz
5.5 Power specification and response to voltage variations	≥ 3 kHz	≥ 3 kHz	≥ 1 Hz
5.7 EMC and power quality	-		
5.7.2.2 Verification procedure for harmonics, interharmonics and higher frequencies up to 9 kHz	≥ 20 kHz	N/A	≥ 1 Hz

Test item	Voltages and currents signals	Set points and reference signals	Other signals (e.g. wind speed, rotational speed, battery state of charge etc.)
5.7.2.3 Verification procedure for flicker and rapid voltage changes	≥ 3 kHz	N/A	≥ 1 Hz
5.7.2.4 Verification procedure for DC injection	≥ 3 kHz	N/A	≥ 1 Hz
5.8 Interface protection	≥ 10 kHz (≥ 1 kHz for voltage protection tests)	N/A	≥ 1 Hz
5.9 Connection and starting	≥ 3 kHz	N/A	≥ 1 Hz
5.10 Active power reduction on set point	≥ 3 kHz	≥ 3 kHz	≥ 1 Hz
5.11 Remote information exchange	N/A	N/A	N/A
5.12 Requirements regarding single fault tolerance of interface protection system and interface switch	N/A	N/A	N/A
5.13 Model definition and model validation for generating units of synchronous generating technology	N/A	N/A	N/A

Related to the measurement uncertainties, the measurement equipment (excluding voltage and current inductive transducers) should meet the following minimum requirements for a coverage factor $k = 2$ as per ISO 21748.

Table 2 — Measurement uncertainty requirements excluding the contribution of voltage and current transducers

Value	Required measurement uncertainty ($k = 2$)
Voltage (fundamental)	$\leq 0,5$ % of U_n
Current (fundamental)	$\leq 0,5$ % of I_n
Harmonic currents up to 9 kHz	
$\geq 0,1$ % of I_n	≤ 30 % of measured value
$< 0,1$ % of I_n	$\leq 0,03$ % of I_n
Set point signals	$\leq 0,5$ % of nominal value
Flicker	$\leq 5,8$ % referenced to $P_{st} = 1$
Interface protection (test signals)	voltage $\leq 0,1$ % of U_n frequency $\leq 0,01$ % of f_n
pole wheel angle	$\leq 4^\circ$ electrical

Voltage and current transducers shall meet at least class 1 requirements as per EN 61869-3 (voltage inductive transducers) and EN 61689-2 (current inductive transducers).

The test report shall declare the measurement uncertainty for the measured electrical quantities, including also the contribution of voltage and current transducer.

4.4 Configuration range and parameter sets

4.4.1 General

EN 50549-1:2019 and EN 50549-2:2019 define a set of configurable parameters. The correct behaviour of the generating unit shall be provided within the complete configuration range of these parameters, as available in the generating unit control.

To plan a test campaign the manufacturer shall provide to the test laboratory a list of configurable parameters including the range of configurability range and minimum step size (see Table B.2 in B.2).

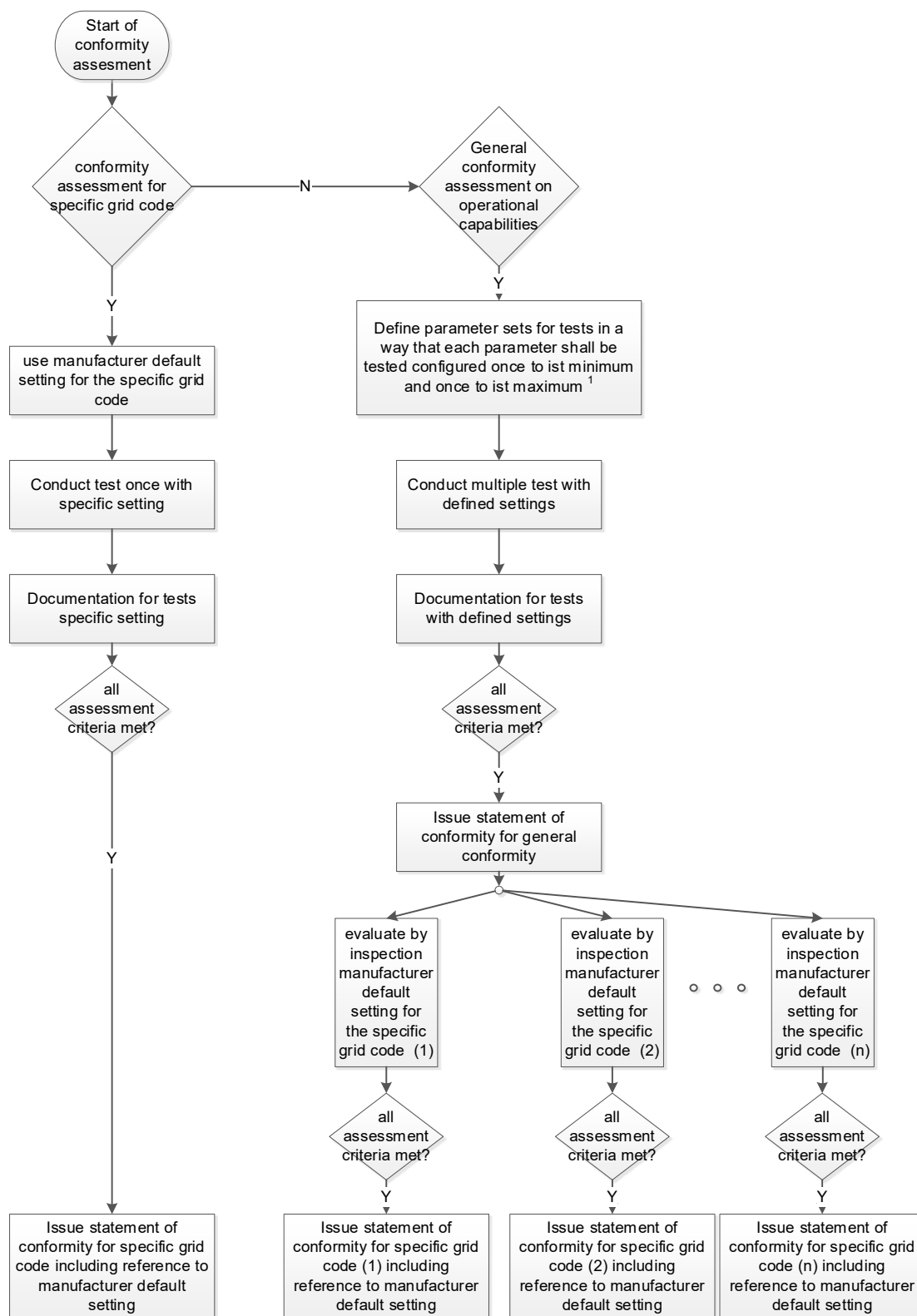
The test on each function can either be carried out for one specific setting verifying one specific grid code or, in general, by testing multiple settings verifying the overall function that may be configured to a specific grid code by the user. The definition of the multiple settings, in absence of different agreements among the involved parties, shall be in a way that each parameter shall be tested configured once to the minimum value and once to the maximum value of the parameter range. For interface protections, sufficient test points shall be used to assess the performance over the entire setting range of the element, but as a minimum the four following settings shall be used, 0 % or minimum of the setting range, ca. 30 %; ca. 60 %; 100 % or maximum of the setting range.

If the generating unit provides additional parameters this concept may be extended to the additional parameters. As it may be that parameters affect each other, it shall be verified that the effect of each parameter is visible in the conducted tests.

Tests conducted according to the principles above with multiple settings, verifying the protection functions or operational capabilities in a general way, may provide evidence of conformity of a specific (preconfigured) setting with a specific technical requirement even if this specific (preconfigured) setting itself has not been tested. Once

- the protection functions or operational capabilities is verified in a general way, and
- the (preconfigured) setting is within the evaluated configuration range,

a statement of conformity according 4.4.2 for a specific technical requirement (e.g. grid code) of a DSO or another responsible party within a member state may be issued based on an inspection of the (preconfigured) setting in the generating unit.



¹ In case of interface protection a minimum of four settings shall be used: 0 % or minimum of the setting range, ca. 30 %; ca. 60 %; 100% or maximum of the setting range

Figure 3 — Process to issue a statement of conformity

4.4.2 Documentation

Test reports and statements of conformity based on this document, e.g. with EN 50549-1:2019 and EN 50549-2:2019, shall include a statement of the parameter set this test report and statement of conformity applies to.

The test report shall include an annex with the following information.

- The version of the software the EUT is operated with during the type test.
- The considered value range (minimum and maximum value) as in 4.4.1 for each parameter.

NOTE If a parameter is not configurable or the test has been conducted for one specific setting, the minimum value and the maximum value of the range are identical.

If one or more default parameter sets within the considered value range are available in the generating unit the following shall be stated for each evaluated parameter set.

- Reference to the specific technical requirement (e.g. grid codes) of the DSO or another responsible party within a member state this default parameter set refers to.
- The name of this parameter set.
- The configured default values of this default parameter set.

The statement of conformity shall include an annex with the following information.

- The version of the software the EUT is operated with during the type test.
- Reference to the specific technical requirement (e.g. grid codes) of the DSO or another responsible party within a member state the statement of conformity refers to.
- The name of the default parameter set the statement of conformity refers to.
- The configured values of this default parameter set.
- A remark, that the statement of conformity is only valid with this parameter set configured in the generating unit.

If multiple default parameter sets are available in the generating unit to conform with specific technical requirements (e.g. grid codes) of the DSO or another responsible party within a member state, an independent statement of conformity shall be issued for each evaluated default setting.

If the test has been conducted with one specific setting to meet the requirements of one specific technical requirement and the parameters are not configurable for the installer and operator of the generating unit the remark that the statement of conformity is only valid with this parameter set may be replaced by a statement that no parameters are configurable for the operator of the generating unit.

Annex B provides a normative template for the documentation of the parameter set.

4.5 EUT Software change requirements

If this clause is applied according to 4.1, each change of software version applied in the equipment under test (EUT), or in the generating unit affecting the protection function or operational capability assessed according to this document shall be evaluated as per this section.

- 1) If software changes do not potentially affect the results of the assessment, there is no need for any additional testing.

EXAMPLE Colour of the display, additional monitoring function.

- 2) If software changes do potentially affect the results of the assessment, the complete assessment procedure according to this document shall be repeated, unless 3) applies.
- 3) If
 - a) software changes do potentially affect the results of the assessment, and
 - b) the changed software as well as the original version has been developed in compliance with the following:
 - the requirements of EN 60730-1:2016¹, H.11.12.3 (measures to avoid errors), or
 - with the measures to avoid errors during the development process (V-Model) of
 - EN 61508-3:2010 for SIL2 or
 - UL 1998:2013 for class 1 software

a re-test is required only for those protection functions or operational capabilities which are affected by the changed software.

5 Testing

5.1 General

If not stated otherwise in relevant clauses of this document, all assessed protection functions and operational capabilities available in the GUT or EUT shall be active during all described tests.

If the test of one protection function or operational capabilities according to this document may be affected by the configuration of another protection function or operational capability, the configuration of the other protection function or operational capability shall be chosen in a way resulting in the worst possible condition. If this condition results in a failure of the tested protection function or operational capability the configuration of the other protection function or operational capability may be adapted. If this is done, only the reduced configuration range for the other protection function or operational capability shall be stated in the declaration of conformity or the exclusiveness of the two functions shall be clearly stated.

For all tests and measurements defined below, the environmental condition, temperature and humidity shall be stated in the test report.

5.2 Normal operating range

5.2.1 Frequency operating range

5.2.1.1 General

The aim of this procedure is to provide evidence of the capability of a generating unit to operate within ranges of frequency as described in EN 50549-1:2019 and EN 50549-2:2019 and as declared by manufacturer.

5.2.1.2 Test application and verification methodology

The verification process can be conducted on the complete unit or on the components that can be affected if running at frequencies different from nominal within the frequency limits. Components not affected by frequency can be excluded from the verification or replaced by other components, for example in laboratories, to facilitate the assessment.

Regarding the energy source and the prime mover of generating units, the following approaches are considered justified in the verification process of a complete unit of some specific technology:

- In case of a PV generating unit, replacing the PV generator by a DC source (e.g. PV Array Simulator) according to 4.2.2.

- In case of full converter generating units (Wind or CHP) replacing the generator and if applicable the generator side inverter/rectifier by an AC or if applicable a DC source according to 4.2.7.
- In case of DFIG generating units, replacing the mechanical drive system by a test bench motor according to 4.2.2.

The relevant party (e.g. system operator, certifying body etc.) will evaluate the boundary (battery limits) for the specific generating unit considering the justification and documentation provided by the manufacturer.

The above shall not be considered as an exhaustive list and additional alternative approaches can be proposed to be evaluated and agreed upon by involved parties (e.g. manufacturer, system operator, certifying body, etc.).

Depending on the generating unit size, generating unit technology, site test or laboratory availability the verification can be carried out using one of the following methods:

- Verification of the generating unit or relevant component using a grid simulator.
- Verification of the generating unit or relevant component by using a dedicated prime mover capable of changing the speed of the generating unit or relevant component.
- Verification of the generating unit or relevant component in island operation with sufficient load.
- Verification of the generating unit based on relevant components evaluation through documentation and calculation (4.2.13).
- In case of synchronous generating technology, verification by calculation and numerical simulation according to 4.2.11

Alternative methodologies can be proposed by the manufacturer. The involved parties shall agree on alternative methodologies given they provide an equivalent level of confidence.

If the verification is carried out on components it is possible to apply different methodologies for the different components.

The duration of the verification can be based on reduced time whereas longer duration does not affect the result of the test. Justification shall be documented by the manufacturer.

During the test, the frequency, RMS voltage, RMS current and active and reactive power measured at the output terminals of the generating unit shall be recorded as 10 cycle average values. If the evaluation is carried out based on component evaluation only the values applicable for the component shall be measured, but at least the frequency (or correspondent speed) shall be measured.

5.2.1.3 Verification procedures

The verification shall be carried out:

- at the maximum active power for this operating frequency as stated by the manufacturer and;
- an active factor equal to 1 shall be used.

The power supplied by the primary energy source shall be kept stable with a maximum error of $2 \% \times S_n$ compared to the value set for the entire duration of each test sequence.

In case of full converter based generating technology where under frequency is not expected to have an effect on the active power capability of the generating unit, it is acceptable to conduct the test at a power level above $50 \% P_n$.

If the verification is carried out on the complete generating unit, any available function that prevents the generating unit from operating at operation frequencies specified for the verification shall be deactivated. Deactivated functions shall be documented in the test report.

The verification can be carried out separately on the relevant components of the generating units. The same frequency limits shall be considered.

In EN 50549-1 / EN 50549-2 the frequency ranges and associated time duration are classified in minimum and stringent requirements (Table 1). If the stringent requirements are tested, it is not necessary to repeat the test for the minimum requirements. The manufacturer can also propose defined frequency limits which shall exceed the minimum requirement.

In case of testing on rotating machine component (e.g. synchronous generator, asynchronous generator etc.), the manufacturer can calculate the expected effect of the frequency variation based on the EN IEC 60034 series. In this case it is the responsibility of the manufacturer to ensure that the temperatures for stator and rotor coils (including hotspot temperature) do not exceed the thermal classes of the insulation system for all the frequencies considered.

In case of testing on static machine component (e.g. converter), to provide verification of conformity with the minimum requirements according to EN 50549-1:2019 and EN 50549-2:2019, at least 2 verifications shall be conducted on the generating unit, respectively on the component, operating at the following frequency and specified duration:

- at 47,5 Hz with a duration of 5 min;
- at 51,5 Hz with a duration of 5 min.

To provide verification with the stringent requirements according to EN 50549-1:2019 and EN 50549-2:2019, at least 2 verifications shall be conducted on the generating unit, respectively on the component, operating at the following frequency and at least the specified duration:

- at 47,0 Hz with a duration of 20 s;
- at 52,0 Hz with a duration of 5 min.

To provide verification of conformity to an operating range proposed by manufacturer, tests shall be conducted as above. In this case the manufacturer shall define the minimum and maximum frequency limits and associated durations. The verification consists of running the generating unit, or the relevant components, at the defined frequency limits. The associated time duration will be limited to 5 min if the manufacturer specified a longer duration and to the declared maximum duration otherwise.

5.2.1.4 Verification through documentation and calculation

This verification process can be adopted, for example, when it is not economically reasonable or technically feasible to conduct the verification described in the previous clauses.

Any component that can affect the generating unit operation when the frequency deviates from nominal value and within the frequency limits shall be subject to the analysis.

For each item the manufacturer shall provide general information, documentation and if applicable calculation supporting the capability of the components to work at the frequency limits for the duration requested.

Examples of components that can be subject to analysis: prime movers, synchronous and asynchronous generators, motors, generating units, auxiliaries if affecting the generating unit operation such as AC operated drives e.g. for fans, pumps, electronic drive systems (PLL etc), transformers, PFCs etc.

5.2.1.5 Acceptance criteria

The results of 5.2.1.3 or 5.2.1.4 shall be evaluated. The verification is considered passed if

- the generating unit does not trip and operates at frequencies stated above or
- the generating unit does not trip and operates at an exceeding frequency range as stated by the manufacturer or responsible party or a specific grid code.

- When evaluating the underfrequency condition the generating unit is allowed to decrease its power output by up to 10 % $P_{\max}$ per Hertz starting from 49,5 Hz according to characteristic described in EN 50549-1:2019 and EN 50549-2:2019, 4.4.3, Figure 5 or to a more stringent power reduction characteristic defined by the manufacturer or responsible party or a specific grid code.

In case of verification through documentation, the information provided shall provide a reasonable confidence the generating unit can meet the frequency limits as declared.

A combination of the two acceptance criteria is acceptable in case the verification is carried out on the components and the components' capabilities are assessed using different methodologies.

5.2.1.6 Documentation

If the verification is conducted on the complete unit a test report documenting the results shall be provided.

If the verification is carried out on the generating unit components, the test report and associated technical documentation of each component shall be provided. The documentation shall cover only the components affected by frequency variation as declared by manufacturer and it shall be limited to frequency requirement. If evidence through calculation or numerical simulation is provided this shall be appropriately documented.

5.2.2 Voltage operating range

5.2.2.1 General

The aim of this procedure is to provide evidence of the capability of generating units to operate within a certain range of voltages.

5.2.2.2 Test application and verification methodology

The verification process can be conducted on the complete unit or on the components that can be affected when operating at voltage different from nominal within the voltage limits. Component not affected by voltage can be excluded from the verification or replaced by the other components, for example in laboratories or testing facilities, to facilitate the assessment.

The following approaches are considered justified in the verification process of some specific technology:

- In case of a PV generating unit, replacing the PV generator by a DC source (e.g. PV Array Simulator) operating at the minimum input voltage (4.2.2).
- In case of full converter generating units (Wind or CHP) replacing the generator and if applicable the generator side inverter/rectifier by an AC or if applicable a DC source according 4.2.7.
- In case of DFIG generating units, replacing the mechanical drive system by a test bench motor (4.2.2).
- In case of a generating unit connected to the grid through a synchronous generator, the test can be carried out on the generator only (for example at the generator manufacturer testing facility) replacing the mechanical drive system by a test bench motor (4.2.2).

The involved party (e.g. system operator, certifying body etc.) will evaluate the boundary (battery limits) for the specific generating unit considering the justification and documentation provided by the manufacturer, e.g. a step-up transformer can be part of the generating unit as declared by manufacturer of the generating unit.

The above shall not be considered as an exhaustive list and additional alternative approaches can be proposed to be evaluated and agreed upon by the involved party (e.g. system operator, certifying body etc.) based on justification and documentation presented by manufacturer.

Depending on the generating unit size, generating unit technology, site test or laboratory availability the verification can be carried out using one of the following methods:

- Verification of the generating unit or relevant component using a grid simulator in a laboratory.
- Verification of the generating unit or relevant component at site.

- Verification of the generating unit or relevant components at manufacturer testing facility.
- Verification of the generating unit or relevant components through analysis and/or calculation provided by manufacturer.

Alternative methodologies can be proposed by the manufacturer. The involved parties shall agree on alternative methodologies given they provide an equivalent level of confidence.

Verification with reduced time duration is permitted whereas longer duration does not affect the result of the test. Justification shall be documented by the manufacturer.

The voltage operating points shall be adjusted with a maximum error of 0,5 % U_n , U_c respectively. The voltage fluctuation during the recording of the test shall not exceed an absolute value of 2 % U_n .

During the test, frequency, RMS voltage, RMS current and active and reactive power measured at the output terminals of the generating unit shall be recorded at a rate of at least 10 cycle average value.

The verification of the voltage limits can be carried out during the verification of the capability limits and using the correspondent procedures (see 5.5.1).

Verification procedures aimed to verify generating unit or component voltage limits present in product standards can be used as an alternative to the ones described in the following clauses, when applicable.

NOTE It is possible to conduct the tests described below in combination with the tests to provide evidence of the frequency operating range in order to simplify the testing procedure. However, voltage range and frequency range are considered separate requirements. The combined deviation of frequency and voltage is a separate and additional requirement eventually to be specified considering technology capability and associated product standard (e.g. EN IEC 60034 for rotating machines).

5.2.2.3 Verification procedure using Grid Simulator

The generating unit can be tested using a Grid Simulator. The Grid Simulator shall be designed to control the voltage up to the limits to be tested.

At least 2 verifications shall be conducted, one at each voltage limit.

The test shall be carried out with the generating unit operating as follows:

- at the apparent power for this operating point as stated by the manufacturer;
- at an active factor or reactive power set point within normal operation range of the generating unit as stated by the manufacturer;

NOTE The active factor or reactive power set point is randomly chosen.

- at nominal frequency or in general not exceeding the voltage over frequency (U/f) ratio as stated by the manufacturer (or as stated in the applicable product standard).

The generating unit shall be operated at nominal voltage as declared by the manufacturer before starting the test. The voltage limits as described below are referred to the nominal voltages indicated by the manufacturer of the generating unit.

The voltage at the terminals shall be modified in steps according to the following sequence:

- The voltage shall be reduced to the minimum voltage and maintained for a minimum of 10 min time;
- The voltage shall be increased to its nominal value and maintained for a minimum of 5 min and up to 10 min;
- The voltage shall be increased to its maximum limit and maintained for a minimum of 10 min time;
- The voltage shall be decreased to the voltage nominal value.

The followings values shall be used as reference when verifying compliance to the EN 50549-1:2019:

- $U \leq 85 \% U_n$
- $U \geq 110 \% U_n$

The followings values shall be used as reference when verifying compliance to the EN 50549-2:2019:

- $U \leq 90 \% U_n$
- $U \geq 110 \% U_n$

To provide verification of conformity to an operating range proposed by manufacturer, tests shall be conducted as above. In this case the manufacturer shall define the minimum and maximum voltage limits. The verification consists of running the generating unit, or the relevant components, at the defined voltage limits.

The tests shall be conducted without modifying the power output of the generating unit. In case of synchronous generator, the temperature on the windings may increase within the declared temperature class during the test.

As an alternative longer time can be maintained at the generating unit terminal up to 30 min. In this case a power reduction may be permitted, depending on local regulation.

In case of synchronous generator, for longer period the winding temperature will likely increase. However, the temperature on the windings shall not exceed the insulation class of the winding.

If the verification is carried out on the complete generating unit, any available logic function that prevents the generating unit from operating at minimum or maximum operation voltage shall be deactivated. Deactivated logic functions shall be stated in the verification report.

5.2.2.4 Verification procedure at site

This clause refers to the possibility of testing a generating unit or component using equipment at site that permits a change in the voltage, different from a grid simulator. Examples are step-up or step-down transformers equipped with on-load tap changer where tap and consequently the voltage at generator terminals can be modified up to and possibly above the limits to be verified. Before assuming this procedure can be conducted at site, it shall be considered that the on-load tap changer controls the voltage within a defined voltage range and the number of steps of the tap changer defines the granularity of the test. Finally, before carrying out any test, possible impact on the plant where the generating unit is installed and on the system shall be properly evaluated.

When using an on-load tap changer, the tap changer shall be fixed during the test to avoid the occurrence of a step.

The verification process consists of varying the voltage using equipment at site. In principle the procedure should be similar to the one described in the case where a grid simulator is used. However due to the unique configuration of every single site, detailed procedure shall be agreed among involved parties. During the tests, the voltage at the terminals of the generating unit or component to be tested shall be equal to or exceed the voltage limits as described in the procedure applicable when using a grid simulator.

It can be expected that the voltage fluctuates during the tests. Permitted voltage deviation during the test shall be within $\pm 3\% U_c$, unless differently stated in applicable standards.

The same consideration regarding the temperature of the generating unit or component applies like the ones described in the verification using a grid simulator.

5.2.2.5 Verification using documentation, calculation and if applicable combined with manufacturer tests

The verification can be carried out based on documentation, calculation if applicable combined with manufacturer test or product specific test.

It is expected that the verification in this case would be based on the component (e.g. inverter, synchronous generator) rather than on the complete unit.

The verification process consists in documenting the justification that proves the generating unit or the component is capable to meet the voltage limits requirement. The documentation can include what the expected stress (thermal, mechanical, etc.) on the component is expected when operating at the voltage limits. In case of synchronous generating technology, this includes expected temperature on the windings.

The manufacturer shall provide expected component or winding temperature deviation calculated for each voltage limit related to the permissible duration. The temperature reached on the component or winding shall not exceed the correspondent insulation class. In case of testing on rotating machine component (e.g. synchronous generator, asynchronous generator etc.), the manufacturer can calculate the expected effect of the voltage variation based on the EN IEC 60034 standard tests. In this case the temperature calculated for stator and rotor coils shall not exceed their correspondent thermal insulation class at voltage limits.

The documentation should include reference to tests carried out on the generating unit or component based on the specific product standard.

5.2.2.6 Assessment criteria

The requirement is considered passed when the generating unit is able to remain in operation and does not disconnect from the system during the test and if the documentation provided shows that the generating unit is expected to run within its operational limits (e.g. temperature on the components does not exceed insulation thermal classes).

5.2.2.7 Documentation

The documentation shall include the following:

- Generating unit documentation showing nominal voltage and limits;
- Test documentation with corresponding recordings of the tests carried out;
- Documentation demonstrating voltage limits of the generating units;
- If applicable documentation based on product test.

5.3 Immunity to disturbances

5.3.1 Rate of change of frequency (ROCOF)

5.3.1.1 General

The aim of this test is to provide evidence of generating unit capability to withstand defined rate of change of frequency.

5.3.1.2 Test application and verification methodology

The verification process can be conducted on the complete unit or on the components that can be affected by frequency variation if running at frequencies different from nominal within the frequency limits. Components not affected by frequency can be excluded from the verification or replaced by other components, for example in laboratory testing, to facilitate the assessment.

As far as the energy source and the prime mover of generating units are concerned, the following approaches are considered justified in the verification process of a complete unit of some specific technology:

- In case of a PV generating unit, replacing the PV generator by a DC source (e.g. PV Array Simulator) (4.2.2).
- In case of full converter generating units (Wind or CHP) replacing the generator and the generator side inverter/rectifier by a DC source (4.2.2).

- In case of DFIG generating units, replacing the mechanical drive system by a test bench motor. The relevant parties (e.g. system operator, certifying body etc.) will evaluate the boundary (battery limits) for the specific generating unit considering the justification and documentation provided by the manufacturer (4.2.2).

The above shall not be considered as an exhaustive list and additional alternative approaches can be proposed to be evaluated and agreed upon by involved parties (e.g. manufacturer, system operator, certifying body, etc.).

The verification can be conducted using the following methodologies:

- verification using Grid Simulator;
- verification of the generating unit or relevant component in island operation with sufficient load;
- verification through calculation and numerical simulation (4.2.11).

Alternative methodologies can be proposed by the manufacturer. The involved parties shall agree on alternative methodologies given they provide an equivalent level of confidence.

During the test, frequency, RMS voltage, RMS current and the active power measured at the output terminals of the generating unit shall be recorded as 10 cycle average values. If the evaluation is carried out based on component evaluation only the values applicable for the component shall be measured, however as a minimum the frequency (or correspondent speed) shall be measured.

5.3.1.3 Verification procedure using Grid Simulator

The test shall be conducted on a grid simulator able to control the frequency within the required range and with the required dynamic.

Initial status of the generating unit before the test shall be as follows:

- The generating unit, connected to a grid simulator, shall be operating between 100 % and 80 % of the nominal power
- with an active factor equal to 1.
- ROCOF protection function shall be inactive during the test. The ROCOF protection function and correspondent settings shall be tested as described in 5.7.

Then the test shall be conducted following the sequence represented in the Figure 4 below.

The control mode and any active logics shall be documented unless they are not relevant for the result of the test.

To check ROCOF condition on overfrequency and underfrequency the grid simulator shall change the frequency at the generator terminals as described in the following graphs and associated tables. The grid simulator shall increase and decrease the frequency linearly over time.

During the Overfrequency and Underfrequency verification, once the higher, respectively, lower values of frequency have been reached, the frequency shall be maintained for a time period equal or longer than 3 s which normally corresponds to the time requested by the system to stabilize during a real event.

During the test, the frequency, RMS voltage, RMS current and active and reactive power measured at the output terminals of the generating unit shall be recorded as 10 cycle average values.

To prove the ROCOF capability, the sequences described in Figure 4 and Table 3 below shall be used.

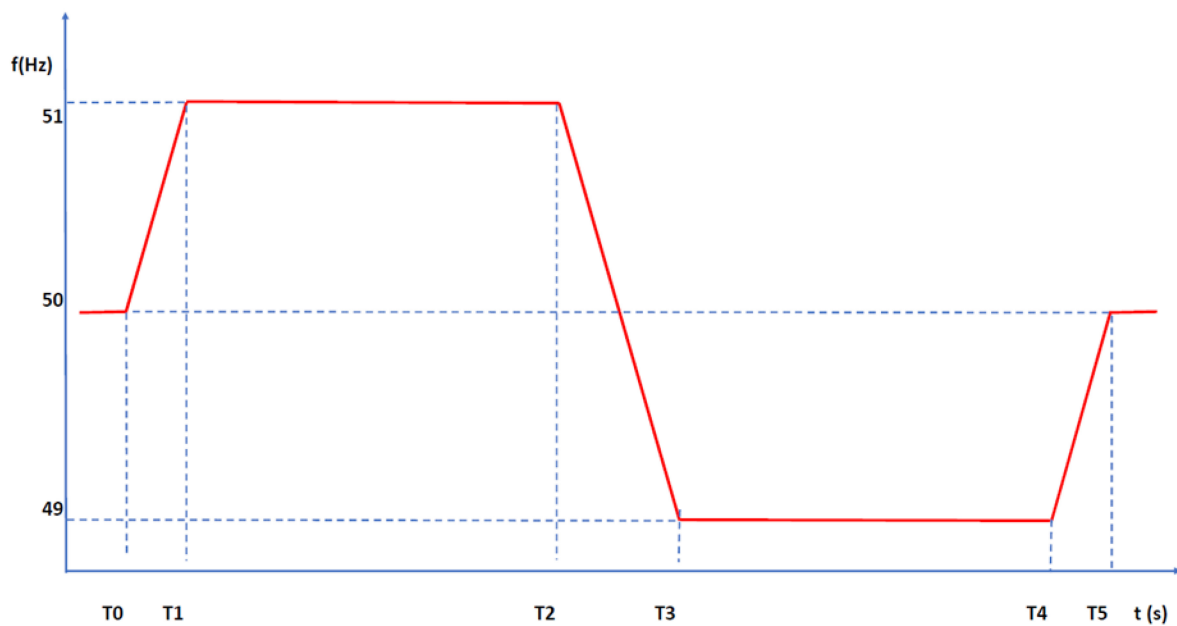


Figure 4 — ROCOF Test

Table 3 — Frequency steps during ROCOF Overfrequency and Underfrequency verifications

Step	Frequency	ROCOF associated with time interval
T0	50 Hz	-
T0 to T1	-	= Required ROCOF Value
$T1 = T0 + (\text{Required Minimum Measurement Time})$	$50 \text{ Hz} + (\text{Required ROCOF Value}) \times (\text{Required Minimum Measurement Time})$	-
T1 to T2	-	Zero
$T2 = T0 + (\text{Required Minimum Measurement Time}) + 3 \text{ s}$	$50 \text{ Hz} + (\text{Required ROCOF Value}) \times (\text{Required Minimum Measurement Time})$	-
T2 to T3	-	= - (Required ROCOF Value)
$T3 = T0 + 3 \times (\text{Required Minimum Measurement Time}) + 3 \text{ s}$	$50 - (\text{Required ROCOF Value}) \times (\text{Required Minimum Measurement Time}) \text{ Hz}$	-
T3 to T4	-	Zero
$T4 = T0 + 3 \times (\text{Required Minimum Measurement Time}) + 6 \text{ s}$	$50 - (\text{Required ROCOF Value}) \times (\text{Required Minimum Measurement Time}) \text{ Hz}$	-
T4 to T5	-	= Required ROCOF Value
$T5 = T0 + 4 \times (\text{Required Minimum Measurement Time}) + 6 \text{ s}$	50 Hz	-

The ROCOF to be used for the ramp rates is the required value as specified in Table C.1 of EN 50549-1:2019 or EN 50549-2:2019 or provided by manufacturer or as requested by the responsible party or a specific grid code.

5.3.1.4 Verification at reduced output power using Grid Simulator

If the power output of the generating unit has no influence on the capability of the generating unit to cope with the ROCOF variation, the generating unit can be tested at any power within the active power range declared by manufacturer.

The verification process shall be the same as described in 5.3.1.3.

5.3.1.5 Verification of the generating unit or relevant component in island operation with sufficient load

If the generating unit is able to operate in island mode and in grid parallel mode without modification of the fundamental control structure, the generating unit can be tested in island operation by connecting and disconnecting appropriate loads to reach the ROCOF events as stated in 5.3.1.3.

The verification process shall be the same as described in 5.3.1.3.

5.3.1.6 Verification procedure using documentation and calculation or numerical simulation

If the generating unit cannot be tested using a grid simulator, the requirement can be also demonstrated by documental process or through simulation.

The manufacturer shall provide associated documentation and/or simulation providing evidence of requirement capability.

Evidence can be provided as an extrapolation or calculation or explanatory documents from tests and measurements taken on the generating unit or corresponding components.

Evidence can include simulations or calculations based on generating unit or component model.

Evidence can include results or measurements from other relevant tests or events like FRT tests, load rejection tests, real event on the grid.

5.3.1.7 Assessment criteria

In case of verification using a Grid Simulator, the verification is considered satisfactory if the generating unit operates or unit component remains in operation without disconnection from the grid (no trip).

In case of verification through documentation, calculation or computer based simulation (e.g. using functional block diagrams representing the unite behaviour) the information shall explicitly provide evidence the unit is capable to cope with the requirements and no malfunction can be expected.

5.3.1.8 Documentation

The following shall be part of the documentation associated to the requirements.

- Description of the test carried out and associated results if real test has been carried out to prove compliance.
- Documentation provided by manufacturer if documental assessment has been carried out.
- Simulation of the tests and associated results if validated model is used to prove compliance.
- ROCOF protection settings as set for the generating unit (see 5.7 for ROCOF protection testing).
- Vector shift protection settings if applicable as set for the generating unit.

5.3.2 Phase jump

5.3.2.1 General

This test procedure is intended to provide evidence of the capability of generating units to withstand a phase jump.

Phase jump immunity considered in this Standard consists in:

- Phase jump immunity caused by change in system impedance (for instance splitting of transmission system) see capability 1 in this clause.
- Phase jump immunity caused by automatic reclosing operation, see capability 2 in this clause.
- Phase jump immunity caused by voltage dips (voltage variations) e.g. 3 phase or 2-phase faults, see UVRT and OVRT in 5.3.3.

As there is no phase jump ride through requirement and no withstand without damage requirement in EN 50549-1:2019 and EN 50549-2:2019 this test is intended to evaluate the operational capability of the generating unit. Once a requirement will be defined, this test procedure will be adapted accordingly.

A phase jump applied to a signal $a(t) = \hat{A} \cos(\omega t + \vartheta_0)$ is defined by the new signal:

$$b(t) = \hat{A} \cos(\omega t + \vartheta_0 + \delta \cdot h1(t))$$

where $h1(t)$ is a unit step function, δ the phase step size.

There are two different capabilities to be evaluated, these are:

- Capability 1, phase jump ride through: The capability of generating units to ride through vector jumps (phase shifts) $+\delta_1$ and $-\delta_1$, due to system events with no tripping of protection functions and a recovery of controlled operation as fast as possible after the event.
- Capability 2, withstand without damage: The capability of generating units to withstand without damage automatic reclosing in phase discordance of $+\delta_2$ and $-\delta_2$. During the test a disconnection of the generating unit due to protection tripping is permissible as long as the generating unit is not affected by any damages.

NOTE EN 50549-1:2019 and EN 50549-2:2019 respectively do not require immunity to phase jump, but a corresponding requirement is in preparation for a new edition of these standards. Therefore, a procedure to evaluate this capability is given here.

For the purpose of the capability 1 test the manufacturer shall declare the ride through capability δ_1 of the generating unit and the active power and reactive power recovery response time and settling time. The test shall be conducted to validate this declaration with a phase jump of at least the declared angle and a magnitude change of at least the declared change.

For the purpose of the capability 2 test the manufacturer shall declare the withstand without damage capability $+\delta_{2.1}$ and if applicable $+\delta_{2.2}$ of the generating unit. The test shall be conducted to validate this declaration with a phase jump of at least the declared angle.

EXAMPLE $\delta_{2.1} = 90^\circ$ and $\delta_{2.2} = 180^\circ$ are often considered as the most unfavourable cases.

5.3.2.2 Test application and verification methodology

The verification process can be conducted on the complete unit or on the components that can be affected by vector jumps. Component not affected by vector jumps can be excluded from the verification or replaced by others components, for example in laboratories, to facilitate the assessment.

If interface protection is included in EUT and if frequency protection and/or ROCOF protection are included in the evaluated protection functions, these functions shall be active.

NOTE Voltage phase jumps can induce false frequency and ROCOF measurements of the interface protection.

As far as the energy source and the prime mover of generating units are concerned, the following approaches are considered justified in the verification process of a complete unit of some specific technology:

- In case of a PV generating unit, replacing the PV generator by a DC source (e.g. PV Array Simulator) according 4.2.2.
- In case of full converter generating units (Wind or CHP) replacing the generator and if applicable the generator side inverter/rectifier by an AC or if applicable a DC source according 4.2.2.
- In case of DFIG generating units, replacing the mechanical drive system by a test bench motor according 4.2.2.
- In case of synchronous generating technology verification of the generating unit based on test by calculation and numerical simulation generating units of synchronous generating technology (see 4.2.11).

The above shall not be considered as an exhaustive list and additional alternative approaches can be proposed to be evaluated and agreed upon by involved parties (e.g. manufacturer, system operator, certifying body, etc.).

To apply the phase jump on the output terminal of the EUT, the EUT can be connected to a grid simulator or to an appropriate electrical circuit able to emulate the phase jump.

EXAMPLE A phase jump can be emulated by connecting a transformer with appropriate coupling in series with the power network to which the EUT is connected.

Alternative methodologies can be proposed by the manufacturer. The involved parties shall agree on alternative methodologies given they provide an equivalent level of confidence.

Each different setting of the test equipment shall be documented by a phase jump test without the generating system operating (no-load test).

For each test, time-series of voltage and current values shall be recorded with a sufficient sampling rate $\geq 10\text{kHz}$. The measurement is taken at the terminals of the EUT for at least 5 s (or according to the DSO's / national regulation) prior to the phase jump and until the effect of the phase jump on the generating unit has abated, but at least for 10 s after the event. The positive and negative sequence of active power, reactive power, active current, reactive current and voltage shall be calculated from the recorded data.

5.3.2.3 Verification procedure

Tests are conducted at nominal frequency. In case of three-phase generating unit, a symmetric three-phase system and all phase to phase voltages shall be tested. In case of single-phase generating unit test is conducted for the active phase only.

Tests are conducted according to the following procedure:

- Before the test the EUT is operating at nominal voltage, at a power level above $0,9 P_n$ and with a unit power factor ($\cos = 1$) at least for 5 min or the needed time for the internal temperature stabilization, whatever is the longer.
- Phase jumps are introduced simultaneously on all phases

- For capability 1 a phase jump shall be applied with two different values, $+\delta_1$ and $-\delta_1$. The phase jump shall be introduced with two different inception angles. One test shall be performed with a phase jump at the voltage zero crossing (0°) of the sinewave and the other with a phase jump at the top of the sinewave ($+90^\circ$). For three-phase systems phase 1 is used as reference.
- For capability 2: The phase jump shall be applied with two different values, $+\delta_{3,1}$ and $+\delta_{3,2}$ at the voltage zero crossing (0°) of the sinewave. The two-phase jumps shall be introduced with two different inception angles. One test shall be performed with a phase jump at the voltage zero crossing (0°) of the sinewave and the other with a phase jump at the top of the sinewave ($+90^\circ$). For three-phase systems phase 1 is used as reference.

5.3.2.4 Assessment criteria

As there is no phase jump ride through requirement and no withstand without damage requirement in EN 50549-1:2019 and EN 50549-2:2019, regarding these standards, no assessment criteria are defined.

The test is considered passed if:

- The phase jump ride through capability 1 as declared by the manufacturer or as requested by the responsible party or a specific grid code is confirmed.
- The active power and reactive power recovery response times and settling times as declared by the manufacturer or as requested by the responsible party or a specific grid code are confirmed.
- The withstand without damage capability as declared by the manufacturer or as requested by the responsible party or a specific grid code is confirmed.

5.3.2.5 Documentation

The following shall be part of the documentation associated to the requirements.

- Description of the test or simulations if applicable and associated results.
- The declared capability of the manufacturer :
 - The ride through capability δ_1 of the generating unit and the active power and reactive power recovery response time and settling time.
 - The withstand without damage capability $+\delta_{2,1}$ and if applicable $+\delta_{2,2}$ of the generating unit.
- The values of the phase of the voltage before and after the phase jump, with a maximum error of 1° ;
- For each test, an X-Y graph representing the currents delivered by the generator as a function of the time, from before the phase jump to at least 200 ms after the phase jump. Currents can be plotted as waveform or as root mean square values calculated over a time window running from 20 ms including amplitude and angle.
- For capability 1 tests: The step response time and the settling time for active and reactive power recovery measured from the phase jump event.
- Vector shift, ROCOF and frequency protection settings if applicable as set for the generating unit.

5.3.3 Fault ride through, over-voltage (OVRT) and under-voltage (UVRT)

5.3.3.1 General

The aim of this procedure is to provide evidence of the capability of generating units to withstand dynamic voltage changes.

When required by the applied grid code or requirement document, this test procedure is also intended to provide evidence of controlled short circuit current contribution.

5.3.3.2 Test application and verification methodology

The assessment shall be performed:

- In case of a PV generating unit, the test shall be done as a complete unit test, alternatively by replacing the PV generator by a PV simulator (see 4.2.2).
- In case of Battery generating units, the test shall be done as complete unit test, alternatively by replacing the battery by a battery simulator (see 4.2.2).
- In case of Wind Turbines generating units, the test shall be done as a complete unit test. If multiple tests are conducted to verify the behaviour of the unit in different control modes, these additional tests might be done as test on the electrical generating system as a nacelle test (see 4.2.3).

NOTE Complete unit test (see also Clause 4) includes test in the field where a test container (FRT) is included into the test setup.

- In case of generating units using synchronous generating technology, the test shall be done as a complete unit test. If multiple tests are conducted to verify the behaviour of the unit in different control modes, these additional tests might be conducted as tests on the electrical generating system. As an alternative to complete unit tests, simulations using a validated model according to 5.13 may be carried out.

In the case of Generating unit technologies not mentioned above, the test shall be conducted as a complete unit test. Alternatively, for technologies not mentioned above, subsystems may be defined and tested when it can be shown that the test on the subsystem has no impact on the results compared to the complete unit test.

A technical description shall be provided making it technically transparent why the test on the subsystem has no effect on the results.

5.3.3.3 Verification procedure through generating unit test

The manufacturer shall define the available configuration parameters that influence the behaviour of EUT.

The test can be carried out at a setup based on a voltage division principle or an AC grid simulator or other suitable setups, see also Annex A.

Any function that might cause a disconnection shall be activated during the test.

The capability of the generating unit to sustain dynamic voltage changes shall be demonstrated for the generating unit operating in the full load and partial load range. Partial load can be performed with a down regulated generating system (de-rating or curtailed) or where applicable by limiting the available power.

The test shall be carried out for the generating system operating at two power levels:

- 1) between $0,1 P_n$ and $0,5 P_n$, or above the minimum regulating level, if the minimum regulating level is higher than $0,5 P_n$

and

- 2) above $0,9 P_n$

The voltage magnitudes specified for the test may be affected by the EUT. Hence they are defined for the generating unit not connected (no-load test). Without the generating unit connected, the voltage-time-characteristic for the undervoltage events shall be within the shape indicated in Figure 5, whereas the characteristic for the overvoltage events shall be within the shape indicated in Figure 6. In these figures,

- U_{pre} indicates the voltage level prior to the event,
- Dip/Swell Level Tested indicates the voltage level during the event,
- t_{fault} indicates the start of the event or the closure of the short circuit switch respectively and
- t_{clear} indicates the start of the voltage recovery or opening of the short circuit switch respectively,
- the p.u. base for the tolerances is U_{pre} ,
- a delay resulting from the calculation of the phasor and the symmetrical components of 20 ms is considered.

The duration and level of the dip or the swell shall be measured at the output terminals of the test equipment. The time-tolerance is included as to account for tolerances in the test equipment and that the calculated positive sequence voltage will not drop or rise instantly, but with a slope of one line period for the RMS calculation.

To define the effect of the generating unit on the voltage magnitude, the short circuit power of the test setup shall be in the range of 2 times to 40 times the nominal power of the generating unit. The X/R ratio of the test impedance shall be at least 3.

In case of two-phase faults besides the voltage drop a phase jump shall be present. Depending on the test setup this phase jump is intrinsic to the test setup e.g. in case of a test set up with a voltage division principle or might be explicitly configured e.g. in case of a grid simulator. Annex A provides further requirements on phase jump for grid simulator test setup.

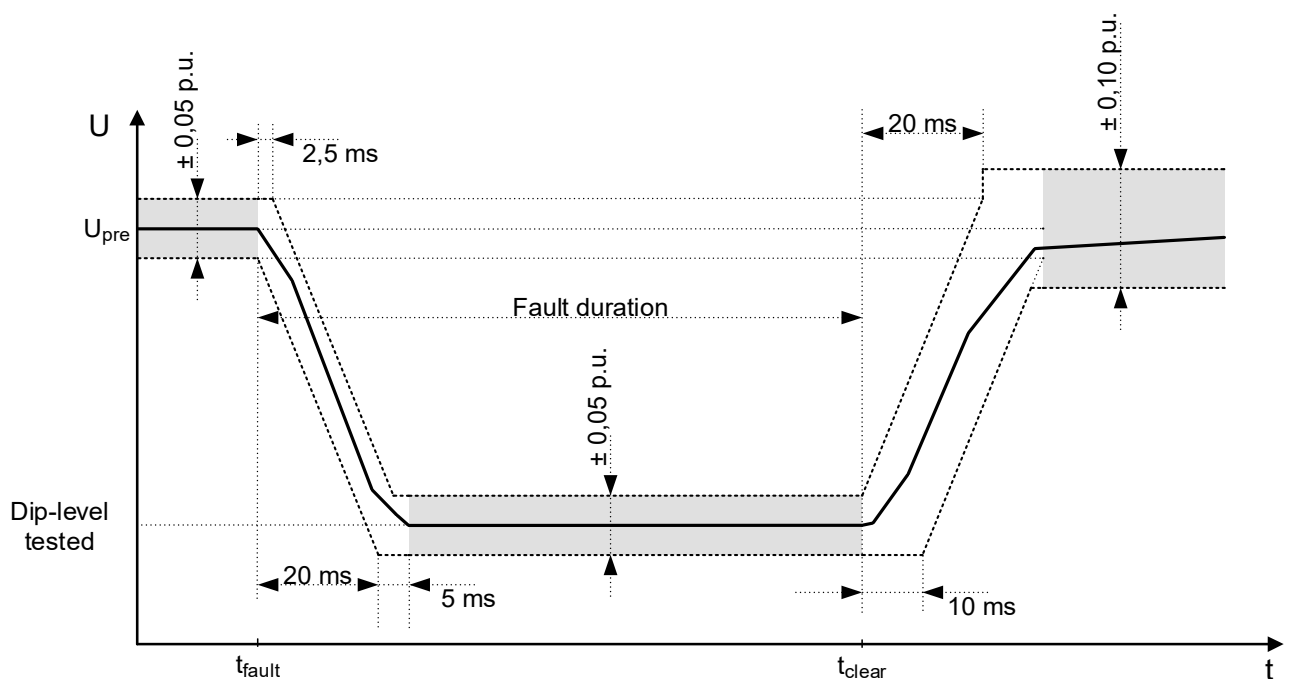


Figure 5 — Tolerances of the positive sequence voltage for the undervoltage event

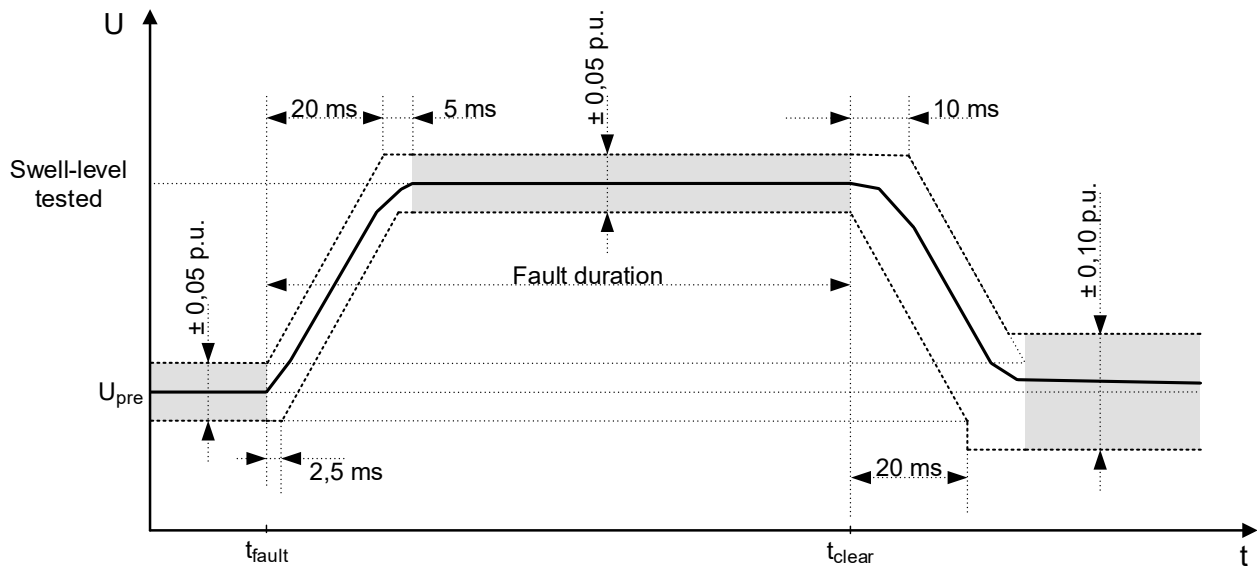


Figure 6 — Tolerances of the positive sequence voltage for the overvoltage event

NOTE 1 The tolerance of the voltage is stated as a percentage in relation to the prefault voltage U_{pre} .

The manufacturer shall define:

- the voltage time diagram to be verified;

and

- the duration and voltage level of each test to be conducted.

The number of tests, the duration and voltage level of the tests conducted shall be chosen in a way to provide evidence of compliance with the voltage time diagram to be verified.

Each test according to Table 4 and Table 5 represents one point in the voltage-time diagram to be verified e.g. Figure 6, 7, 8 of EN 50549-1:2019 and EN 50549-2:2019. If the voltage-time diagram includes vertical sections as Figure 7 and 8 of EN 50549-1:2019 and EN 50549-2:2019, the voltage level and duration according to Table 4 and Table 5 shall be chosen in a way that the most severe voltage level at this duration shall be tested. For each vertical section at least one test shall be included. If necessary additional tests shall be added to Table 4 and Table 5.

If the test is intended to provide evidence of controlled short circuit current contribution, at least the voltage levels for undervoltage according to Table 4 and at least the voltage levels for overvoltage according to Table 5 shall be tested, with each level tested for (at least) a symmetric event and an asymmetric event (simulated two-phase fault).

NOTE 2 The described number of tests is considered an absolute minimum to minimize the effort in an accredited environment. It is expected that for reasons of quality assurance the manufacturer conducts additional and thorough assessments for all possible parameter variation.

If an available (active) islanding detection causes additional inaccuracy to the controlled short circuit current contribution, the test may be repeated with deactivated islanding detection. The inaccuracy caused by the active islanding detection shall be stated in the report.

The tests may also be used to provide a basis for generating system numerical simulation model validation.

Table 4 — Example of undervoltage tests

1	2	3	4	5
Case	voltage level ^a (according capability curve)	Duration ^b (according capability curve) [ms]	Default requirement according EN50549-1/2 Synchronous / non-synchronous generation technology	
VD1 – symmetrical three-phase undervoltage	$(U_{min} + 0.0U_{UVRC}) \pm 0.05U_n$		30 % U_n / 5 % U_n	150ms / 200ms
VD2 – symmetrical three-phase undervoltage	$(U_{min} + 0.2U_{UVRC}) \pm 0.05U_n$		44 % U_n / 24 % U_n	150ms ^c / 630ms
VD3 – symmetrical three-phase undervoltage	$(U_{min} + 0.5U_{UVRC}) \pm 0.05U_n$		65 % U_n / 52 % U_n	150ms ^c / 1.260ms
VD4 – symmetrical three-phase undervoltage	$(U_{min} + 0.75U_{UVRC}) \pm 0.05U_n$		82 % U_n / 76 % U_n	1.340ms \ 1.800ms
VD5 – symmetrical three-phase undervoltage	$(U_{min} + 0.9U_{UVRC}) \pm 0.05U_n$		93 % U_n / 90 % U_n	6.000ms / 6.000ms
VD6 – two- phase undervoltage	$(U_{min} + 0.0U_{UVRC}) \pm 0.05U_n$		30 % U_n / 5 % U_n	150ms / 200ms
VD7 – two- phase undervoltage	$(U_{min} + 0.2U_{UVRC}) \pm 0.05U_n$		44 % U_n / 24 % U_n	150ms ^c / 630ms
VD8 – two- phase undervoltage	$(U_{min} + 0.5U_{UVRC}) \pm 0.05U_n$		65 % U_n / 52 % U_n	150ms ^c / 1.260ms
VD9 – two- phase undervoltage	$(U_{min} + 0.75U_{UVRC}) \pm 0.05U_n$		82 % U_n / 76 % U_n	1.340ms \ 1.800ms
VD10 – two- phase undervoltage	$(U_{min} + 0.9U_{UVRC}) \pm 0.05U_n$		93 % U_n / 90 % U_n	6.000ms / 6.000ms

^a The stated voltage level shall be adapted in case the voltage-time diagram includes vertical sections. At the duration of the vertical section, the most severe voltage level shall be tested. If multiple vertical lines are included, additional tests might be needed to test the most severe voltage for each vertical section.

^b This column is intended as template for the actual characteristic as stated by the manufacturer

^c If the voltage-time diagram includes vertical sections, only the most severe voltage level at this duration shall be tested. In case of the EN 50549-2:2019 default requirement for synchronous generating technology VD 2, VD 3, VD 7, VD 8 are consequently optional.

Table 4 specifies magnitudes for the undervoltage testing. Voltage levels refer to no-load-tests. $U_{\min}$ is the minimum voltage the generating unit can ride through, UVRC is the under voltage range capability calculated as $U_{UVRC} = U_n - U_{\min}$ (see Figure 7).

Table 5 — Example of overvoltage tests

1	2	3	4	5
Case	voltage level ^a (according capability curve)	Duration ^b (according to capability curve) [ms]	Default requirement according to EN 50549-1 / EN 50549-2 Synchronous and non-synchronous generation technology	
VS1 – symmetrical three-phase overvoltage	$(U_n + 1.0U_{OVRC}) \pm 0.05U_n$		125 % U_n	100ms
VS2.1 – symmetrical three-phase overvoltage	— ^c		120 % U_n	5.000ms
VS2.2 – symmetrical three-phase overvoltage	$(U_n + 0.6U_{OVRC}) \pm 0.05U_n$		115 % U_n	60.000ms
VS3 – two-phase overvoltage	$(U_n + 1.0U_{OVRC}) \pm 0.05U_n$		125 % U_n	100ms
VS4.1 – two- phase overvoltage	— ^c		120 % U_n	5.000ms
VS4.2 – two- phase overvoltage	$(U_n + 0.6U_{OVRC}) \pm 0.05U_n$		115 % U_n	60.000ms
^a The stated voltage level shall be adapted in case the voltage-time diagram includes vertical sections. At the duration of the vertical section, the most severe voltage level shall be tested. If multiple vertical lines are included, additional tests might be needed to test the most severe voltage for each vertical section. ^b This column is intended as template for the actual characteristic as stated by the manufacturer. ^c As Figure 8 of EN 50549-1:2019 and EN 50549-2:2019 includes two vertical sections, one additional test is needed.				

Table 5 specifies magnitudes for the overvoltage testing. Voltage levels refer to no-load-tests. $U_{\max}$ is the maximum voltage the generating unit can ride through, U_{OVRC} is the over voltage range capability calculated as $U_{OVRC} = U_{\max} - U_n$ (see Figure 7)

Column 3 of Table 4 and Table 5 can be used as template for the test report for a specific capability deviating of EN 50549-1:2019 and EN 50549-2:2019 default requirements.

Column 4 and 5 of Table 4 and Table 5 provide example values for the default requirement of EN 50549-1:2019 and 50549-2:2019. The stated duration is the absolute minimum to comply with the default requirement of EN 50549-1:2019 and 50549-2:2019. Timing tolerances of the test setup shall be added if appropriate. If the voltage magnitude during the test diverges from the set value within the stated tolerances of $\pm 0,05 U_n$ the test duration shall be adapted to meet the requirements of required characteristic at the actually tested magnitude.

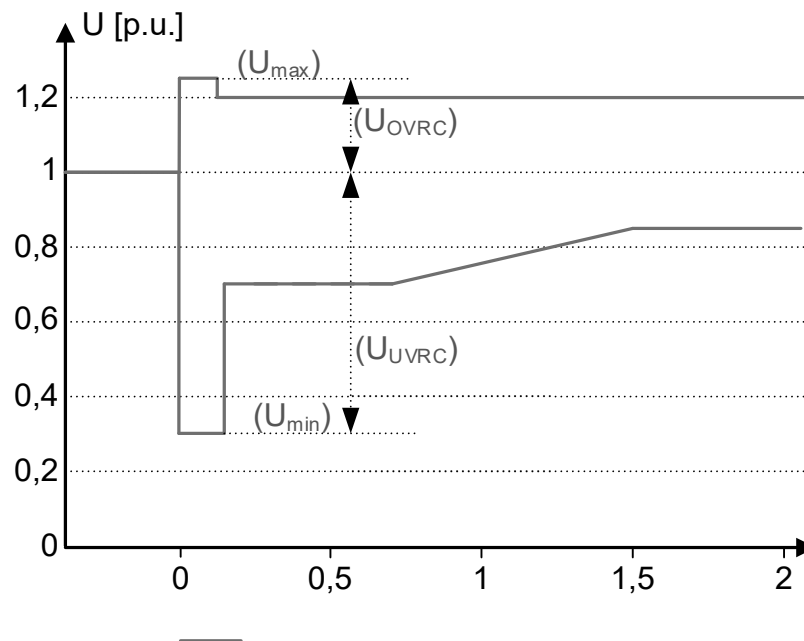


Figure 7 — U_{UVRC} and U_{OVRC} for the default requirement of a generating plant of synchronous generating technology

The number of tests and operating modes shall be defined and described by the manufacturer in order to document the generating system's capability.

In general, the tests should demonstrate the generating unit's maximum capacity to withstand undervoltage and overvoltage events. Hence, the longest feasible individual duration for each dip and swell should be chosen, in order to prove conformity with individual national requirements.

Tests VD5, VD10, VS2 and VS4 are intended to provide evidence of the insensitivity range against a sudden change in voltage for additional reactive current. The depth of tests VD5, VD10, VS2, VS4 might need to be adapted for this purpose depending on the configured insensitivity range of the EUT. The Dip/Swell level tested shall be chosen in a way to leave the insensitivity range. These tests only need to be conducted if controlled short circuit contribution is configured. As these tests are only relevant for the control of the generating unit, these tests may be conducted as on the electrical generating system.

If evidence of controlled short circuit current contribution is provided, following tests shall be additionally executed:

- with respect to UVRT testing, test VD4 shall be repeated with an underexcited operating mode (e.g. active factor 0,95 under excited) of the generating unit before fault occurrence (full or partial load) with a gradient according EN 50549-2:2019 4.7.4 $k \geq 2$.
- with respect to OVRT testing, test VS2 shall be repeated with an overexcited operating mode of the generating unit before fault occurrence (full or partial load) with a k-gradient $k \geq 2$.
- In order to demonstrate the correct parameterization, test VD5 shall be executed with an alternative gradient $k \geq 5$.

If evidence of optional modes for controlled short circuit current contribution is provided, following tests shall be additionally executed:

- With respect to active power priority: Test VD 2 in partial load shall be repeated.
- With respect to reactive current limitation: With a reactive current limitation configured to 90 % I_n test VD 2 in partial load shall be repeated.

- With respect to zero current threshold: With a zero current threshold configured to 60 % U_n test VD3 and VD 4 shall be repeated

The specified settings above apply for a general conformity assessment according Figure 3. In case of a conformity assessment for a specific grid code, the settings and the Dip/Swell level tested shall be adapted as required by the specific technical requirement (e.g. grid code).

If evidence of zero current mode contribution is provided, following tests shall be additionally executed:

- If zero current mode is the only mode available in the EUT, no further tests are needed as the correct behaviour may be evaluated based on the tests according Table 4 and Table 5.
- If zero current mode is an optional mode in the EUT, two tests of Table 4 and two tests of Table 5 shall be repeated. The tests shall be chosen to test one overvoltage and one undervoltage event within the static operating range and one of each outside the static operating range.

For each test case two consecutive tests shall be passed successfully.

Each different setting of the test equipment shall be documented by a dynamic voltage change test without the generating system operating (no-load test).

For each test, time-series of voltage and current values shall be recorded with a sufficient sampling rate according 4.3. The measurement is taken at the terminals of the EUT for at least 5 s (or according to the DSO's / national regulation) prior to the dynamic voltage changes or the first switching event and until the effect of the voltage change on the generating unit has abated, but at least for 10 s after fault clearance or after the switching event post the fault clearance. The positive and negative sequence of active power, reactive power, active current, reactive current and voltage shall be calculated from the recorded data.

The step behaviour shall be evaluated according EN 50549-2:2019 3.7.3. The instant of the fault t_{fault} shall be used as instant of the step inception evaluated based on the sampled values,

NOTE 3 It is expected that the voltage change at t_{fault} is significant in the recorded sampled voltage values.

5.3.3.4 Additional specifications for test of inverters with specified DC input voltage range

For some generating technologies the DC input voltage of the grid side inverter depends on the status of the primary energy source.

This is for example the case for photovoltaic generating technology where the DC voltage depends on the PV-module string sizing and the module temperature and for Battery generating technology where the DC voltage depends on the cell string sizing and the state of charge.

In this case it shall be verified that the requirements regarding immunity to under and overvoltage and the provision of short circuit current contribution is available over the full declared DC voltage input range of the inverter.

The two consecutive tests as specified in 5.3.3.3 shall be conducted with different DC input voltages:

- One test near the minimum DC input voltage, between 0 % – 20 % of the voltage range;
- One test near the maximum DC input voltage, between 80 % – 100 % of the voltage range.

EXAMPLE If voltage range is 300 V – 900 V: 300 V = 0 %; 900 V = 100 %, $U_{\text{testmin}} = 300 \text{ V} - 420 \text{ V}$ as $300 \text{ V} + 0,2 \cdot 600 \text{ V} = 420 \text{ V}$; $U_{\text{testmax}} = 780 \text{ V} - 900 \text{ V}$ as $300 \text{ V} + 0,8 \cdot 600 \text{ V} = 780 \text{ V}$

For PV inverter the maximum and minimum DC input voltage shall be the minimum and maximum MPP voltage according to EN 50524.

NOTE In case of photovoltaic (PV) generating technology a reduction of active power during the fault will cause an increase of PV generator voltage. As a result the PV generator voltage can rise above the maximum MPP voltage during the fault.

5.3.3.5 Verification procedure through generating unit simulation for units with synchronous generating technology

This verification method is only applicable for generating units with synchronous generating technology. The simulation model shall be based on the design of the synchronous generator and the design of the prime mover according to 5.13.

NOTE Subclause 5.13 provides requirements including model validation based on operation in normal operating voltage range and normal operating frequency range due to natural grid voltage and set point variations and by simulation of a voltage dip in the control of the generating unit while connecting the generating unit to the grid in normal operating voltage range and normal operating frequency range.

If this method is applied, the requirements of 5.13 apply. The test set-up shall be modelled using standard library models of the used simulation environment. Alternatively, manufacturer provided models that can run in the used simulation environment may be used.

The model of the GUT shall comply with the requirements of 5.13. All functions within the control and protection of the prime mover and the synchronous machine that may cause a disconnection of the device shall be included in the model.

Each relevant protection function shall be described in the documentation including:

- energizing quantity,
- pick up time,
- reset time and reset ratio,
- configurable threshold range and default setting,
- configurable time delay setting and default setting.

The capability to withstand dynamic voltage changes of auxiliary equipment not included in the simulation model shall additionally be evaluated by inspection (see 4.2.13).

5.3.3.6 Assessment criteria of immunity

The test is considered passed if all of the following applies.

- The conducted tests verify the specified capability curve of the manufacturer.
- No trip occurred.
- Conducted tests represent the specified capability in duration and depth of voltage dips.

NOTE 1 The number of tests necessary to conduct in order to represent the specified capability depends on the complexity of the specified capability curve.

- The specified capability curve of the manufacturer does not show any “may disconnect” areas above (test case UVRT) or below (test case OVRT) the voltage time characteristic as specified by the DSO or applied grid code.
- The active power recovery time after fault is equal or less the time specified by the DSO or applied grid code.

NOTE 2 The default requirements of EN 50549-1:2019 and EN 50549-2:2019 are summarized in Annex C of EN 50549-1:2019 and EN 50549-2

5.3.3.7 Assessment criteria of zero current mode for non-synchronous generating technology

The test is considered passed if all of the following applies.

- All criteria of 5.3.3.6 apply.
- The conducted tests verify the activation threshold with an accuracy of 5 % of nominal voltage.

NOTE According to 5.3.3.3 test to verify the accuracy of the activation threshold might be conducted on the electrical generating system.

- The EUT reduced its current as fast as technically feasible below 10 % of rated current. A response time below 30 ms and a settling time below 60 ms is considered sufficient. In case of longer response and/or settling times, justification shall be provided. Delays resulting from the calculation of the phasor and the symmetrical components, typically 20 ms, shall be considered in the evaluation of the controlled short circuit current.
- The settings of the function, as well as the enabling and disabling of the function, are field adjustable and means are provided to protect these from unpermitted interference (e.g. password or seal).

5.3.3.8 Assessment criteria of controlled short circuit current contribution for non-synchronous generating technology

The test is considered passed if all of the following applies.

- The tests and the selection of voltage levels and fault duration have been conducted according to 5.3.3.3. All requirements of 5.3.3.6 apply.
- The settings of the function, as well as the enabling and disabling of the function, are field adjustable and means are provided to protect these from unpermitted interference (e.g. password or seal).
- For non-synchronous generating technology:
 - The conducted tests verify the activation beyond the insensitivity range with an accuracy of 5 % of nominal voltage.

NOTE According to 5.3.3.3 test to verify the accuracy of the activation threshold might be conducted on the electrical generating system.

- The conducted tests verify the provision of controlled short circuit current with:
 - Accuracy for positive and negative sequence current as required of the applicable grid code, or according to Figure 17 of EN 50549-2:2019.
 - Dynamic of response and settling time as required of the applicable grid code. In case of EN 50549-2:2019: 30 ms response time, 60 ms settling time for both fault inception and fault clearance. Delays resulting from the calculation of the phasor and the symmetrical components, typically 20 ms, shall be considered in the evaluation of the controlled short circuit current.

5.3.3.9 Assessment criteria for short circuit current for synchronous generating technology

- All criteria of 5.3.3.6 apply.
- The conducted tests shows that the excitation system varies the excitation current during the fault to contribute sustaining the grid voltage.
- If 4.2.11 is applied in addition to the above:
 - The generating unit shall not pole slip.
 - The dynamic angle deviation shall be less than 120°.