
**Reciprocating internal combustion
engine driven alternating current
generating sets —**

**Part 6:
Test methods**

*Groupes électrogènes à courant alternatif entraînés par moteurs
alternatifs à combustion interne —*

Partie 6: Méthodes d'essais

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*.

This third edition cancels and replaces the second edition (ISO 8528-6:2005), which has been technically revised.

The main changes are as follows:

- structure of testing completely modified (table updated);
- [Clause 7](#) now includes a test procedure related to generating sets connected to the grid;
- [Clause 8](#) introduced for accessing the performance of generating sets in isochronous mode and grid parallel mode.

A list of all parts in the ISO 8528 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Reciprocating internal combustion engine driven alternating current generating sets —

Part 6: Test methods

1 Scope

This document specifies the test methods to be used for characterizing an entire generating set. It applies to alternating current (AC) generating sets driven by reciprocating internal combustion (RIC) engines for land and marine use, excluding generating sets used on aircraft or to propel land vehicles and locomotives. This document also provides simulation methods as an alternative method for assessing the generating set capability to meet the requirements defined in ISO 8528-5.

For some specific applications (e.g., essential hospital supplies, high-rise buildings, operation in parallel with the grid), supplementary requirements can be necessary. The provisions of this document are intended as a basis for establishing any supplementary requirements.

For AC generating sets driven by other reciprocating-type prime movers (e.g., steam engines), this document is intended as a basis for establishing these requirements.

NOTE Existing test methods for the engine (ISO 3046-1 and ISO 3046-3) and generator (IEC 60034-2) are applicable for those components. The generating set manufacturer is responsible for specifying these characteristics and the tests to be performed to verify them.

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.

ISO 8528-1:2018, *Reciprocating internal combustion engine driven alternating current generating sets — Part 1: Application, ratings and performance*

ISO 8528-2, *Reciprocating internal combustion engine driven alternating current generating sets — Part 2: Engines*

ISO 8528-3:2020, *Reciprocating internal combustion engine driven alternating current generating sets — Part 3: Alternating current generators for generating sets*

ISO 8528-5:2022, *Reciprocating internal combustion engine driven alternating current generating sets — Part 5: Generating sets*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

IEC 60034-5, *Rotating electrical machines — Part 5: Classification of degrees of protection provided by enclosures for rotating machines*

IEC 60947-1, *Low-voltage switchgear and control gear — Part 1: General rules*

IEC 60034-1:2017, *Rotating electrical machines — Part 1: Rating and performance*

IEC 61400-27-2:2020, *Wind energy generation systems – Part 27-1: Electrical simulation models — Model validation*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

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

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

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

3.1.1

envelope width oscillation of generating set

f

envelope width oscillation of the generating set frequency at constant power around a mean value

3.1.2

no-load frequency

f_i

frequency at which the generating set is operating without load

3.1.3

rated no-load frequency

$f_{i,r}$

frequency at which the generating set is designed to operate without load

3.1.4

rated frequency

declared frequency

f_r

frequency at which the generating set is designed to operate

3.1.5

frequency at actual power

f_{arb}

frequency at which the generating set is actually operating

3.1.6

overshoot frequency

$f_{d,max}$

maximum transient frequency rise which occurs upon a sudden decrease from a higher to a lower power

Note 1 to entry: The symbol is different from that given in ISO 3046-4.

3.1.7

undershoot frequency

$f_{d,min}$

maximum transient frequency drop which occurs due to a sudden increase of load from a lower to a higher power

Note 1 to entry: The symbol is different from that given in ISO 3046-4.

3.1.8 total stopping time

 t_a

time interval between the stop command being received by the generating set control system and the generating set completely stopping

Note 1 to entry: $t_a = t_i + t_c + t_d$

where

- t_i is time interval from a stop command being given until the load is disconnected;
- t_c is the time interval from the removal of the load until the generating stop command is triggered, also known as the cooling run-on time;
- t_d is the time from the generating set stop command is triggered (also known as cooling run-on time) to when the generating set has come to complete stop.

3.1.9 load pick-up readiness time

 t_b

time interval between the start command and readiness for supplying an agreed power, taking into account a given frequency and voltage tolerance

Note 1 to entry: $t_b = t_p + t_g$

where

- t_p is time interval from the start command until the beginning of cranking;
- t_g is time interval from the beginning of cranking until ready for supplying an agreed power, taking into account a given frequency and voltage tolerance.

3.1.10 block functional block

mathematical representation of a system or element with one or more input variables and one or more output variables, in which the functional relationship between the input and output variables is given

Note 1 to entry: The functional relationship can be given by an arithmetic instruction, a transfer function, a differential or difference equation, a characteristic curve or a family of characteristic curves, or a switching function.

3.1.11 parameter accuracy

characteristic that reflects the product quality of component suppliers, and it is one of the key factors by which the simulation results are reliable

3.1.12 frequency recovery time after load decrease

 $t_{f,de}$

time interval between the departure from the *steady-state frequency band* (3.1.27) after a sudden specified load decrease and the permanent re-entry of the frequency into the specified *steady-state frequency tolerance band* (3.1.25)

3.1.13 frequency recovery time after load increase

 $t_{f,in}$

time interval between the departure from the *steady-state frequency band* (3.1.27) after a sudden specified load increase and the permanent re-entry of the frequency into the specified *steady-state frequency tolerance band* (3.1.25)

3.1.14
voltage recovery time after load decrease

$t_{u,de}$
time interval from the point at which a load decrease is initiated, until the point when the voltage returns to and remains within the specified *steady-state voltage tolerance band* (3.1.26)

3.1.15
voltage recovery time after load increase

$t_{u,in}$
time interval from the point at which a load increase is initiated, until the point when the voltage returns to and remains within the specified *steady-state voltage tolerance band* (3.1.26)

3.1.16
downward adjustment of voltage

$U_{s,do}$
lower limit of adjustment of voltage at the generator terminals at rated frequency, for all loads between no-load and rated output and within the agreed range of power factor

3.1.17
upward adjustment of voltage

$U_{s,up}$
upper limit of adjustment of voltage at the generator terminals at rated frequency, for all loads between no-load and rated output and within the agreed range of power factor

3.1.18
maximum steady-state voltage

$U_{st,max}$
maximum voltage under steady-state conditions at the rated frequency, for all powers between no-load and rated output and at the specified power factor, taking into account the influence of temperature rise

3.1.19
minimum steady-state voltage

$U_{st,min}$
minimum voltage under steady-state conditions at the rated frequency, for all powers between no-load and rated output and at the specified power factor, taking into account the influence of temperature rise

3.1.20
no-load voltage

U_0
line-to-line voltage at the terminals of the generator at the rated no-load frequency and no-load

3.1.21
maximum upward transient voltage on load decrease

$U_{dyn,max}$
maximum voltage which results from a sudden decrease from a higher load to a lower load

3.1.22
minimum downward transient voltage on load increase

$U_{dyn,min}$
minimum voltage which results from a sudden increase from a lower load to a higher load

3.1.23 transient voltage drop

$$\Delta U_{\text{dyn}}^-$$

maximum voltage drop when the AC generator, driven at the rated speed and at the rated voltage under normal excitation control, is switched onto a symmetrical load which absorbs a specified current at the rated voltage at a given power factor or range of power factors

[SOURCE: ISO 8528-3:2020, 3.12, modified — Notes to entry removed.]

3.1.24 transient voltage rise

$$\Delta U_{\text{dyn}}^+$$

maximum voltage rise when the AC generator, driven at the rated speed and at the rated voltage under normal excitation control, has a sudden rejection of the rated output.

[SOURCE: ISO 8528-3:2020, 3.13, modified — Notes to entry removed.]

3.1.25 steady-state frequency tolerance band

$$\Delta f$$

agreed frequency band about the steady-state frequency which the frequency reaches within a given governing period after an increase or decrease of the load

3.1.26 steady-state voltage tolerance band

$$\Delta U$$

agreed voltage band about the steady-state voltage that the voltage reaches within a given regulating period after a specified sudden increase or decrease of load

Note 1 to entry: $\Delta U = 2\Delta U_{\text{st}} \times \frac{U_r}{100}$.

3.1.27 steady-state frequency band

$$\beta_f$$

envelope width oscillation of generating set (3.1.1) frequency at a constant power around a mean value

Note 1 to entry: Expressed as a percentage of rated frequency.

Note 2 to entry: $\beta_f = \frac{\Delta f}{f_r} \times 100$

3.1.28 transient frequency deviation (from initial frequency) on load increase (-) related to initial frequency

$$\delta f_d^-$$

temporary frequency deviation between *undershoot frequency* (3.1.7) and initial frequency during the governing process following a sudden load increase, related to the initial frequency

3.1.29 transient frequency deviation (from initial frequency) on load decrease (+) related to initial frequency

$$\delta f_d^+$$

temporary frequency deviation between *overshoot frequency* (3.1.6) and initial frequency during the governing process following a sudden load decrease, related to the initial frequency

3.1.30

transient frequency deviation (from initial frequency) on load increase (-) related to rated frequency

$$\delta f_{\text{dyn}}^-$$

temporary frequency deviation between undershoot frequency and initial frequency during the governing process following a sudden load increase, related to the rated frequency

Note 1 to entry:
$$\delta f_{\text{dyn}}^- = \frac{f_{\text{d,min}} - f_{\text{arb}}}{f_{\text{r}}} \times 100.$$

3.1.31

transient frequency deviation (from initial frequency) on load decrease (+) related to rated frequency

$$\delta f_{\text{dyn}}^+$$

temporary frequency deviation between *overshoot frequency* (3.1.6) and initial frequency during the governing process following a sudden load change, related to the rated frequency

Note 1 to entry:
$$\delta f_{\text{dyn}}^+ = \frac{f_{\text{d,max}} - f_{\text{arb}}}{f_{\text{r}}} \times 100.$$

3.1.32

frequency droop

$$\delta f_{\text{st}}$$

frequency difference between *rated no-load frequency* (3.1.3) and the *rated frequency* (3.1.4) at declared power, expressed as a percentage of rated frequency at fixed frequency setting

Note 1 to entry:
$$\delta f_{\text{st}} = \frac{f_{\text{i,r}} - f_{\text{r}}}{f_{\text{r}}} \times 100.$$

3.1.33

steady-state voltage deviation

$$\Delta U_{\text{st}}$$

maximum deviation from the set voltage under steady-state conditions at rated frequency for all powers between no-load and rated output and at specified power factor, taking into account the influence of the temperature rise

Note 1 to entry: The steady-state voltage deviation is expressed as a percentage of the *rated voltage* (3.1.34).

Note 2 to entry:
$$\Delta U_{\text{st}} = \pm \frac{U_{\text{st,max}} - U_{\text{st,min}}}{2U_{\text{r}}} \times 100.$$

3.1.34

rated voltage

$$U_{\text{r}}$$

rated value of the voltage assigned by the manufacturer to a component, device or equipment and to which operation and performance characteristics are referred

[SOURCE: IEC 442-09-10.]

3.1.35

generating set family

group of generating sets with similar behaviour, the same technology and the same structure of components, but with different rated output and/or different voltage levels

3.1.36

component

individual physical building elements of the generating set

EXAMPLE Engine, AC generator, controller.

Note 1 to entry: This definition does not apply when used in reference to negative or positive sequence components in [Clause 8](#).

3.1.37

rated load

P_n

real power that the generating set is capable of producing at the *rated voltage* ([3.1.34](#)) and frequency as recommended by the manufacturer

3.1.38

load angle

internal angle between the vectors of terminal voltage and e.m.f., the latter indicating the quadrature axis direction

[SOURCE: IEC 60034-4-1:2018; 6.9]

3.1.39

national grid code

details of technical requirement for connecting to and using the national electricity transmission and distribution system (also known as grid paralleling) in different regions or nations

3.2 Abbreviated terms

AC	alternating current
AVR	automatic voltage regulator
AGM	absorbant glass material used for making batteries
AMC	Agreement between manufacturer and customer
CSV	comma separated value files
ECU	electronic control unit
e.m.f	electro magnetic force
ESP	emergency standby power
FRT	fault ride through
UVRT	under-voltage ride through
OVRT	over-voltage ride through
LFSM-O	limited frequency sensitive mode at over frequency
LFSM-U	limited frequency sensitive mode at under frequency
PQ curve	active power – reactive power curve
PRP	prime power
p.u	per unit
RoCoF	rate of change of frequency

4 Other regulations and additional requirements

For AC generating sets used on board ships and offshore installations which are subject to the rules of a classification society, it is presupposed that the additional requirements of the classification society are observed. The classification society name shall be stated by the customer prior to placing the order.

For AC generating sets operating in non-classified equipment, any additional requirements are subject to agreement between the manufacturer and customer.

If special requirements from regulations of any other authority (e.g. inspecting and/or legislative authorities) apply, the authority name shall be stated by the customer prior to placing the order. If it is agreed to use any other authority, then the testing shall be performed in accordance with ISO/IEC 17025 testing and measurement standards.

NOTE 1 Attention is drawn to the need to take note of additional regulations or requirements imposed by various regulatory bodies.

NOTE 2 Examples of regulatory authorities include:

- classification societies, for generating sets used on ships and offshore installations;
- government agencies;
- inspection agencies, local utilities.

5 General test requirements

5.1 General

Generating sets shall be tested in accordance with the following tests:

a) Functional test:

This test procedure is intended for use with the generating set installed on the manufacturer's test bed.

As a minimum, the manufacturer shall perform the functional testing in accordance with the correct rating and performance class of the generating set.

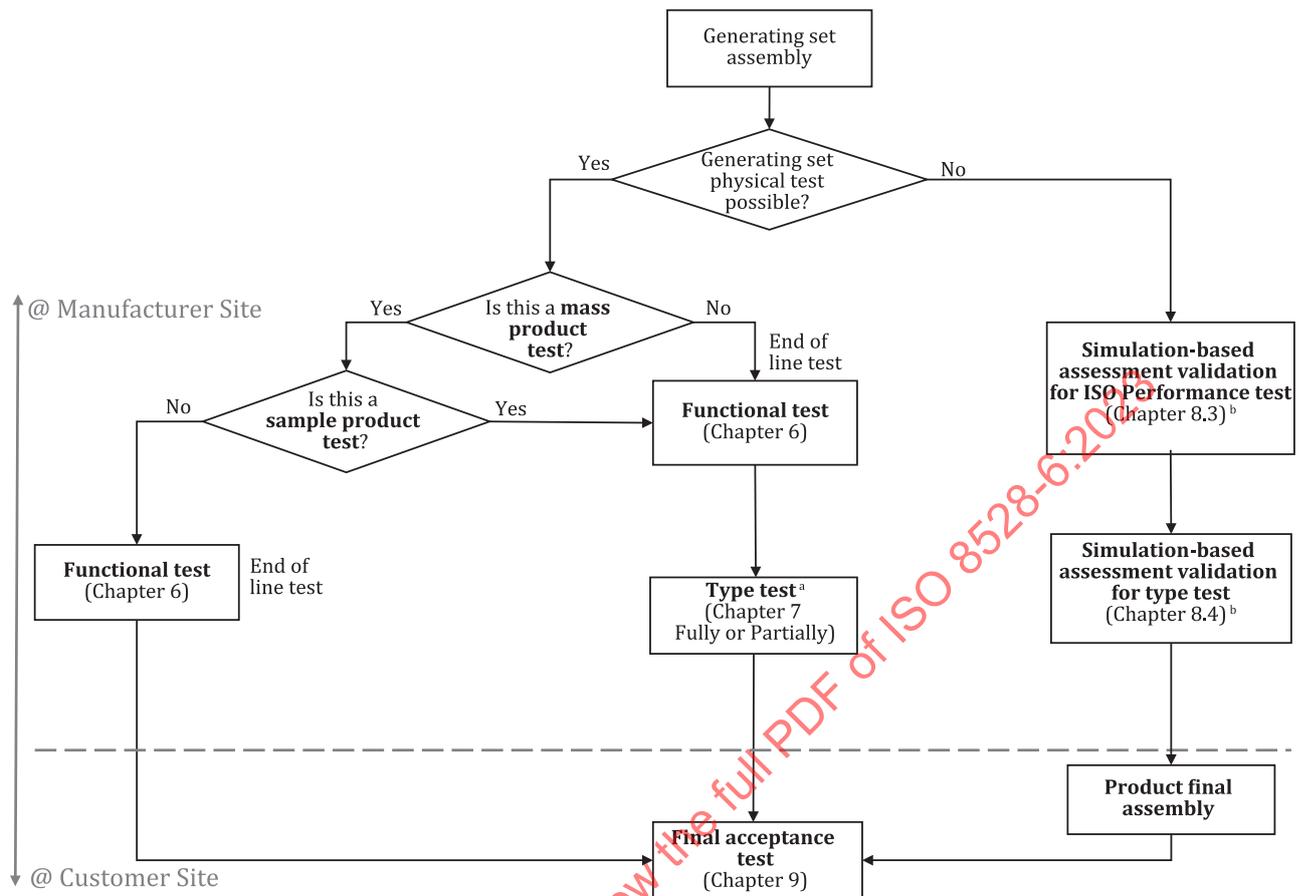
b) Type test for sample product:

This test is applicable only for a sample product that represents generating sets in a family. All these tests can be performed or selected tests can be performed, depending on the application of the generating set and any additional requirements are to be fulfilled.

c) Acceptance test (if required by the customer):

Subject to contractual agreement between the generating set manufacturer and the customer, any or all of the functional tests can be combined with the acceptance test.

[Figure 1](#) can be used as guidance on how the tests can be applied for mass produced products or sample products, generating sets that can only be assembled at customer sites.



^a Requirements in ISO 8528-1, ISO 8528-2, ISO 8528-3, and ISO 8528-5 to be verified.

^b For validated models, see the assessments in 8.3 and 8.4.

Figure 1 — Flowchart for testing procedure

5.2 Measurement equipment accuracy

The accuracy of the instrumentation used in the test shall be as shown in [Table 1](#). The measurement of time series data shall be carried out with a sampling rate of at least twice the frequency of the measured signal, i.e., 10 ms for 50 Hz frequency operation or 8,3 ms for 60 Hz frequency operation to prevent any aliasing of data. The measured time series data shall be reported in accordance with how the data shall be analysed.

Signal processing in measured time series data shall be done according to IEC 61400-27-2:2020, 6.4. Measuring transformers and transducers should be of a corresponding accuracy class.

Table 1 — Measurement equipment accuracy

Parameter	Unit	Total band-width of accuracy (%)
Current	A	≤1,5
Voltage	V	≤1,5
Real power	W	≤1,5
Reactive power	kVA	≤1,5
Power factor	—	≤3,0
Frequency	Hz	≤0,5

6 Functional test

6.1 General

6.1.1 General

A functional test is the validation that the generating set operates as intended. This can be achieved by a physical functional test (6.1.2) or by a simulation methodology (6.1.3). If the output power of the generating set allows it to be tested at the manufacturer’s site, it is recommended that physical functional tests are performed. Proof of performance by simulation is expected only for generating sets for which test beds are not applicable and a validated model is available.

6.1.2 Physical functional test

This functional test with the generating set shall be performed on the manufacturer’s test bed. The rated power factor load is normally used for testing, considering the rated active power and associated AC generator efficiency. If this is not possible because of the test equipment used, this test can be performed at a power factor of unity. This shall be by agreement between the manufacturer and customer.

The power factor load used for testing should be documented in the test report. The manufacturer and customer shall agree that operation at a certain range of power factors can be tested.

6.1.3 Functional test by simulation

For generating sets where physical testing is not possible due to technical constraints, the functional test at the manufacturer’s facility can be substituted by simulation models that represent functionally tested individual component parts and the simulation of a fully assembled equipment prior to the acceptance test. The acceptance criteria of such models shall be by agreement between the manufacturer and the customer. The simulation shall demonstrate the performance characteristics as described in [Clause 7](#). For details of simulation method, see [Clause 8](#).

If the performance of the generating set is demonstrated by simulation, it is recommended to perform a final physical acceptance test at the customer site or at the installation site before commissioning the generating set.

6.2 General inspection

A general inspection shall be made to determine if the following are being met in accordance with the generator set manufacturer’s instructions. The following shall be considered as a minimum:

- a) completeness of the equipment supplied and to be tested;
- b) alignment;

- c) functional operations of the auxiliary equipment supplied (by agreement);
- d) tightness of pipework joints and components;
- e) degree of mechanical and electrical protection, as described in IEC 60034-5 and IEC 60947-1;
- f) operating and monitoring functions;
- g) insulation resistance values of main stator coils, main rotor coils, exciter stator coils and exciter rotor coils;
- h) vibration level in accordance with ISO 8528-9;
- i) Emissions limit; If no emission limits are defined, then these should be defined by agreement between the manufacturer and the customer. If no test method standards are defined, then ISO 8178 can be adopted.

NOTE When measuring non-precision parts, such as a fan guard, a statistical approach to protection based on risk prediction is acceptable.

6.3 Measurements

The following data shall be recorded (as a minimum):

- a) ambient temperature, humidity and barometric pressure;
- b) generating set voltage, current and frequency at rated output;
- c) time-based variation for generating set voltage, frequency and current while loading and unloading to assess transient behaviour;
- d) the proper functioning of any monitoring and control equipment.

6.4 Functional test report

The functional test report shall include the following information (as a minimum):

- a) the generating set performance class in accordance with the requirements of ISO 8528-1;
- b) the customer and order number (if known);
- c) the manufacturer;
- d) the engine, generator, controlgear and switchgear serial numbers;
- e) technical data, both declared (rated) and measured, as follows:
 - 1) power;
 - 2) voltage;
 - 3) frequency;
 - 4) current;
 - 5) power factor;
 - 6) speed;
 - 7) circuit diagram number;
 - 8) type of cooling system.
- f) enclosure protection;

- g) test site ambient conditions:
 - 1) altitude;
 - 2) barometric pressure;
 - 3) temperature;
 - 4) relative humidity;
 - 5) inlet air temperature;
 - 6) inlet coolant temperature.
- h) fuel type (specification number):
 - 1) density;
 - 2) calorific value (lower calorific value).
- i) lubricating oil type (specification number).

7 Type test

7.1 General

The purpose of type tests is to determine the technical capabilities of a generating set with an identified representative configuration in accordance with the requirements given in ISO 8528-1, ISO 8528-2, ISO 8528-3 and ISO 8528-5.

Identification of configuration should include:

- engine brand and reference;
- speed controller brand, reference and software version, if any;
- AC generator brand and reference;
- excitation system type;
- excitation controller brand, reference and software version, if any;
- mode of operation according to ISO 8528-1:2018, Clause 7;

Type test can be used to demonstrate validity of the simulation models used in [Clause 8](#). In this case, type test shall be conducted on one sample product of the generating sets family that illustrates the performance of the entire family. The validated model can then be used to verify the performance of the family through simulation, as defined in [Clause 8](#).

For generating sets that are only assembled at the customer site, the list of required tests to be performed should be agreed based on an AMC.

7.2 Testing conditions

The rated power of the generating set according to ISO 8528-1 is adjusted or corrected, as determined by engine and generator manufacturer specifications, to the ambient condition of test. There are:

- a) ambient temperature;
- b) humidity;
- c) barometric pressure;

d) altitude.

The test shall be performed on generating sets that have reached their stable engine operating temperature. The time required to warm up the generating set will vary. It is the responsibility of the test engineer to ensure that the set has run for an adequate time in order to stabilize temperatures.

7.3 Characterisation of performance class

7.3.1 Steady state verification at constant power

7.3.1.1 General

The aim of this test is to determine declared rated power of unit in accordance with ISO 8528-1:2018; Clause 14 and to assess voltage and frequency stability.

The parameters in Table 2 shall be obtained before the test. The parameters in Table 3 shall be measured during the test.

Table 2 — Parameters to be obtained before the test

Symbol	Parameter	Unit
$f_{i,r}$	Rated no-load frequency	Hz
f_r	Declared frequency (rated frequency)	Hz

Table 3 — Parameters to be measured during load test

Symbol	Parameter	Unit
P	Power	kW
$U_{s,do}$	Downward adjustment voltage	V
$U_{s,up}$	Upward adjustment voltage	V
$U_{st,max}$	Maximum steady-state voltage	V
$U_{st,min}$	Minimum steady-state voltage	V
f_i	No-load frequency	Hz
f_{arb}	Frequency at actual power	Hz

7.3.1.2 Testing method

The test shall be performed on generating sets that have reached their stable engine operating temperature. It is the responsibility of the test engineer to ensure that the set has run for an adequate time in order to stabilize engine operating temperature at each load step.

Test power is gradually increased as per the load level increments recommended by the generating set manufacturer until the rated power or maximum power for PRP and ESP is reached (see ISO 8528-1:2018, Clause 14). After each load increment and following engine temperature stabilization, the electrical parameters shall be recorded for a minimum of 10 minutes. For PRP, the electrical parameters shall be measured at 110 % load or maximum stated overload power for a minimum of 10 minutes.

At each load level, vary the voltage from 90 % to 110 % of nominal voltage and load adjusted accordingly to maintain the desired load value. Based on this test, record the minimum and maximum steady state voltage and the voltage adjustment range.

The frequency shall be measured at no load and full load during this test to calculate f_i and f_{arb} .

All test results are recorded on test record at the defined levels of applied power.

During the test, applied power shall be monitored to maintain a constant level of load.

7.3.1.3 Assessment

The parameters in [Table 4](#) shall be calculated as per ISO-8528-5:2022, Table 4.

Table 4 — Post-treatments to be performed after load test

Symbol	Parameter	Unit
ΔU	Steady-state voltage tolerance band	V
ΔU_{st}	Steady-state voltage deviation	%
β_f	Steady-state frequency band	%
δf_{st}	Frequency droop	%

7.3.1.4 Criteria of acceptance

Acceptance refers to ISO 8528-5:2022, Table 4, for all parameters measured or obtained by calculation.

7.3.2 Verification of power-sharing capability

7.3.2.1 General

This test is applicable only for generator sets coupled with each other without a grid, as defined in ISO 8528-5:2022, Clause 12.

7.3.2.2 Active power-sharing test

This test is intended to demonstrate the active power sharing between a number of generating sets operating synchronously, connected to the same busbar. The first test is to achieve the same frequency deviation on all generating sets when connected to the busbar individually. The second test is to check that all the units are operating synchronously connected to same busbar to achieve an active power difference less than the value defined in ISO 8528-5:2022, Table 4 at the individual generating set terminal. The active power-sharing value shall be calculated based on ISO 8528-5:2022, 12.1.1.2. The assessed active power-sharing value between 80 % to 100 % loading and between 20 % to 80 % nominal rating can be used for accessing the performance class operating limit values according to ISO 8528-5:2022, Table 4.

7.3.2.3 Reactive power-sharing test

This test is intended to demonstrate the reactive power sharing between a number of generating sets operating synchronously, connected to the same busbar. The first test is to achieve the same voltage deviation on all generating sets when connected to the busbar individually. The second test is to check that all the units are operating synchronously connected to same busbar to achieve a reactive power difference less than the value defined in ISO 8528-5:2022, Table 4 at the individual generating set terminal. The reactive power-sharing value shall be calculated based on ISO 8528-5:2022, 12.1.2.2. The assessed reactive power-sharing value between 20 % to 100 % nominal rating can be used for accessing the performance class operating limit values according to ISO 8528-5:2022, Table 4.

7.3.2.4 Criteria of acceptance

The active and reactive power-sharing capability shall conform with the performance criteria requirements in ISO 8528-5:2022, Table 4.

7.3.3 Step load test

7.3.3.1 General

The aim of the test is to assess load acceptance and load rejection of generating set under test and determine its performance class.

During the test the parameters in [Table 5](#) shall be measured.

Table 5 — Parameters to be measured during step load test

Symbol	Parameter	Unit
$f_{d,max}$	Overshoot frequency	Hz
$f_{d,min}$	Undershoot frequency	Hz
$t_{f,de}$	Frequency recovery time after load decrease	s
$t_{f,in}$	Frequency recovery time after load increase	s
$t_{u,de}$	Voltage recovery time after load decrease	s
$t_{u,in}$	Voltage recovery time after load increase	s
$U_{st,max}$	Maximum steady-state voltage	V
$U_{st,min}$	Minimum steady-state voltage	V
U_0	No-load voltage	V
$U_{dyn,max}$	Maximum upward transient voltage on load decrease	V
$U_{dyn,min}$	Minimum downward transient voltage on load increase	V

7.3.3.2 Testing method

This test shall be performed at rated power factor by varying the load in step changes recommended by generating set manufacturer (refer to [Table 6](#) for example load steps). The genset manufacturer shall declare the number and size of the load steps needed to meet the performance class of the generator set noted in ISO 8528-5:2022, Table 4 with reference to the generator set rating. This test will be made after running the generating set until the engine operating temperature is stable. Alternatively, where the manufacturer test facility precludes the testing at rated power factor, the load acceptance test can be performed as per the agreement between manufacturer and customer.

The frequency and voltage variations shall be recorded in the form of time-based voltage and frequency plots or transcripts showing the frequency and voltage levels (e.g., file type in CSV format, digital format or hard copy).

Table 6 — Example of load steps declared to validate performance class

Load step	Sudden load variation
Step 1	0 – 1 st power stage
Step 2	1 st power stage – 2 nd power stage
Step 3	2 nd power stage – 3 rd power stage
...	...
Step N	$N-1$ power stage – 100 %
Step $N+1$	100 % – 0

7.3.3.3 Measured data processing

Following parameters in [Table 7](#) shall be calculated from the measured values.

Table 7 — Post treatment to be performed after step load test

Symbol	Parameter	Unit
Δf	Steady-state frequency tolerance band	Hz
δf_{d}^-	Transient frequency deviation (from initial frequency) on load increase (-) related to initial frequency	%
δf_{d}^+	Transient frequency deviation (from initial frequency) on load decrease (+) related to initial frequency	%
δf_{dyn}^-	Transient frequency deviation (from initial frequency) on load increase (-) related to rated frequency	%
δf_{dyn}^+	Transient frequency deviation (from initial frequency) on load decrease (+) related to rated frequency	%
ΔU	Steady-state voltage tolerance band	V
δU_{st}	Steady-state voltage deviation	%
ΔU_{dyn}^-	Transient voltage drop	%
ΔU_{dyn}^+	Transient voltage rise	%

7.3.3.4 Criteria of acceptance

Acceptance refers to limits defined in ISO 8528-5 for all parameters measured or obtained by calculation. During these tests the variation of voltage and frequency shall be within the limits of the performance class defined in ISO 8528-5 for each load step performed.

7.3.3.5 Performance class and load acceptance report

The report shall include an executive summary showing features and characteristics of the unit under test and one calculation and measurement sheet for each load test performed for increasing or decreasing load steps. Files (CSV format, digital or hard copy), including all measured parameters, shall be included in the report. Refer to [Annex C](#) for an example report.

Performance class is determined by the worst-case response to the different load steps applied as per generating set manufacturer recommendations.

7.3.4 Start and stop time characteristics

7.3.4.1 General

The aim of this test is to verify the start time and stop time according to ISO 8528-5:2022, Clauses 10 and 11.

During the test the parameters in [Table 8](#) shall be measured.

Table 8 — Parameters to be measured during the test

Symbol	Parameter	Unit
t	Time	s
U_{r}	Rated voltage	V
f_{r}	Declared frequency (rated frequency)	Hz

7.3.4.2 Testing method

7.3.4.2.1 General

Following parameters are subject to agreement between the customer and the generating set manufacturer and shall be defined prior to the test:

- ambient air temperature and pressure;
- operating temperature of the RIC engine (i.e. coolant and lubricant temperatures);
- starter battery condition;
- oil viscosity;
- total inertia of the generating set;
- fuel quality;
- state of the starting equipment.

7.3.4.2.2 Starting characteristics

The initial condition of the generating set for this test should be in a stopped state, and ready to run. Simultaneously start the generating set and begin to log the test data until the generator reaches stable operating voltage and frequency and is ready to be loaded, as shown in ISO 8528-5:2022, Figure 10. Record the electrical parameters against the time plot along with the start signal.

7.3.4.2.3 Stopping characteristics

The initial condition of the generating set for this test should be running at rated speed and voltage, at full load and at rated power factor. Start the measurement of the test data and initiate a normal shutdown. Wait until the load is ramped down and the AC generator comes to a complete stop, as specified in ISO 8528-5. Record electrical parameters along with the stop signal.

During these tests, the frequency and voltage variations shall be recorded in the form of curves or transcripts from frequency and voltage levels measured (data file in the CSV format, hard copy or digital).

7.3.4.3 Post-treatment of measurement data

The parameters in [Table 9](#) shall be calculated.

Table 9 — Post-treatment to be performed after the test

Symbol	Parameter	Unit
t_b	Load pick-up readiness time	s
t_a	Total stopping time	s

7.3.4.4 Criteria of acceptance

For criteria of acceptance refer to specific customer requirement or agreement between the manufacturer and the customer.

7.4 Reactive power capability

7.4.1 General

This subclause describes the test method to access the reactive power capability of the AC generator and the control regulation using different control modes.

7.4.2 Verification of reactive power capability

7.4.2.1 Test method

This test can be performed to verify the stable operating active and reactive power capability of the AC generator.

Units under test shall be connected to the grid or to a load bank capable of testing lagging (over-excited) and leading (under-excited) power factors. It is the responsibility of the manufacturer to ensure that the limits of maximum over-excited and under-excited condition are within the stable operating region of the generating set at the operating voltage.

NOTE For this test, the prime mover can be replaced by an electrical motor or another kind of rotating engine.

This test shall be performed at maximum reactive power capability of the AC generator for each active power step for a minimum duration of 1 minute after stabilization following a change of active power. The limits of reactive power in under-excited and over-excited conditions should be assessed as per [Figure 2](#) at the operating voltage. If the grid voltage is influencing the reactive power capability of the generating unit, it shall be recorded in the test report. Example steps are shown in [Table 10](#).

Table 10 — Example test steps for reactive power capability assessment

Active power %	Reactive power at maximum over-excited condition kVAr	Reactive power at max- imum under-excited condition kVAr
0 % or minimum stable operating load		
10 %		
20 %		
30 %		
40 %		
50 %		
60 %		
70 %		
80 %		
90 %		
100 %		

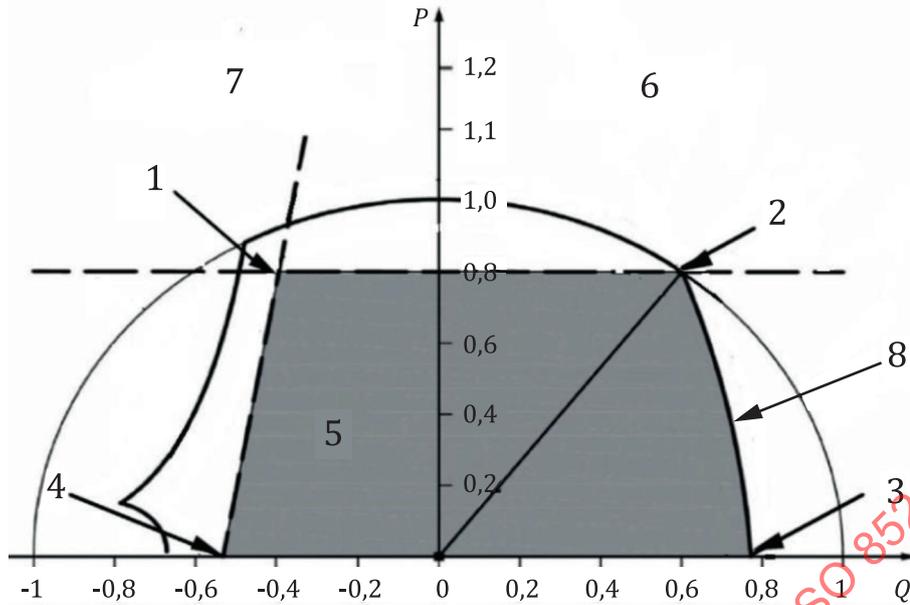
7.4.2.2 Document to be provided before tests

This assessment considers the AC generator reactive power capability in accordance with the regulator setup and protection setup.

The generating set manufacturer provides the reactive power capability datasheet for assessment. For grid application, the AC generator manufacturer shall provide information of the PQ curve estimated at rated voltage and at the voltage deviation limits as required by the local grid code (see ISO 8528-5:2022, Figure 14). These values can be used to establish the thermal limits and reactance values of the generator.

The example of stable operating region for reactive power capability at rated voltage is shown in [Figure 2](#).

If there are restrictions from the local grid operator with respect to reactive power limit, then the limits on the grid connection could be applicable for region 5 in [Figure 2](#). In this case, additional manufacturer declarations shall be provided to prove the capability of the generating set.



Key

- 1, 2, 3, 4 setpoint limits of the AVR for the stable operation of the generating set
- 5 stable area of generating set operation
- 6 over-excited region
- 7 under-excited region
- 8 stability curve for salient pole AC generator, where $U=U_r$

NOTE If the generating set cannot be operated at points 3 and 4 due to minimum operating load restrictions, this test can be performed at the minimum stable operating load level.

Figure 2 — Example of generating set manufacturer PQ diagram

7.4.2.3 Acceptance criteria

The test is considered accepted if all operating points are inside the generating set stable operating area (i.e. region 5) of the PQ diagram of the AC generator. Refer to specific PQ diagram for generating set and AC generator.

NOTE 1 The running points 1 and 4 are representative of the ability of the generating set to remain stable such that, when connected to the grid, the generating set does not lose synchronism or, when connected to a passive testing bench, the generating set is able to regulate the voltage at the nominal value.

NOTE 2 The running points 2 and 3 are representative of the settings of the excitation current limitation of the generating set. The risk of losing the stability of the system is considered as low.

7.4.3 Test method for verification of reactive power capability control methods

7.4.3.1 General

The objective of the tests described in this section are to verify the reactive power capability of the generating set under different control modes such as fixed VAR, fixed power factor, Q(P) and Q(U) control as referred in ISO 8528-3:2020, 7.3.3. The tests defined in this section shall be performed to the reactive power capability modes available in the generating set and required by the installation.

This subclause can be used as a guideline using the following methods in the absence of test methods predefined in applicable grid codes or relevant standards:

- test using grid simulator;
- test by injecting variable analogue signal to change setpoint;
- test by modification of control parameter;
- manufacturer declaration with suitable supporting documentation;
- mathematical modelling.

If the testing is performed against the grid, it is recommended that testing is avoided during any instability in the grid that could affect the test results. If such tests are carried out, suitable documentation of the test modification, relevant results and the grid status shall be recorded.

7.4.3.2 Verification of VAr/power factor control

7.4.3.2.1 General

This test is to verify the response (settling time and accuracy) of generating set to reactive power setpoint change in fixed VAr/fixed power factor control. The parametric settings, accuracy and settling time of the reactive power and its control mode shall be recorded.

7.4.3.2.2 Test method

The generating set can be running in grid parallel or in parallel operation without grid with fixed VAr/fixed power factor control mode enabled. The test shall be conducted at partial load and full load at unity, maximum under-excited and maximum over-excited in accordance with Table 11. If the reactive power settling time can be adjusted, the test shall be repeated for longest (not exceeding 60 s) and shortest possible time. Each step to be recorded for a minimum duration of 120 s.

Table 11 — Example steps for VAr/power factor verification

Step	P_n %	Q/P_n	Duration for recording (s)
Step 0	Partial load (45 % - 55 %)	0	120
Step 1	Partial load (45 % - 55 %)	Q_{Max} over excited/ P_n	120
Step 2	Partial load (45 % - 55 %)	0	120
Step 3	Partial load (45 % - 55 %)	Q_{Max} under excited/ P_n	120
Step 4	Partial load (45 % - 55 %)	0	120
Step 5	Full load	0	120
Step 6	Full load	Q_{Max} over excited/ P_n	120
Step 7	Full load	0	120
Step 8	Full load	Q_{Max} under excited/ P_n	120
Step 9	Full load	0	120

If there are restrictions from the local grid operator with respect to reactive power limit, then the limits on grid connection could be applicable. In this, case additional manufacturer declarations shall be provided to prove the capability of the generating set.

7.4.3.2.3 Acceptance criteria

Reactive power control requirements for VAr and power factor control shall be agreed upon between the AC generator manufacturer and the generating set manufacturer, based on the intended application of the generating set and any applicable grid codes.

In absence of stated values, the overall settling time for reactive power shall be within the adjusted settling time of 10 s to achieve a value within the tolerance band of $\pm 5\%$ of P_n centred around the target reactive power setpoint.

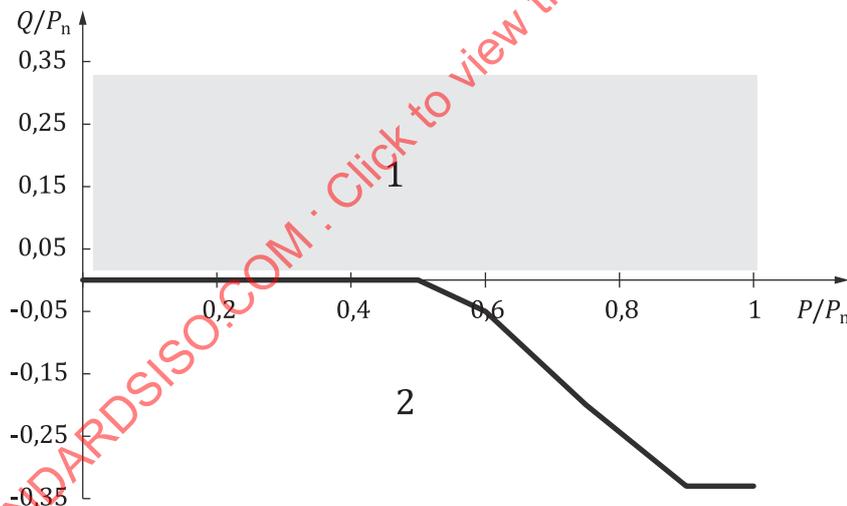
7.4.3.3 Verification of Q(P)

7.4.3.3.1 General

This test is performed to verify the reactive power response based on active power change. Manufacturer shall provide expected Q(P) behaviour.

7.4.3.3.2 Test method

The AC generator shall be operated in grid paralleling mode with Q(P) reactive control mode enabled. The reactive power response shall be set at the fastest response time. The unit shall be operated at minimum stable operating load or at 0 % of P_n if possible. Then the load shall be increased in steps of 10 % using an external signal or by varying the control parameter until the load reaches 100 %. During each step of active power, the reactive power setpoint shall be recorded. The reactive power, active power and the active power setpoint shall be recorded at each step until the reactive power value falls within the tolerance band for a minimum duration of 120 s. An example Q(P) curve is shown in [Figure 3](#).



Key

- 1 over excitation
- 2 under excitation

Q/P_n reactive power/active power (no unit)

P/P_n active power/nominal active power (p.u)

Figure 3 — Example Q(P) diagram

7.4.3.3.3 Acceptance criteria

Reactive power control response shall replicate the behaviour of the defined Q(P) curve as defined in the agreement between the generating set manufacturer and customer based on the intended application of the generating set or any applicable grid codes.

In absence of any stated values, the measured reactive power based on the active power change shall follow the response as per the Q(P) curve as shown in [Figure 3](#).

7.4.3.4 Verification of Q/P - U

7.4.3.4.1 General

This test shall be performed to verify the reactive power response based on voltage change. The generating set manufacturer shall provide expected Q/P - U behaviour.

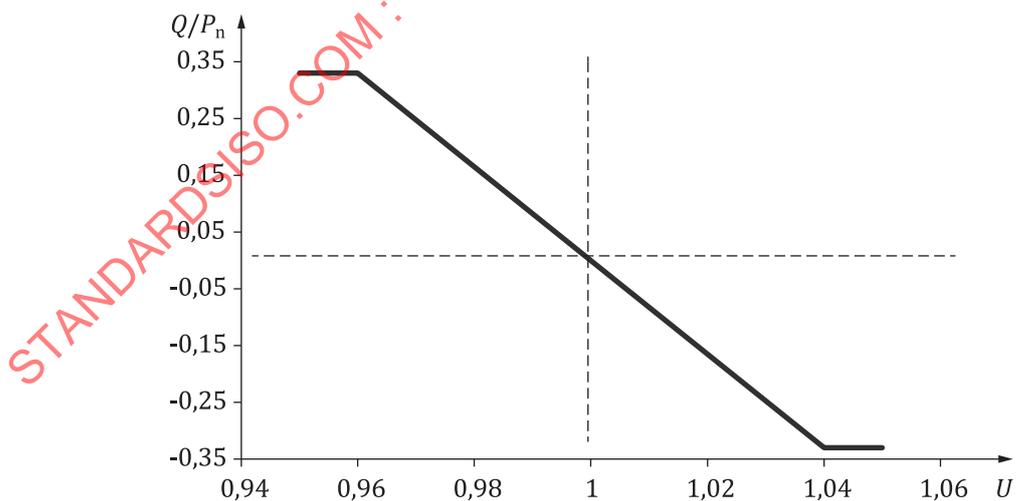
This test can be conducted by using a signal generator or grid simulator or by varying control parameter for voltage setpoint reference.

7.4.3.4.2 Test method

The generating set shall be operated in grid paralleling mode with Q/P - U reactive control mode enabled. The reactive power response shall be set at fastest response time. The unit shall be operated at rated load. Using a signal generator or modification of voltage control variable, the steps of the voltage change as shown in [Table 12](#) shall be applied. Additional steps can be recorded depending on the Q/P - U curve required (example curve shown in [Figure 4](#)). Each step shall be applied after a minimum of 120 s (example steps shown in [Table 12](#)). Depending on the voltage change, the reactive power response shall be recorded until the values fall within the tolerance band.

Table 12 — Example verification steps of Q/P- U characteristics

Voltage (p.u)	Measurement duration (s)
U_r	120
$0,97U_r$	120
$1,03U_r$	120
U_r	120



Key

Q/P_n reactive power/nominal active power (no unit)

U voltage in p.u

Figure 4 — Example verification for Q/P -U curve

7.4.3.4.3 Acceptance criteria

Reactive power control requirements for Q/P - U response shall be agreed upon between the generating set manufacturer and customer based on the intended application of the generating set and any applicable grid codes.

In absence of any stated values, the measured reactive power based on the voltage change shall follow the response as per the example Q/P - U curve provided. The reactive power change shall occur within the response time limits defined by the applicable grid codes.

7.5 Verification of grid synchronization limits

7.5.1 General

This test is applicable only for grid parallel generating sets to demonstrate the connection condition of the AC generating set. The generating set shall be able to synchronise within the voltage and frequency windows or range as specified in ISO 8528-3:2020, 7.3.1.

7.5.2 Testing method for verification of grid synchronisation limits

7.5.2.1 General

This test can be conducted using a grid simulator with the generating set in non-running condition. The test is to verify the connection under synchronisation limits specified in ISO 8528-3:2020, 7.3.1.

7.5.2.2 Under-voltage connection limit verification

For this test, the voltage shall be increased in steps of 1 % from 89 % to the synchronisation limit with the generator voltage within synchronisation limits when compared to grid simulator voltage. A connection signal shall be provided when the synchronisation window is reached.

7.5.2.3 Over-voltage connection limit verification

For this test, the voltage shall be decreased in steps of 1 % from 112 % to the system synchronisation limit with the generator voltage within synchronisation limits when compared to grid simulator voltage. A connection signal shall be provided when the synchronisation window is reached.

7.5.2.4 Under-frequency connection limit verification

For this test, the frequency shall be increased in steps of 0,1 Hz from a frequency limit lower than synchronisation limit (e.g. if synchronisation window is $f_r - 0,2$ Hz then $f_r - 0,3$ Hz shall be the starting point) to the synchronization limit with the generator frequency within synchronisation limits when compared to grid simulator frequency. A connection signal shall be provided when the synchronisation window is reached.

7.5.2.5 Over-frequency connection limit verification

For this test, the frequency shall be decreased in steps of 0,1 Hz from the frequency limit higher than the synchronisation limit (e.g. if synchronization window is $f_r + 0,2$ Hz then $f_r + 0,3$ Hz shall be starting point) to the system synchronisation limit with generator frequency within synchronisation limits when compared to grid simulator frequency. A connection signal shall be provided when the synchronisation window is reached.

The synchronization limits test shall be completed and recorded as in [Table 13](#).

Table 13 — Example steps for synchronisation limit verification

Under-voltage limit		Over-voltage limit		Under-frequency limit		Over-frequency limit	
Voltage steps %	Connection condition (yes/no)	Voltage steps %	Connection condition (yes/no)	Frequency step Hz	Connection condition (yes/no)	Frequency step Hz	Connection condition (yes/no)
89		112		$f_r-0,3$		$f_r+0,3$	
90		111		$f_r-0,2$		$f_r+0,2$	
....		

7.5.2.6 Acceptance criteria

The generating set shall demonstrate synchronisation within the limits declared as per the agreement between the manufacturer and customer or applicable grid code requirements.

7.6 Test method for verification of FRT capability

7.6.1 General

This test is performed with the unit connected to the grid through FRT test equipment or other methods allowed for verification of FRT capability as permitted by the regional grid network operator or as agreed between manufacturer and customer. The required FRT characteristics (OVRT or UVRT) shall be defined based on one of the following criteria:

- regional grid code requirement at final installation site;
- most stringent voltage time profile of applicable grid codes;
- by agreement between manufacturer and customer.

In the absence of any confirmed values, it is recommended to use the values in IEC/TS 62786-1.

This test shall be performed only on a generating set capable of meeting FRT demands for grid parallel application. As there is significant variation in configuration of auxiliaries for RIC engine-driven AC generating sets, the generating set consisting of the engine, AC generator and associated controls with one of the combinations of the auxiliaries shall be tested. The generating set manufacturer shall ensure that any individual auxiliary components supplied with the generating set shall be capable of operating during and after the fault without system failure.

7.6.2 Aim of the test

The aim of the test is to verify the generating set's ride through capability and its ability to support recovery of grid voltage during and after under-voltage or over-voltage grid faults.

Measurements performed during the test can be used to validate the manufacturer's simulation model of the generating set. The validated generating set simulation results can be used to prove compliance for a generating set family, as in [8.4.3.2](#), according to the applicable grid code requirements as an alternative to physical type test.

7.6.3 Documents to be provided before test

A report shall be provided by the manufacturer before starting the test. This report shall include:

- voltage-time profile defined for the generating set under test – both under-voltage ride through (UVRT) and over-voltage ride through (OVRT);
- reference point for measurements of voltage, current, active power and reactive power (e.g. AC generator terminals, after step-up transformer, grid connection point);

- ECU type including a list of parameter settings affecting performance of FRT;
- AVR type including a list of parameter settings affecting performance of FRT;
- generating set controller type, list of parameters and settings that can be considered to influence FRT response.

If parameter settings are adjusted during the FRT testing, the final list of parametric changes shall be recorded.

7.6.4 Test method

This test is performed by applying the required voltage steps as per the FRT curve profile provided in 7.6.3 using an agreed method for validating FRT as described in 7.6. If no methods are defined or agreed, the test method in Annex A can be adopted.

- a) Generating set pre-fault load condition:
 - partial load (at 50 % or at the recommended minimum stable operating power of the generating set);
 - full load or >90 % of the rated active power of the generating set.
- b) Fault type:
 - symmetrical;
 - asymmetrical.
- c) Pre-fault reactive power:
 - declared maximum under-excited (one sample FRT test);
 - declared maximum over-excited (one sample FRT test);
 - unity power factor.
- d) Fault phases change by repeating one sample asymmetrical FRT test.
- e) Optional illustrative excitation controller setting change by repeating one sample FRT test (e.g. different PID gain).

It is recommended to measure the magnitude of the voltage dip or swell (no load dip or swell) with the generating set disconnected to ensure that the required voltage dip or swell is applied. An example of combination of these conditions for each step is shown in Table 14. If no voltage profile is defined, the voltage profile and test steps in Annex A can be adopted.

Table 14 — Recommended voltage step profile test combination

Voltage profile	Pre-fault reactive power condition	Full load				Partial load			
		3 Phase test 1	3 Phase test 2	2 Phase test 1	2 Phase test 2	3 Phase test 1	3 Phase test 2	2 Phase test 1	2 Phase test 2
Voltage step 1	Maximum under-excited	Voltage step 1 duration for symmetrical fault		Voltage step 1 duration for asymmetrical fault		Voltage step 1 duration for symmetrical fault		Voltage step 1 duration for symmetrical fault	
	Maximum over-excited								
	Unity Power Factor								

The test report and results shall be recorded in accordance with the requirements in 8.4.3.2.2.

7.6.5 Acceptance criteria

7.6.5.1 General

The FRT test is considered passed if the criteria in the following subclauses are met.

7.6.5.1.1 UVRT acceptance criteria

The requirements given in ISO 8528-5:2022, 12.2.3.3 shall be followed.

The generating set shall remain connected to the grid during and after the fault event without automatic disconnection within the specified duration of the fault. The active and reactive power shall recover to the pre-fault value (within the allowed tolerance band if possible) and duration as per the regional grid codes or as per the agreement between manufacturer and customer.

7.6.5.1.2 OVRT acceptance criteria

The requirements given in ISO 8528-5:2022, 12.2.3.3 shall be followed.

The generating set shall remain connected to the grid during OVRT without automatic disconnection within the specified duration of the fault.

7.7 Test method for verification of active power response to frequency variation

7.7.1 General

The objective of this test is to validate the active power response to frequency deviation for grid-connected generating sets. This test can be performed using a grid simulator, by varying the frequency measurement parameter in genset controller (i.e., signal injection) or by simulation, as in [8.4.3.4](#).

The generating set manufacturer shall ensure that individual auxiliaries supporting the main generating set continue to operate as intended during and after the frequency variation without system failure for the required time duration.

This test can be performed with the unit connected to the grid, with facility to vary the grid frequency through simulated input or by varying the control parameters. Alternatively, this test can be done with a grid simulator or by using a validated simulation model capable of demonstrating the active power response to frequency variation. Any alternative method as suggested by the local grid code, as agreed by the grid network operator or as agreed by manufacturer and customer can be used. The required active power response to frequency variation shall be defined based on one of the following criteria:

- regional grid code requirement at final installation site;
- most stringent active power response vs frequency requirement of applicable grid codes;
- operating range of active power response vs frequency requirement;
- by agreement between manufacturer and customer.

In the absence of any confirmed values, it is recommended to use the values in IEC/TS 62786-1.

This test is recommended to be performed only on generating sets capable of meeting frequency variation requirements for grid parallel application.

7.7.2 Aim of the test

The aim of the test is to verify the generating set's active power response to frequency variation as per [7.7.1](#).

Measurements recorded during the test can be used to validate the manufacturer's simulation model of the generating set. The validated generating set simulation results can be used to prove compliance against the applicable grid code requirements as an alternative to real time test.

7.7.3 Documents to be provided before test

A report should be provided by the manufacturer before starting the test. This report shall include:

- active power response to under-frequency;
- active power response to over-frequency;
- declared RoCoF value withstanding ability of generating set;
- reference point for measurement (AC generator terminals);
- method of frequency variation;
- ECU type, list of parameter settings affecting performance of frequency response;
- protection setting affecting frequency response;
- generating set controller type, list of parameters and settings that can be considered to influence frequency variation.

7.7.4 Test method

This test shall be performed by applying required frequency variation as per the curve provided in [7.7.1](#) using an agreed method for validating active power response to frequency variation as described in [7.7.1](#). If no methods are defined or agreed, the test method in [Annex B](#) can be adopted.

Frequency variation steps shall be applied to verify the under-frequency and over-frequency response. Successive step changes shall be applied until load variation is observed as per the defined active power response to frequency variation curve in accordance with [7.7.3](#). The test shall be repeated with the expected load response at specific frequency point for the minimum duration suggest as per [7.7.1](#).

For examples of frequency steps, refer to [Annex B](#).

The test shall be repeated under the following conditions:

- a) Generating set pre-fault load condition
 - partial load (at active power between 50 % and 75 % of P_n of generating set);
 - full load or ≥ 90 % of the rated active power of the generating set.
- b) Under-frequency response with highest and lowest droop requirement (if applicable).
- c) Over-frequency response with highest and lowest droop requirement (if applicable).
- d) Deadband frequency point at under-frequency and over-frequency limit as defined by applicable grid code. In absence of any frequency deadband limits, refer to [Annex B](#).

If the generating set active power capability limits the performance of the test, then it shall be documented in the report. Suitable manufacturer documentation can be provided to prove the generating set capability at or to LFSM-O and LFSM-U requirements.

It is recommended that the test is initiated from the normal frequency band at unity power factor. For under-frequency response variation, the frequency shall be reduced until the expected load change occurs and the frequency is further to be decreased until the lowest frequency that the national grid code requires a generating set to operate or to the breaker tripping protection limit (whichever occurs

first). Record the frequency change input signal and active power response observed on the generating set.

For over-frequency response variation, the frequency shall be increased until the expected load change occurs, and the frequency is further to be increased until the highest frequency which the national grid code requires a generating set to operate or to the breaker tripping protection limit (whichever occurs first). Record the frequency change input signal and active power response observed on the generating set.

Additional steps for over-frequency and under-frequency can be performed as per the local grid code requirements or by agreement between manufacturer and customer if required.

7.7.5 Acceptance criteria

For under frequency, requirements shall be met as per local grid codes or as per the agreement between manufacturer and customer.

For over-frequency, requirements shall be met as per local grid codes or as per the agreement between the manufacturer and customer.

7.8 Test method for verification of generating set protections

7.8.1 General

The following tests shall be performed to verify the generating set protection and the reaction time to disconnect the generating set from the grid or load. The test is applicable regardless of whether the generating set is operated in isochronous mode (i.e. stand-alone) or parallel without a grid or parallel to a grid.

7.8.2 Verification of generating set disconnection time from the grid

7.8.2.1 Objective

The objective of this test is to verify the duration of complete disconnection of the generating set following protection trip signal initiation. The measured delay shall be used in modelling to verify the protection setting and its function as in [7.8.3](#) is applicable for generating sets with integrated protection relay or protection signals that will initiate generating set disconnection during FRT or frequency variation events.

7.8.2.2 Testing method

This test can be conducted on the generating set which is non-running but with the means for verification of the generating set circuit breaker disconnection following a trip signal. The description of how the test is conducted (e.g. event that triggered the fault, configuration of the generating set circuit breaker) shall be included in the report. The trip signal can be caused by any one of the parameters in [7.8.3](#).

7.8.2.3 Acceptance criteria

This test does not have any additional acceptance criteria and is only performed to estimate the time delay from the start of a trip event to complete disconnection of the generating set. The time duration shall be used as the delay for protection settings in modelling section in [Clause 8](#).

7.8.3 Verification of protection limits

7.8.3.1 Objective

The objective of this test is to verify the protection limits that can disconnect the generating set from grid once triggered.

7.8.3.2 Testing method

This test can be conducted using a grid simulator with generating set in non-running condition. The test is to verify the disconnection of generating set based on values defined based on either regional grid code requirement at final installation site or by agreement between manufacturer and customer, as shown in [Table 15](#).

a) Under-voltage trip limit verification

For this test, the voltage shall be decreased in steps of 1 % from nominal voltage down to the protection limit. The disconnection signal shall be initiated when the protection limit is reached. The protection limit and the time taken to trip shall be recorded.

b) Over-voltage connection limit verification

For this test, the voltage shall be increased in steps of 1 % from nominal voltage up to the protection limit. The disconnection signal shall be initiated when the protection limit is reached. The protection limit and the time taken to trip shall be recorded.

c) Under-frequency limit verification

For this test, the frequency shall be decreased in steps of 0,1 Hz from nominal frequency limit down to the protection limit. The disconnection signal shall be initiated when the protection limit is reached. The protection limit and the time taken to trip shall be recorded.

d) Over-frequency limit verification

For this test, the frequency shall be increased in steps of 0,1 Hz from nominal frequency value up to the protection limit. The disconnection signal shall be initiated when the protection limit is reached. The protection limit and the time taken to trip shall be recorded.

e) Overcurrent protection limit verification (optional)

For this test, the overcurrent protection function and short-circuit protection function is verified by connecting the primary side of the current transformers to the generator current sensing point. Taking into account the transformation ratio of the current transformer, an AC current signal with rated frequency can be fed into the measuring chain via a variable power supply unit in the secondary side of the transformer.

For this test the overcurrent protection value shall be decreased to a value closer to the nominal operating current value. Starting from the rated secondary current, the current in the secondary side of the transformer is increased until the overcurrent protection limit triggers a tripping signal. The protection limit and the duration taken to trip shall be recorded. Example steps for protection limit verification are given in [Table 15](#).

After the test, the overcurrent protection value shall be reset to the original values.

Table 15 — Example steps for protection limit verification

Under-voltage limit	Voltage steps (%)	nominal voltage	nominal voltage -1 %	...
	Trip signal (yes/no)			

Table 15 (continued)

Over-voltage limit	Voltage steps (%)	Nominal voltage	nominal voltage+1 %	...
	Trip signal (yes/no)			
Under-frequency limit	Frequency step (Hz)	f_r	$f_r-0,1$ Hz	...
	Trip signal (yes/no)			
Over-frequency limit	Frequency step (Hz)	f_r	$f_r+0,1$ Hz	...
	Trip signal (yes/no)			
Overcurrent protection limit	Generator current signal (%)	Nominal current	nominal current+1 %	...
	Trip signal (yes/no)			...

7.8.3.3 Documentation and acceptance criteria

The protection limits test shall be completed and recorded according to [Table 15](#). The protection limit and the duration for trip shall be recorded.

7.8.3.4 Acceptance criteria

The generating set shall comply with protection limits based on values defined based on either regional grid code requirement at final installation site or by agreement between manufacturer and customer.

For overcurrent protection limit, it is to be verified if the protection limit triggers the trip signal.

8 Simulation-method-based assessment

8.1 General

This clause provides guidance and specifications for developing a mathematical simulation model that can be validated and used for accessing the performance requirements for generating sets used in island and grid parallel modes to fulfil the requirements of ISO 8528-5:2022, Table 4 and for grid code conformity requirements specified in ISO 8528-5. The validated simulation model can be used as an alternate method to real-time testing as described in [Clause 7](#).

In general, a root mean square (RMS) model is sufficient. More powerful models such as electromagnetic transient (EMT) models or real-time models are allowed but not mandatory. The model can be configured to use any fixed or variable step size and use discrete-time or continuous-time solver, provided that it passes the model validation outlined in [8.3](#) and [8.4](#).

A generating set model can consist of the following functional blocks:

- engine and engine controller or governor;
- AC generator;
- excitation machine;
- excitation controller or automatic voltage regulator (AVR);
- generating set controller (if applicable);

- protective devices (if available);
- measurement transformers (if applicable).

The manufacturer is responsible for the definition of the mathematical simulation model or blocks. Depending on the design of the generating set, it is possible to combine the individual blocks to provide the response that represents the generating set behaviour.

A validated generating set model shall be used to demonstrate conformity. Therefore, the generating set model shall be validated against a sample generating set in the same family to ensure that the model provides a sufficient level of accuracy. The generating set shall be tested to demonstrate compliance using, in part, the results of the validation tests described in [Clause 7](#) and, in part, results of simulations with a validated model. Validated individual blocks of the generating set can be combined to be considered as a model of the whole generating set. The generating set model shall be accompanied with relevant technical documentation for users to effectively use the simulation model.

A validated model of a generating set can also be used to demonstrate conformity of “families” of generating sets, provided the model parameters only change and the transfer function and its model structure remains the same. The generating set model or blocks can be encrypted if required to protect intellectual property and sensitive information. The validated generating set model can be exchanged within the families as defined in *generating set family* ([3.1.35](#)). The parameter accuracy of the model shall ensure that simulation results are reliable and representative of generating set electrical behaviour.

The simulation model shall represent a generating set on its own, connected to a load or parallel to the grid. It shall have sufficient model complexity to replicate dynamic behaviours. [Figure 5](#) illustrates how a simulation model can be constructed. The model can consist of blocks, as outlined in [8.2](#).

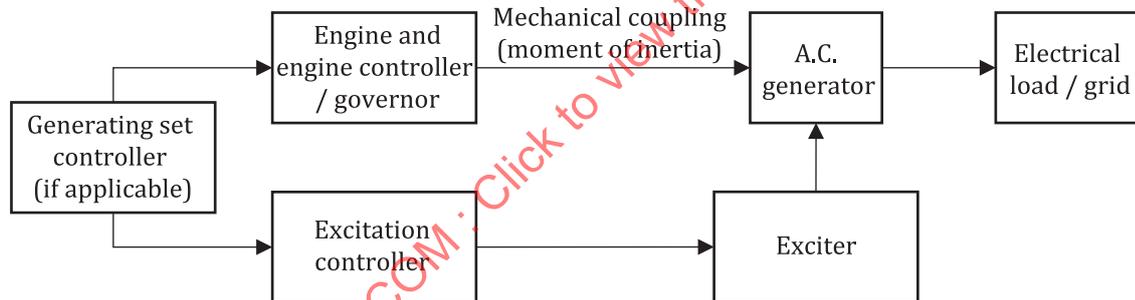


Figure 5 — Example of simulation model structure for simulation-based assessment

8.2 Specification of model blocks

8.2.1 General

This subclause provides guidance and requirements for the minimum requirements for each block used in [Figure 5](#). The overall moment of inertia of the generating set is essential information to be considered in the model. The inertia can be specified for the rotating elements or as a single value for the entire unit. The inertia value can be represented in either AC generator block or in the engine block.

8.2.2 Engine and engine controller or governor block

This block shall contain the dynamics and characteristics of the engine and engine controller or governor. The engine governor block shall contain the relevant information that enables validation of the block itself or with the full generating set model. The manufacturer shall provide the relevant parameters and constants, moment of inertia and the associated transfer functions that represent the engine and governor behaviour. The inertia of the engine shall be considered while estimating the inertia of complete rotating element if not otherwise included in the AC generator block.

For standalone island operation, the block shall capture the effect of time delays and time constants due to governor and engine designs, engine inertia, key speed regulation dynamics of the governor and any non-linearities that are dominant during transient behaviour.

8.2.3 AC generator block

The properties of the AC generator shall include the time constants, capability curve, AC generator moment of inertia, saturated reactances or unsaturated reactance values with saturation characteristics. The AC generator moment of inertia can include the inertia of engine and coupling system if not otherwise included in the engine block. The manufacturer of the AC generator shall provide information in respect of all relevant modelling parameters with related accuracy level.

8.2.4 Generating set controller block

The model of the generating set controller can be provided as a product-specific transfer function. If the controller has multiple functions, such as active power control and reactive power control, then these functions shall be part of the model.

The manufacturer shall provide the relevant blocks that define the dynamic behaviour. The user-modifiable settings shall be described in the appropriate manufacturer documentation.

8.2.5 Excitation controller (AVR) block

The model of the excitation controller (AVR) can be provided as a product-specific transfer function. If the AVR has multiple functions, in addition to regulation loops, such as reactive power control and power factor control, then these functions shall be part of the model.

Active limiters that affect the dynamic behaviour of the excitation controller shall be included in the model.

The manufacturer shall provide the setting for the excitation controller, including those settings affecting the dynamic behaviour and operation mode of the excitation controller. Standard IEEE 421.5 models are also acceptable.

8.2.6 Exciter block

If applicable, excitation system blocks, such as exciter, permanent magnet generator and rectifier, shall be included. It shall capture the time constants and limits in excitation dynamics during transient events. Excitation system model can be represented using transfer functions suitable for the type of excitation system on the generating set.

The manufacturer of the AC generator shall provide the parameters of the exciter (IEEE 421.5 models are acceptable).

8.2.7 Protective devices block

If protective functions are in the scope of the generating-set simulation, then a protection block shall be applied to allow a realistic representation of generating-set disconnection following grid disturbances.

As a minimum, this block includes protection against over-frequency and under-frequency, and against over-voltage and under-voltage. The definitive generating set (and grid) protection is characterised by a series of protection levels and a corresponding series of switch-off times as specified and tested in [7.8.3](#). User-definable curves can be entered to model specific trip profiles by defining a set of voltage/time or frequency/time coordinates.

NOTE Some grid codes can request additional protection functions such as RoCoF or pole slip.

8.2.8 Measurement transformer (if applicable)

If a measurement transformer is used for voltage and current deduction in the model, it shall match the physical configuration on phases that are being sensed (i.e., for a two-phase sensing system, the transformer shall match the two phases on which the voltage or current is being sensed). Commercially available voltage and current transformer simulation model can also be used to represent the measurement transformer.

8.3 Simulation for ISO performance class in standalone island operation

8.3.1 General

The purpose of this simulation-based assessment is to predict and classify the performance of a generating set operating in standalone island mode with respect to performance classification in accordance with ISO 8528-5:2022, Table 4 using a simulation. The scope of this assessment covers transient characteristics only. It does not cover steady-state or paralleling characteristics such as active or reactive power sharing. This approach can be undertaken as an alternative method to ISO performance test when it is technically not feasible to conduct the test.

The simulation model shall satisfy model specifications as outlined in [8.3](#). It shall be validated against test data according to [8.3.2](#). Once validated, the simulation model can be used to predict and classify performance according to [8.5.2](#) for generating set family.

8.3.2 Model validation for standalone island mode

8.3.2.1 General

A simulation model that meets the specifications in [8.3](#) shall be validated against test data to justify its accuracy before it can be used to predict performance according to [8.5.2.2](#).

The validation procedure only specifies measures to quantify the accuracy of the model. Specification of requirements to model accuracy is the agreement between manufacturer and customer.

Based on the accuracy of the simulation result with respect to test data, the simulation model can be calibrated to improve accuracy. Such calibration can be based on manufacturer data, test data or modification of block fidelity provided the simulation model still satisfies the model specification requirements in [8.3](#) and parameter tunings are within tolerance according to [8.3](#) or IEC 60034-1:2017, Table 21. Any deviations in tuning of parameters in reference to stated manufacturer data shall be documented.

For comparability, the measurement and simulation time series data shall be carried out with a common sampling time of half cycle, 10 ms for 50 Hz frequency or 8,3 ms for 60 Hz frequency. To calculate the deviation between simulated and measured values, a common time base shall be created for the two data sets. This can be done by time synchronization, decimation or interpolation between samples.

Signal processing in test data and simulation can be done in accordance with IEC 61400-27-2:2020, 6.4.

8.3.2.2 Test requirements

ISO 8528-5 specifies requirements to test a generating set and classify its performance. Load steps as per [7.3.3](#) shall be used for model validation.

Each load step is a test case in model validation and is characterised by a different starting load condition and finishing load condition. Although several measurements can be available for a test case, it is sufficient to analyse only the following outputs to validate the model against the real ISO 8528-5 test data that is available. All load step test data shall provide the following outputs to the validation:

- initial active and reactive load applied;

- final active and reactive load applied;
- time series of measured positive-sequence voltage;
- time series of measured frequency.

8.3.2.3 Simulation requirements

The following requirements apply to the simulations of each test case:

- a) The simulation model shall be set up to represent the same generating set configuration as in the test data, including controller modes.
- b) The simulation model shall be subject to the same load step transient as in the test case.
- c) The simulation model shall output:
 - time series of measured positive-sequence voltage;
 - time series of measured frequency.

8.3.2.4 Validated results

The following validation results shall be provided for each test case:

- a plot showing time series, presented in per-unit values, of the following variables:
 - measured positive-sequence voltage;
 - simulated positive-sequence voltage;
 - measured frequency;
 - simulated frequency;
- [Table 16](#) showing transient characteristics of measured data and simulated data, and the errors between them.

Applicable transient characteristics for the simulation model are provided in [Table 16](#). The limits for the parameters defined in [Table 16](#) are listed in ISO 8528-5:2022, Table 4. The characteristics shall be assessed at the performance class of the type test data. This list is the minimum requirement through modelling-based assessment. The manufacturer and customer shall agree to evaluate additional metrics for performance and accuracy. The specification of requirements to these error metrics shall be covered by the agreement between manufacturer and customer.

Table 16 — Performance class operating limit for simulation-based assessment

Parameter		Symbol
Steady-state frequency band		β_f
Transient frequency difference from initial frequency	100 % sudden power decrease	δf_d^+
	sudden power increase	δf_d^-
Transient frequency deviation from rated frequency	100 % sudden power decrease	δf_{dyn}^+
	sudden power increase	δf_{dyn}^-
Frequency recovery time		$t_{f,in}$
		$t_{f,de}$
Related frequency tolerance band		α_f

Table 16 (continued)

Parameter		Symbol
Transient voltage deviation	100 % sudden power decrease	ΔU_{dyn}^+
	sudden power increase	ΔU_{dyn}^-
Voltage recovery time after load increase		$t_{u,in}$
Voltage recovery time after load decrease		$t_{u,de}$

8.4 Simulation for generating sets used in grid connected applications

8.4.1 General

This subclause describes the minimum requirements for a mathematical model to prove the electrical behaviour of a generating set in grid-parallel operation in the event of:

- dynamic grid support;
- behaviour of active power injection at over-frequency and under-frequency;
- protection functions and settings;
- stability margin for AC generator (i.e. internal rotor angle).

8.4.2 Requirements and methodologies for model validation

The objective of this subclause is to provide formal specifications of the procedure for validation of a generating set simulation model against generating set type test results as defined in 8.4. Before using a model for simulations, the model must be validated based on measurements from physical tests. The validation procedure is based on tests of generating set control performance and dynamic performance.

The validation procedure shall be applicable to the models defined in 8.1 of this document to compare the fundamental frequency positive and negative sequence response of generating set models against measurements. Simulated positive sequence values shall be validated against the measured positive sequence values. In the case of models with negative sequence components, the simulated negative sequence components shall also be validated against the measured negative sequence components. The results of the validation process shall be suitable for use in various network stability assessments and planning studies. Other test results should also be accepted provided that the required measurement results are available.

Based on IEC 61400-27-2:2020, Clause 7, the results shall include procedure to validate:

- time series of measured and simulated fundamental frequency quantities;
- time series of errors between simulated and measured fundamental frequency currents and voltages, active and reactive power;
- mean error, mean absolute error and maximum error in pre-fault, during-fault and post-fault windows of voltage dips and voltage swells;
- measured and simulated reaction time, rise time, settling time and overshoot of reference point changes;
- presented in per-unit values.

For comparability, the measurement and simulation time series data shall be carried out with a common sampling time of half cycle, 10 ms for 50 Hz frequency or 8,3 ms for 60 Hz frequency. To calculate the deviation between simulated and measured values, a common time base shall be created for the two data sets. This can be done by time synchronization, data decimation or interpolation between samples.

8.4.3 Model validation for different grid requirements

8.4.3.1 General

The validated model can be considered for assessment if the difference between the measurement results and the simulation results for comparable scenarios lies within defined tolerances as referred in [8.4.2](#) of this standard. Where no values are defined, agreement between manufacturer and customer shall clarify the tolerances.

The following cases are considered for validation:

- FRT capability;
- active power control;
- active power response depending on frequency variation;
- protection.

8.4.3.2 FRT capability

8.4.3.2.1 General

The FRT capability of the generating set refers to the response of the generating set to voltage dips and voltage swells. The validation shall consider symmetrical and asymmetrical faults.

8.4.3.2.2 Test requirements

[Subclause 7.6](#) specifies the requirements for testing the generating set FRT capability, which includes the dynamic response to voltage dips and voltage swells. Each test case shall provide the following output to the validation:

- applied generating set control modes and gains;
- time series at AC generator terminals for:
 - voltage characteristics for all phases;
 - active power;
 - reactive power;
 - load angle in reference to generator terminal voltage;
- grid-relevant parameters (e.g., short circuit power, grid impedance, transformer data, cable information, impedance of FRT test equipment).

The minimum pre-fault recording period shall be 5 seconds. The minimum post-fault recording period shall be 5 seconds.

8.4.3.2.3 Simulation requirements

The generating set simulation model shall use the same control modes and test scenario as the generating set during the test. All reactive power control modes shall be included in the model. It shall be initialised in accordance with the measured initial values of voltage, active power and reactive power. The simulated time series shall be provided with minimum quarter cycle time step resolution.

8.4.3.2.4 Validation results

The following validation results shall be provided:

- plots showing time series of the following positive sequence components:
 - measured and simulated voltage;
 - measured and simulated active current;
 - measured and simulated reactive current;
 - measured load angle in reference to AC generator terminal voltage (optional).
- a table showing the maximum error, mean error, mean absolute error of positive sequence active power, reactive power, active current and reactive current in the pre-fault, fault and post-fault windows. In the case of validation of models including negative sequence, the validation of unbalanced fault cases shall include the equivalent values as for the positive sequence. The tolerance bands of the simulated and measured values are defined within the applicable national grid code. In absence of the requirement, it shall be agreed between the manufacturer and customer.

If correlation between simulation and measurement results is impacted by DC component of AC generator flux or if the reactive current is affected by transformer inrush, the validation of simulated result within fault window can be excluded if required in accordance with IEC 61400-27-2:2020, 6.4.4.

8.4.3.3 Active power control (optional)

8.4.3.3.1 General

The active power control of the generating set refers to the dynamic response of the generating set to step changes in active power reference value. The validated model shall be used to analyse the active power response to a step change of active power setpoint. The model shall account for any delay in the active power setpoint input.

8.4.3.3.2 Simulation requirements

The generating set model shall include the dynamic response to an active power setpoint. The simulation shall be performed by increasing the active power in steps of 10 %, from 0 % to 100 % rated active power. Each load step change shall include the following data:

- applied generating set control modes and reference values including power ramp rate;
- time series of:
 - simulated result for positive sequence of active power;
 - power reference (setpoint) value.

The generating set simulation model shall use the same control modes and reference values as the physical generating set. The generating set simulation model shall be initialised in accordance with the initial values of voltage, active power and reactive power. The simulated time series shall be provided with minimum quarter cycle time step resolution.

8.4.3.3.3 Acceptance criteria for simulated results

The following simulation results shall be provided:

- a plot showing time series of the following variables:
 - active power reference;

- simulated active power;
- a table showing the reaction time, rise time, settling time and overshoot of the simulated result.

The tolerance bands of the simulated and measured values should be either agreed between the manufacturer and customer or defined within the applicable national grid code.

8.4.3.4 Active power response depending on frequency variation

8.4.3.4.1 General

This test refers to verification of the active power response of the generating set to grid over-frequency or under-frequency events and applies only to generating set models that support this feature.

8.4.3.4.2 Test requirements

[Subclause 7.7](#) specifies the requirements for testing the generating set active power response to frequency variation, which includes the dynamic response to a step change in frequency. Each test case shall provide the following output for validation:

- Frequency-active power characteristics reference values (LFSM-O or LFSM-U characteristics);
- time series of:
 - measured frequency;
 - measured active power.

8.4.3.4.3 Simulation requirements

The generating set simulation model shall use the same control modes and reference values as the generating set during the test. The generating set simulation model shall be initialised in accordance with the measured initial values of frequency and active power. The simulated time series shall be provided with a minimum quarter cycle time step resolution.

8.4.3.4.4 Validation results

The following validation results shall be provided:

- a plot showing time series of the following variables:
 - simulated frequency variation input to generating set controller;
 - operating frequency of the generating set;
- a plot showing time series of the following variables:
 - measured and simulated frequency;
 - measured and simulated active power.
- a table showing the maximum error, mean error and mean absolute error of active power.

The tolerance bands of the simulated and measured values shall be either agreed between the manufacturer and customer or to defined within the applicable national grid code.

8.4.3.5 Grid protection

8.4.3.5.1 General

The grid protection of the generating set refers to the response of the generating set to over-voltage, under-voltage, over-frequency and under-frequency as a minimum. Additional protection, like RoCoF, can be included as required.

8.4.3.5.2 Test requirements

At least one test of over-voltage protection, under-voltage protection, over-frequency protection and under-frequency protection shall be used in the validation. The following inputs are required for protection function from [7.8](#):

- measured trip level;
- measured disconnection time;
- time series of trip signal.

8.4.3.5.3 Simulation requirements

The simulation shall be used to validate both the protection trip levels and determine the corresponding disconnection times. The following procedure shall be applied to validate the protection test:

- Over-voltage protection test: the relay trip time and level in the model shall be verified. With the simulations started at nominal voltage and frequency, increase the voltage by 1 % above the trip at a time until the model trips. Record the voltage level and time from the step in the voltage until the trip occurs.
- Under-voltage protection test: the relay trip time and level in the model shall be verified. With the simulations started at nominal voltage and frequency, decrease the voltage by 1 % below the trip level at a time until the model trips. Record the voltage level and time from the step in the voltage and until the trip occurs.
- Over-frequency protection test: the relay trip time and level in the model shall be verified. With the simulations started at nominal voltage and frequency, increase frequency by 0,1 Hz above the trip level at a time until the trip occurs. Record the frequency level and time until the model trips.
- Under-frequency protection test: the relay trip time and level in the model shall be verified. With the simulations started at nominal voltage and frequency, decrease the frequency by 0,1 Hz below the trip level at a time until the trip occurs. Record the frequency level and time until the model trips.

8.4.3.5.4 Validation results

Provide a table showing the setpoint, measured and simulated values for protection levels and disconnection times for each test. The tolerance bands of the simulated and measured values should be either agreed between the manufacturer and customer or defined within the applicable national grid code. The simulation model block shall represent the actual protection relay behaviour.

8.5 Assessment for generating set family

8.5.1 Methodology

Only a validated simulation model shall be used to conduct test by simulation to predict the type test response in grid parallel operation. The simulation model may be used to assess the generating set family based on the validated model in [8.3.2](#), given it satisfies the following requirements:

- AC generator and excitation system shall be of the same family as used in the validated model, which covers different apparent power, voltage range, operating frequency and core length of the AC generator. Model parameters for the assessed generating set can be obtained from the manufacturer.
- Controllers (governor, generating set controller, AVR) shall use the same control mechanism in the assessed generating set as in the validated model. The model parameters shall be obtained from the manufacturer's design or datasheet.
- If blocks are derived empirically during validation, such as governor or engine sub-model, block parameters of the assessed generating set can be extrapolated from validated model parameters if both configurations are of the same family, provided the transfer function and the structure of the block does not change.

Signal processing in test data and in simulation shall be done in accordance with IEC 61400-27-2:2020, 6.4.

8.5.2 Assessment for ISO performance class for family

8.5.2.1 Simulation results

Simulation model shall be set up to represent the assessed generating set. The model shall be subject to load steps according to ISO 8528-5:2022, Table 4 as test cases in the simulation environment.

The following simulation results shall be provided for each test case:

- a plot showing time series, in per-unit values, of the following variables:
 - simulated positive sequence voltage;
 - simulated frequency;
- a table showing transient characteristics of simulated data.

Applicable transient characteristics are outlined in [Table 7](#).

8.5.2.2 Performance classification

Performance classification (G1 to G4) of the assessed generating set shall be evaluated by comparing simulated results against performance class thresholds in ISO 8528-5:2022, Table 4 for the transient characteristics in [Table 7](#).

If the assessed generating set meets all ISO 8528-5 transient performance criteria in simulation, the manufacturer shall claim the configuration as attaining the ISO 8528-5:2022, Table 4 transient performance classification by simulation.

8.5.3 Assessment for type test for family in grid parallel application

8.5.3.1 Simulation results

The simulation model shall be set up to represent the assessed generating set. The model shall be subjected to the test requirements as requested in [8.4](#). The required test cases shall be simulated.

The following simulation results shall be provided for each test case:

- a plot showing required output in time series, in per-unit values, of the following variables:
 - simulated voltage;
 - simulated active and reactive power;
 - simulated load angle in reference to generator terminal voltage;
 - and any additional signals.

8.5.3.2 Type test compliance

The simulation results are evaluated against the requirements as specified in the relevant sections of [Clause 7](#). The assessed generating set simulation results can be used to prove compliance against the applicable grid code requirements as an alternative to physical test.

9 Acceptance test

9.1 General

The acceptance test is a test or series of tests carried out to demonstrate to the customer that a generating set meets the relevant requirements from ISO 8528-1 to ISO 8528-5.

The acceptance test can specify agreed variations in the performance classification of ISO 8528-1 to ISO 8528-5 or additional tests to meet specific operating limits, such as local grid codes at point of installation.

The acceptance test can be carried out at the final assembly site or the manufacturer's site, taking account of available facilities. The acceptance test can include separate component tests or simulation results as necessary to determine if the generating set performance is acceptable, taking account of available facilities.

The requisites of the acceptance test shall be agreed in writing between the manufacturer and customer, including which documents shall be made available, by which party and at what time.

9.2 Responsibility

The generating set manufacturer shall be responsible for the different parts of the acceptance test that is defined by agreement between manufacturer and customer.

9.3 Preparation

9.3.1 Provision of auxiliary personnel, test equipment and operating materials

Provision of auxiliary personnel, measuring equipment and operating materials shall be as follows:

- a) In the case of an acceptance test performed at the manufacturer's site, the manufacturer shall provide the normal operating materials (e.g., load banks, fuel), the measuring equipment necessary for the test and any auxiliary personnel.
- b) In the case of an acceptance test at the site of installation, the customer shall provide the necessary operating materials (e.g., load banks, fuel). If the customer is to provide auxiliary personnel to assist the manufacturer in performing the tests and any additional measuring equipment that can be necessary. This shall be agreed between the manufacturer and customer.

9.3.2 Acceptance test preparation at the installation site

The manufacturer shall be given the opportunity to inspect the generating set as per 9.3.4 before the acceptance test is performed and carry out any necessary adjustments and checks. This also applies when the manufacturer has not carried out the installation by themselves.

9.3.3 Acceptance test preparation at the manufacturer's site or facility

When the acceptance test is carried out at the manufacturer's site, the normal air ducting and exhaust gas ducting used shall be accepted. The use of the auxiliary equipment (e.g. cooling water pumps, lubricating oil filters, coolers, switchgear) installed at the manufacturer's site, instead of that to be supplied with the generating set, is permissible unless otherwise agreed. The manufacturer shall inspect the generating set as per 9.3.4 before the acceptance test is performed and carry out any necessary adjustments and checks.

If the specified ambient conditions and properties of the operating materials cannot be realized for the acceptance test, agreement shall be reached before starting the acceptance test regarding the influence of the deviant conditions and any necessary conversion of the test results.

9.3.4 Preliminary safety checks on generating set prior to testing

Before starting the generating set for the acceptance test, it is recommended to carry out the following safety checks:

- a) check condition of electrical insulation of AC generator. The insulation resistances of main stator coils, main rotor coils, exciter stator coils and exciter rotor coils shall be above minimum acceptable values as described in the manual of the AC generator manufacturer.
- b) check the fuel, coolant and oil levels in the engine. Ensure there is no leakage.
- c) verify that the emergency stop is functional.
- d) verify that all protection systems are functional and operating correctly.
- e) verify the software versions and hardware versions on the generating set control system.
- f) check status, connections and mechanical integrity of the batteries and their enclosures. For flooded batteries, check the fluid level and remaining voltage. For AGM and gel batteries, verify the voltage remaining in the batteries.
- g) check that electrical terminals are connected securely with suitable creepage and clearance distances.
- h) verify that the generating set is earthed as required.

9.4 Further details

If the acceptance test is interrupted by minor faults which can be quickly rectified and are not regarded as fundamental, with agreement with the manufacturer and customer the acceptance test shall be continued after the interruption has been rectified.

If the acceptance test is interrupted by major faults which necessitate the repair or replacement of important components, the specific part of the acceptance test shall be repeated either wholly or in part once the interruption has been rectified. The amount of testing to be repeated shall be subject to agreement between the manufacturer and customer.

During any part of the acceptance test, the only adjustments or maintenance that shall be carried out on the generating set are those which are:

- a) necessary for maintaining the test conditions within tolerance;

- b) those maintenance operations and/or adjustments specified in the operations manual.

Special provisions can be necessary for generating sets operating at their installation site which use fuel other than that of a distillate type (e.g. gas, residual fuel).

9.5 Extent of acceptance test

9.5.1 General

This procedure can be used as guidelines for the extent of the acceptance test; specific requirements applicable to the installation or the equipment shall be defined by agreement between manufacturer and customer. The extent of the acceptance test depends on the designated application of the generating set and is divided into the groups of checks and measurements shown in 9.5.2 and 9.5.3. Checks and measurements over and above those mentioned necessitate an additional agreement. The prevailing conditions shall be taken into account in the case of an acceptance test at the site of installation.

9.5.2 Checks (C)

9.5.2.1 Group CA

Completeness of items supplied and to be tested.

9.5.2.2 Group CB

- a) alignment;
- b) operating functions of auxiliary equipment;
- c) tightness of pipework joints and components;
- d) protection against accidental contact (mechanical and electrical);
- e) operating and monitoring functions;
- f) vibrations (steadiness);
- g) unusual running noises;
- h) temperature rise of important components.

9.5.2.3 Group CC

- a) switching functions of the associated switchgear;
- b) control functions of the associated switchgear;
- c) monitoring functions of the associated switchgear.

9.5.2.4 Group CD

Suitability for parallel operation:

- a) check performance of automatic paralleling equipment, if applicable;
- b) check power-sharing (active and reactive power sharing) operation;
- c) auto switching from island to parallel or vice-versa.

9.5.3 Measurements (M)

9.5.3.1 General

Typical measurements are listed in 9.5.3.2 to 9.5.3.14. The requirements of [9.7](#) apply to the extent of the measurements to be carried out during the acceptance test.

9.5.3.2 Group MA

The following parameters shall be measured under steady-state operating conditions under no load:

- a) voltage;
- b) frequency.

9.5.3.3 Group MB

The following parameters shall be measured under steady-state operating conditions:

- a) current;
- b) range of voltage setting;
- c) range of frequency setting;
- d) active power;
- e) power factor or reactive power;
- f) steady-state frequency band;
- g) rate of change of voltage setting under remote control;
- h) rate of change of frequency setting under remote control.

9.5.3.4 Group MC

Starting behaviour.

9.5.3.5 Group MD

The following parameters shall be measured under steady-state operating conditions:

- a) lubricating oil pressure or temperature;
- b) coolant temperature at input and output of engine and generator.

9.5.3.6 Group ME

Exhaust gas temperature.

9.5.3.7 Group MF

Noise emission.

9.5.3.8 Group MG

Exhaust gas emission.

9.5.3.9 Group MH

The following parameters shall be measured using an oscillograph or similar device with defined power factor while loading and unloading the generator to assess transient behaviour:

- a) voltage;
- b) current;
- c) frequency.

This test shall be performed with consideration of the final application of the generating set in relation to mode of operation as defined in ISO 8528-1:2018, Clause 7.

9.5.3.10 Group MJ

The harmonic content of the voltage waveform at rated performance of generating set shall be within the limits specified in ISO 8528-3:2020, 8.5.

9.5.3.11 Group MK

The amplitude modulation of the voltage waveform shall conform with ISO 8528-5:2022, Table 4.

9.5.3.12 Group ML

The following parameters shall be measured under steady-state operating conditions and shall conform with ISO 8528-5:2022, Table 4:

- a) active power sharing in parallel operation;
- b) reactive power sharing in parallel operation.

9.5.3.13 Group MM

The fuel consumption of the generating set relative to the electric power available at the AC generator terminals, taking into account the calorific value of the fuel.

9.5.3.14 Group MN

Effectiveness of the electrical protection device(s).

9.6 Accuracy of measurement equipment and acceptance test procedure

9.6.1 Measurement equipment accuracy

The required accuracy of the electrical instrumentation shall be subject to agreement between the manufacturer and the customer. The tolerances shown in [Table 1](#) shall be used as the minimum accuracy of the measurement equipment.

The waveform dependence of the measuring instruments used can be taken into account.

9.6.2 Warm-up time

The acceptance test shall be performed on generating sets that have reached their normal operating engine temperature and pressures. It is the responsibility of the test engineer to ensure that the set has run for an adequate time to stabilize the engine temperatures.

9.6.3 Generating set load test duration

The duration of the load test depends on the generating set rating and application.

NOTE The duration is generally a period up to 2 h but will usually be specified by the manufacturer.

9.6.4 Performing acceptance tests at the manufacturer's works

9.6.4.1 Acceptance test with electrical load

A unity power factor load is usually used for testing, with due regard to rated active power and associated generator efficiency. Optionally, if suitable test equipment is available, this test can be run at the generating set rated power factor.

Measurements which are affected by the power output shall be taken with the generating set at no load, 25 % rated power, 50 % rated power, 75 % rated power and 100 % rated power. The load acceptance test is subject to agreement between the generating set manufacturer and customer.

If the ambient conditions during the test differ from the standard reference conditions (see ISO 8528-1), the measured power data shall be converted to be in line with the standard reference conditions.

9.6.4.2 Acceptance test using test-bed switchgear

Unless otherwise agreed, the following checks and measurements shall be carried out:

- a) groups CA and CB, checks (see [9.5.2.1](#) and [9.5.2.2](#));
- b) groups MA and MB, measurements (see [9.5.3.2](#) and [9.5.3.3](#)).

9.6.4.3 Acceptance test including generating set's own switchgear

Unless otherwise agreed, the following checks and measurements shall be carried out:

- a) groups CA, CB and CC, checks (see [9.5.2.1](#), [9.5.2.2](#) and [9.5.2.3](#));
- b) groups MA, MB and MN, measurements (see [9.5.3.2](#), [9.5.3.3](#) and [9.5.3.14](#)).

9.6.4.4 Additional checks and measurements

Further checks and measurements can be agreed in addition to those specified in [9.6.4.2](#) and [9.6.4.3](#) (see [9.5.2](#) and [9.5.3](#)).

9.6.4.5 Acceptance test without electric load

Unless otherwise agreed, the checks shown in groups CA and CB shall be carried out (see [9.5.2](#)). The measurements of group MA shall be carried out (see [9.5.3](#)).

NOTE It is not possible to measure voltage and frequency without electrical excitation equipment being connected.

9.6.5 Installation site acceptance test

The acceptance test shall be carried out with the electrical load available at the site of installation, which shall be as near as possible to the rated power. Unless otherwise agreed, the following checks and measurements shall be carried out:

- a) groups CA, CB and CC, checks (see [9.5.2.1](#), [9.5.2.2](#) and [9.5.2.3](#));
- b) groups MA and MB, measurements (see [9.5.3.2](#) and [9.5.3.3](#)).

Further checks and measurements can also be agreed (see [9.5.2](#) and [9.5.3](#)).

The groups for the checks and measurements are summarized in [Table 17](#).

Table 17 — Checks and measurements groups

Acceptance test	Groups for	
	checks (9.5.2)	measurements (9.5.3)
Using test bed switchgear	CA and CB	MA and MB
Using generating set's own switchgear	CA, CB and CC	MA, MB and MN
Without electrical load	CA and CB	MA
At site of installation	CA, CB and CC	MA and MB
If no separate acceptance test has been carried out on the engine itself, the measurements of groups ME and MF (see 9.5.3.6 and 9.5.3.7) shall be performed.		
NOTE For continuous and prime power application, test MM can be carried out.		

9.7 Acceptance test report

9.7.1 General

The performance of the acceptance test in accordance with the requirements specified in 9.6, on a generating set in accordance with the requirements of ISO 8528-1 to ISO 8528-5, shall be recorded in the form of an acceptance test report.

9.7.2 General data

The acceptance test report shall include the following general data (as a minimum):

- a) the generating set performance class in accordance with ISO 8528-1 and ISO 8528-5;
- b) the customer and order number;
- c) the manufacturer and order number;
- d) the generating set serial number;
- e) technical data (as a minimum):
 - 1) rated power;
 - 2) rated voltage;
 - 3) rated frequency;
 - 4) rated current;
 - 5) rated power factor;
 - 6) circuit diagram number.
- f) details of the RIC engine, as follows (as a minimum):
 - 1) manufacturer;
 - 2) engine model;
 - 3) engine serial number;

- 4) number of cylinders and configuration;
 - 5) type of cooling;
 - 6) manufacturer's declared power, in kilowatts, quoting corresponding engine speed;
 - 7) type of starting system.
- g) details of the generator, as follows (as a minimum):
- 1) manufacturer;
 - 2) AC generator model;
 - 3) AC generator serial number;
 - 4) rated output, in kilovolt-amperes;
 - 5) rated power factor;
 - 6) type of construction;
 - 7) type of protection.
 - 8) AC generator PQ diagram
 - 9) AC generator electrical performance data sheet including reactances;
- h) details of the equipment installed, as follows (as a minimum):
- 1) switchgear:
 - i) manufacturer;
 - ii) model;
 - iii) switchgear number;
 - 2) coupling:
 - i) manufacturer;
 - ii) model;
 - iii) type.
 - 3) speed governor:
 - i) manufacturer;
 - ii) model;
 - iii) governor number;
 - iv) details of any other installed or used equipment, such as:
 - 1) battery;
 - 2) compressed air starting equipment;
 - 3) pumps;
 - 4) compressed air reservoir;
 - 5) cooling equipment.

9.7.3 Additional measured data for acceptance test

The acceptance test report shall include the following measured data (as a minimum):

a) test site conditions, as follows:

- 1) altitude;
- 2) barometric pressure;
- 3) ambient temperature;
- 4) relative humidity;
- 5) inlet air temperature;
- 6) inlet coolant temperature;

NOTE Values for 3), 5) and 6) could be different for the RIC engine and the generator.

b) the fuel type (specification number), as follows:

- 1) density;
- 2) calorific value (lower calorific value);

c) technical data of the generating set, as follows:

- 1) power;
- 2) voltage;
- 3) frequency;
- 4) number of phases;
- 5) current;
- 6) power factor;
- 7) speed adjustment range;
- 8) frequency setting rate of change;
- 9) voltage range.

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Annex A (informative)

Test method using OVRT/UVRT test equipment

The test should be performed using a fault emulator, widely known in the industry as a “fault ride-through container”. The design of the testing equipment should permit the required voltage against time profile to be achieved.

The fault is created by a short-circuit emulator that connects three or two phases to ground via an impedance or connecting the three, or two phases together through an impedance. An example one-line diagram of the equipment to be used is provided in [Figure A.1](#).

A series impedance ‘ Z_1 ’ is used to limit the impact of short-circuits prior to the connection point of the generating set to the grid. The size of the impedance shall be selected so that the fault ride-through testing does not cause an unacceptable voltage variation on the grid, and at the same time not significantly affecting the transient response of the generating set. A by-pass connection of Z_1 can be applied pre-fault and post-fault using switch S_1 . During the FRT test S_1 shall be opened and the generating set is allowed to operate in a stable condition parallel to the grid.

The emulated fault is created by connecting the shunt impedance Z_2 using switch S_2 for the required duration based on the FRT curve defined by the selective method in [7.6](#). The magnitude of impedance Z_2 shall be adjusted to achieve the desired change in voltage at the generating set terminal.

The values of the impedances Z_1 and Z_2 used in each test shall be documented in the test report. The short circuit power of the test setup shall be within the range of two times to 30 times the nominal power at the generating set terminal. The X/R ratio of the test impedance shall be at least 3.

Switch S_2 shall be able to accurately control the time between connection and disconnection of Z_2 (fault clearing time), for both symmetrical and asymmetrical faults. The switch can be, for example, a mechanical circuit breaker or a power electronic device.