INTERNATIONAL STANDARD

ISO 8528-5

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Reciprocating internal combustion engine driven alternating current generating sets —

Part 5:
Generating sets

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

Partie 5: Groupes électrogènes

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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 documents 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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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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 fifth edition cancels and replaces the fourth edition (ISO 8528-5:2018), which has been technically revised.

The main changes are as follows:

— Clause 3 has been revised;

— a list of symbols has been added in 3.2;

— mistakes have been corrected in Table 4;

— previous Figures 3, 7, 8, 14 and 16 have been modified and renumbered;

— previous Figures 1 and 17 have been deleted;

— Annex A has been deleted.

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.

Reciprocating internal combustion engine driven alternating current generating sets —

Part 5:
Generating sets

1 Scope

This document specifies design and performance criteria arising out of the combination of a reciprocating internal combustion (RIC) engine and an alternating current (AC) generator when operating as a unit. This unit can run in parallel to the grid or not.

This document applies to AC generating sets driven by RIC engines for land and marine use, excluding generating sets used on aircraft, or to propel land vehicles and locomotives.

For some specific applications (e.g. essential hospital supplies and high-rise buildings), supplementary requirements can apply. The provisions of this document are a basis for establishing any supplementary requirements.

For generating sets driven by other reciprocating-type prime movers (e.g. steam engines), the provisions of this document can be used as a basis for establishing these requirements.

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 3046-5, *Reciprocating internal combustion engines — Performance — Part 5: Torsional vibrations*

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

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

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

3 Terms, definitions and symbols

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/

1

3.1.1
frequency
f
reciprocal of the period

Note 1 to entry: The symbol f is mainly used when the period is a time.

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
f_r
frequency at which the generating set is designed to operate

3.1.5
maximum safety frequency
f_{maxs}
maximum frequency which causes a stop to production

3.1.6
minimum safety frequency
f_{mins}
minimum frequency which causes a stop to production

3.1.7
frequency setting rate of change
v_f
rate of change of frequency setting under remote control

Note 1 to entry: $v_f = \dfrac{(f_{i,max} - f_{i,min})/f_r}{t} \times 100$

where

$f_{i,max}$ is maximum no-load frequency;

$f_{i,min}$ is minimum no-load frequency;

f_r is *rated frequency* (3.1.4).

Note 2 to entry: Expressed as a percentage of related range of frequency setting per second.

3.1.8
voltage setting rate of change
v_U
rate of change of voltage setting under remote control

Note 1 to entry: $v_U = \dfrac{(U_{s,up} - U_{s,do})/U_r}{t} \times 100$

where

U_r is *rated voltage* (3.1.11);

$U_{s,do}$ is *downward adjustment of voltage* (3.1.9);

$U_{s,up}$ is *upward adjustment of voltage* (3.1.10).

Note 2 to entry: Expressed as a percentage of the related range of voltage setting per second.

3.1.9
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

3.1.10
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

3.1.11
rated voltage
U_r

line-to-line voltage at the terminals of the generator at rated frequency and rated output

3.1.12
set voltage
U_s

maximum obtainable steady-state voltage for a specified load condition or line-to-line voltage for defined operation selected by adjustment

3.1.13
no-load voltage
U_0

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

3.1.14
voltage modulation
$\hat{U}_{mod,s}$

quasi-periodic voltage variation (peak-to-peak) about a steady-state voltage having typical frequencies below the fundamental generation frequency

Note 1 to entry: Expressed as a percentage of average peak voltage at rated frequency and constant speed.

Note 2 to entry:
$$U_{mod,s} = 2 \times \frac{\hat{U}_{mod,s,max} - \hat{U}_{mod,s,min}}{\hat{U}_{mod,s,max} + \hat{U}_{mod,s,min}} \times 100$$

where

$\hat{U}_{mod,s,max}$ is maximum peak of voltage modulation;

$\hat{U}_{mod,s,min}$ is minimum peak of voltage modulation.

Note 3 to entry: This is a cyclic or random disturbance which can be caused by regulators, cyclic irregularity or intermittent loads. Flickering lights are a special case of voltage modulation (see Figures 7 and 8).

3.1.15
steady-state frequency tolerance band
Δf

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

3.1.16
related range of frequency setting
δf_s
range of frequency setting

Note 1 to entry: See Figure 1.

Note 2 to entry: Expressed as a percentage of rated frequency.

Note 3 to entry: $\delta f_s = \dfrac{f_{i,max} - f_{i,min}}{f_r} \times 100$

where

$f_{i,max}$ is maximum no-load frequency;

$f_{i,min}$ is minimum no-load frequency;

f_r is *rated frequency* (3.1.4).

Key
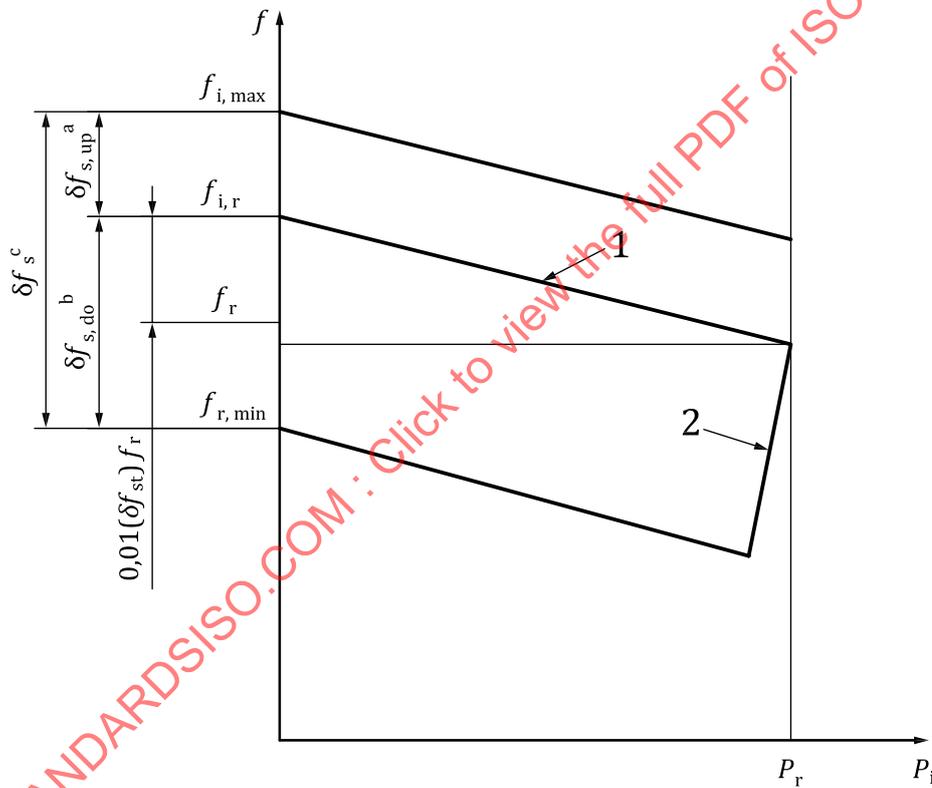
P power
f frequency
P_r rated power
1   frequency/power characteristic curve
2   power limit [the power limit of the generating set depends upon the power limit of the RIC engine (e.g. fuel stop power) taking into account the efficiency of the AC generator]
a   Related upward range of frequency setting.
b   Related downward range of frequency setting.
c   Related range of frequency setting.

Figure 1 — Frequency/power characteristic, range of frequency setting

3.1.17
downward range of frequency setting
$\Delta f_{s,do}$
range between the declared no-load frequency and the lowest adjustable no-load

Note 1 to entry: See Figure 1.

Note 2 to entry: $\Delta f_{s,do} = f_{i,r} - f_{i,min}$

where

    $f_{i,r}$ is *rated no-load frequency* (3.1.3);

    $f_{i,min}$ is minimum no-load frequency.

3.1.18
upward range of frequency setting
$\Delta f_{s,up}$
range between the highest adjustable no-load frequency and the declared no-load frequency

Note 1 to entry: See Figure 1.

Note 2 to entry: $\Delta f_{s,up} = f_{i,max} - f_{i,r}$

where

    $f_{i,max}$ is maximum no-load frequency;

    $f_{i,r}$ is *rated no-load frequency* (3.1.3).

3.1.19
range of voltage setting
ΔU_s
range of maximum possible upward and downward adjustments 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

Note 1 to entry: $\Delta U_s = \Delta U_{s,up} + \Delta U_{s,do}$.

3.1.20
frequency/power characteristic deviation
$\Delta \delta f_{st}$
maximum deviation from a linear frequency/power characteristic curve in the power range between no-load and declared power

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

Note 2 to entry: See Figure 2.

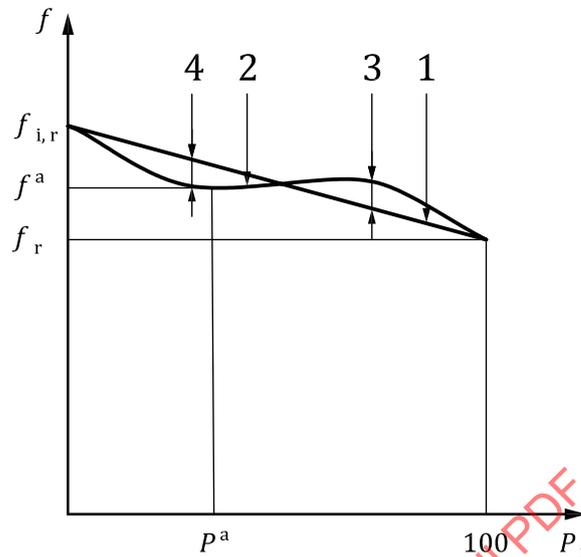Note 3 to entry: $\Delta \delta f_{st} = \dfrac{\Delta f_c}{f_r} \times 100$

where

    Δf_c is maximum frequency deviation from a linear curve;

    f_r is *rated frequency* (3.1.4).

3.1.21
frequency/power characteristic curve
curve of steady-state frequencies in the power range between no-load and declared power, plotted against active power of the generating set

Note 1 to entry: See Figure 2.

Key

P power

f frequency

1 linear frequency/power characteristic curve

2 frequency/power characteristic curve

3 positive deviation from a linear curve, Δf_{pos}

4 negative deviation from a linear curve, Δf_{neg}

a Frequency/power characteristic deviation.

Figure 2 — Frequency/power characteristic, deviation from the linear curve

3.1.22
relative steady-state frequency tolerance band
α_f
ratio of the magnitude of frequency change to rated frequency

Note 1 to entry: $\alpha_f = \dfrac{\Delta f}{f_r} \times 100$

where

Δf is *steady-state frequency tolerance band* (3.1.15);

f_r is *rated frequency* (3.1.4).

3.1.23
steady-state frequency band
β_f
ratio of frequency oscillation envelope width frequency at constant power around a mean value of rated frequency at constant power

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

Note 2 to entry: See Figure 3.

Note 3 to entry: $\beta_{\mathrm{f}} = \dfrac{\overset{\wedge}{\underset{\vee}{f}}}{f_{\mathrm{r}}} \times 100$

where

$\overset{\wedge}{\underset{\vee}{f}}$ is envelope width oscillation of generating set;

f_{r} is *rated frequency* (3.1.4).

Key
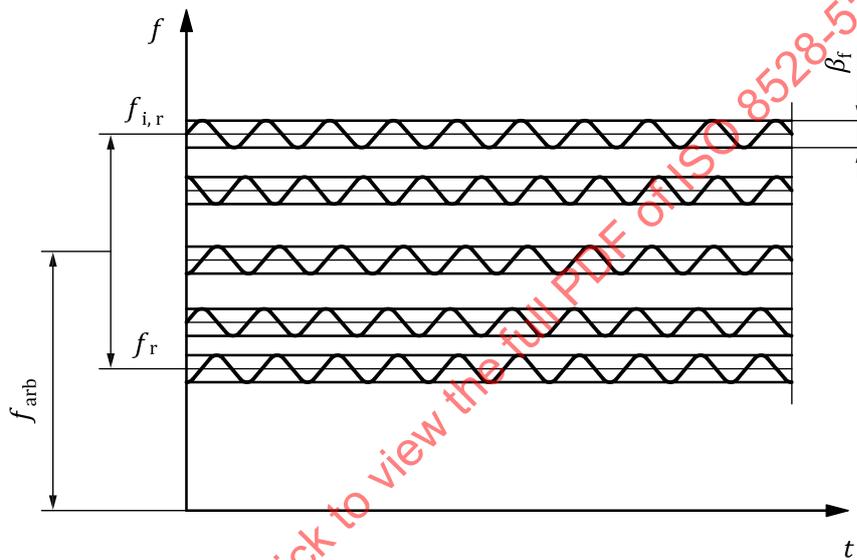
t time

f frequency

f_{arb} frequency at actual power

Figure 3 — Steady-state frequency band

3.1.24
related downward range of frequency setting
$\delta f_{\mathrm{s,do}}$
range of downward frequency setting

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

Note 2 to entry: $\delta f_{\mathrm{s,do}} = \dfrac{f_{\mathrm{i,r}} - f_{\mathrm{i,min}}}{f_{\mathrm{r}}} \times 100$

where

$f_{\mathrm{i,r}}$ is *rated no-load frequency* (3.1.3);

$f_{\mathrm{i,min}}$ is minimum no-load frequency;

f_{r} is *rated frequency* (3.1.4).

3.1.25
related upward range of frequency setting
$\delta f_{s,up}$
range of upward frequency setting

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

Note 2 to entry: $\delta f_{s,up} = \dfrac{f_{i,max} - f_{i,r}}{f_r} \times 100$

where

$f_{i,r}$ is *rated no-load frequency* (3.1.3);

$f_{i,max}$ is maximum no-load frequency;

f_r is *rated frequency* (3.1.4).

3.1.26
frequency droop
δf_{st}
frequency difference between rated no-load frequency and the rated frequency f_r at declared power

Note 1 to entry: See Figure 1.

Note 2 to entry: $\delta f_{st} = \dfrac{f_{i,r} - f_r}{f_r} \times 100$

where

$f_{i,r}$ is *rated no-load frequency* (3.1.3);

f_r is *rated frequency* (3.1.4).

Note 3 to entry: Expressed as a percentage of rated frequency at fixed frequency setting.

3.1.27
cyclic irregularity
δ_s
periodic fluctuation of speed caused by the rotational irregularity of the prime mover

3.1.28
steady-state voltage deviation
ΔU_{st}
change in steady-state voltage for all load changes between no-load and rated output, considering the influence of temperature but ignoring the effect of quadrature current compensation voltage droop

Note 1 to entry: $\Delta U_{st} = \pm \dfrac{U_{st,max} - U_{st,min}}{2 \cdot U_r} \times 100$

where

$U_{st,max}$ is maximum steady-state voltage;

$U_{st,min}$ is minimum steady-state voltage;

U_r is *rated voltage* (3.1.11).

Note 2 to entry: The initial set voltage is usually the rated voltage but can be anywhere within the range of voltage setting.

Note 3 to entry: ΔU_{st} is expressed as a percentage of the rated voltage.

3.1.29
voltage unbalance
$\Delta U_{2 \cdot 0}$
ratio of the negative-sequence or the zero-sequence voltage components to the positive-sequence voltage components at no-load

Note 1 to entry: Voltage unbalance is expressed as a percentage of rated voltage.

3.2   Symbols

Symbol	Term	Meaning
$\overset{\wedge}{\underset{\vee}{f}}$	envelope width oscillation of generating set	oscillation frequency at constant power around rated frequency caused by the reciprocating internal combustion engine
$f_{i,max}$	maximum no-load frequency	maximum frequency at which the generating set is operating without load
$f_{i,min}$	minimum no-load frequency	minimum frequency at which the generating set is operating without load
f_r	rated frequency	frequency at which the generating set is designed to operate
f_{arb}	frequency at actual power	frequency at which the generating set is rated to operate
$t_{f,de}$	frequency recovery time after load decrease	time interval between the departure from the steady-state frequency band after a sudden specified load decrease and the permanent re-entry of the frequency into the specified steady-state frequency tolerance band
$t_{f,in}$	frequency recovery time after load increase	time interval between the departure from the steady-state frequency band after a sudden specified load increase and the permanent re-entry of the frequency into the specified steady-state frequency tolerance band
$t_{u,de}$	voltage recovery time after load decrease	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
$t_{u,in}$	voltage recovery time after load increase	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
ΔU	steady-state voltage tolerance band	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

Symbol	Term	Meaning
$\Delta U_{\mathrm{dyn}}^{-}$	transient voltage deviation on load increase	voltage drop when the generator, driven at rated frequency and at rated voltage under normal excitation control, is switched onto rated load
$\Delta U_{\mathrm{dyn}}^{+}$	transient voltage rise	maximum voltage rise, when the a.c. generator, driven at the rated speed and at the rated voltage under normal excitation control, has a sudden rejection of the rated output
$\hat{U}_{\mathrm{mod,s,max}}$	maximum peak of voltage modulation	quasi-periodic maximum voltage variation (peak-to-peak) about a steady-state voltage
$\hat{U}_{\mathrm{mod,s,min}}$	minimum peak of voltage modulation	quasi-periodic minimum voltage variation (peak-to-peak) about a steady-state voltage
ΔP	active power sharing	proportional distribution of active power between generating sets in parallel operation by means of suitable control methods
ΔQ	reactive power sharing	proportional distribution of reactive power between generating sets in parallel operation by means of suitable control methods
$\delta f_{\mathrm{d}}^{-}$	transient frequency deviation (from initial frequency) on load increase (−) related to initial frequency	temporary frequency deviation between undershoot frequency and initial frequency during the governing process following a sudden load increase, related to initial frequency
$\delta f_{\mathrm{d}}^{+}$	transient frequency deviation (from initial frequency) on load decrease (+) related to initial frequency	temporary frequency deviation between overshoot frequency and initial frequency during the governing process following a sudden load decrease, related to initial frequency
$\delta f_{\mathrm{dyn}}^{-}$	transient frequency deviation (from initial frequency) on load increase (−) related to rated frequency	temporary frequency deviation between undershoot (or overshoot) frequency and initial frequency during the governing process following a sudden load change, related to rated frequency
$\delta f_{\mathrm{dyn}}^{+}$	transient frequency deviation (from initial frequency) on load decrease (+) related to rated frequency	temporary frequency deviation between overshoot frequency and initial frequency during the governing process following a sudden load change, related to rated frequency

4 Other regulations and additional requirements

For AC generating sets used on board ships and offshore installations which shall comply with rules of a classification society, the additional requirements of the classification society shall be observed. The classification society shall be identified by the customer prior to placing of the order.

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

Any additional requirements shall be subject to agreement between the manufacturer and customer.

5 Frequency characteristics

5.1 General

The generating set steady-state frequency characteristics depend mainly on the performance of the engine speed governor.

The dynamic frequency characteristics, i.e. the response to load changes, depend on the combined behaviour of all the system components (e.g. the engine torque characteristics, including the type of turbocharging system, the characteristics of the load, the inertias and the damping) and thus on the individual design of all the relevant components. The dynamic frequency behaviour of the generating set can be related directly to the generator speed.

5.2 Safety frequency

The threshold of the maximum and minimum safety frequency shall be different according to the operating mode of the generating set: islanded or coupled to the grid. These values shall be higher or lower than the range of frequency of each operating mode.

6 Voltage characteristics

The generating set voltage characteristics are determined mainly by the inherent design of the AC generator and the performance of the automatic voltage regulator. Both the steady-state and the transient frequency characteristics can also influence the generator voltage (see Figure 4).

Key
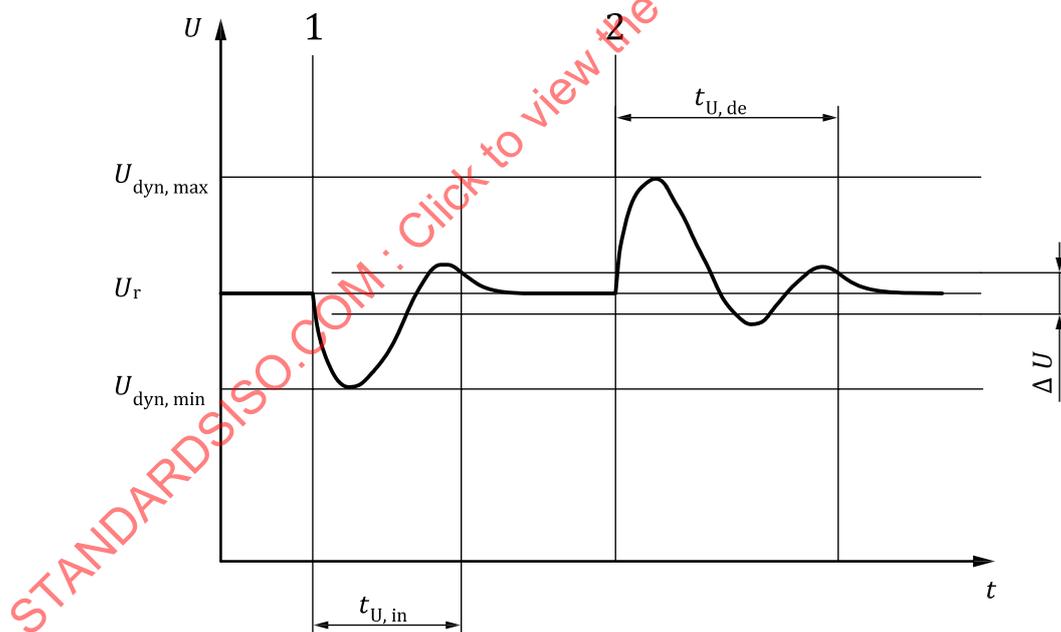
t time

U voltage

ΔU steady-state voltage tolerance band

1   power increase

2   power decrease

Figure 4 — Transient voltage characteristics without quadrature-current compensation voltage droop

7 Sustained short-circuit current

The sustained short-circuit current, I_k, which can be important to current-operated protective devices, may be lower in service than the "ideal" value specified by the generator manufacturer for a fault at the generator terminals. The actual value is influenced by the circuit impedance between the generator and the location of the fault (see ISO 8528-3: 2020, 8.3).

8 Factors affecting generating set performance

8.1 General

The frequency and voltage performance of a generating set depends on the characteristics of components and parts of the generating set.

8.2 Power

Among other factors with respect to the power, the following are particularly relevant and shall be considered when "sizing" the generating set and switchgear:

a) application;

b) power requirements of the connected load;

c) load power factor;

d) starting characteristics of any connected electrical motors;

e) diversity factor of the connected load;

f) intermittent loads;

g) effect of nonlinear loads;

h) characteristics of the grid to which the generating set can be coupled.

Consideration shall be given to the profile of the connected load in "sizing" the RIC engine and generator, as well as the switchgear.

8.3 Frequency and voltage

The effect on the transient frequency and voltage characteristics of the generating set to a sudden load change depends on such influences as the following:

a) The turbo-charging system of the RIC engine.

b) Brake mean effective pressure (bmep) of the RIC engine at declared power.

c) Speed governor behaviour.

d) AC generator design.

e) AC generator excitation system characteristics.

f) Voltage regulator behaviour.

g) Rotational inertia of the whole generating set. In order to establish the frequency and voltage characteristics of the generating set due to load changes, it is necessary to determine maximum switched-on or switched-off loads given by the connected load equipment.

h) Characteristics of the grid to which the generating set can be coupled.

8.4   Load acceptance

Since it is practically impossible to quantify all influences on the generating set response to dynamic loading, reference values for load application are given based on the permissible drop in frequency. A higher bmep usually makes loading in several steps necessary. Figures 5 and 6 show reference values for suddenly applied load steps depending on bmep at declared power for RIC engines.

The response behaviour of spark ignition engines is quite different to the response behaviour of diesel engines because of completely different combustion phenomena. The procedure of dynamic loading shall be decided by mutual agreement between the customer and the manufacturer.

The time intervals between the application of consecutive load steps depend on:

a)   the swept volume of the RIC engine;

b)   the RIC engine bmep;

c)   the RIC engine turbo-charging system installed;

d)   the type of RIC engine governor installed;

e)   the installed voltage regulator characteristics;

f)   the rotational inertia of the complete generating set and RIC engine combination.

If necessary, these time intervals shall be agreed between the generating set manufacturer and the customer.

Criteria for establishing the required minimum rotational inertia are:

— the permitted drop in frequency;

— the cyclic irregularity;

— if appropriate, the behaviour in the case of parallel operation.
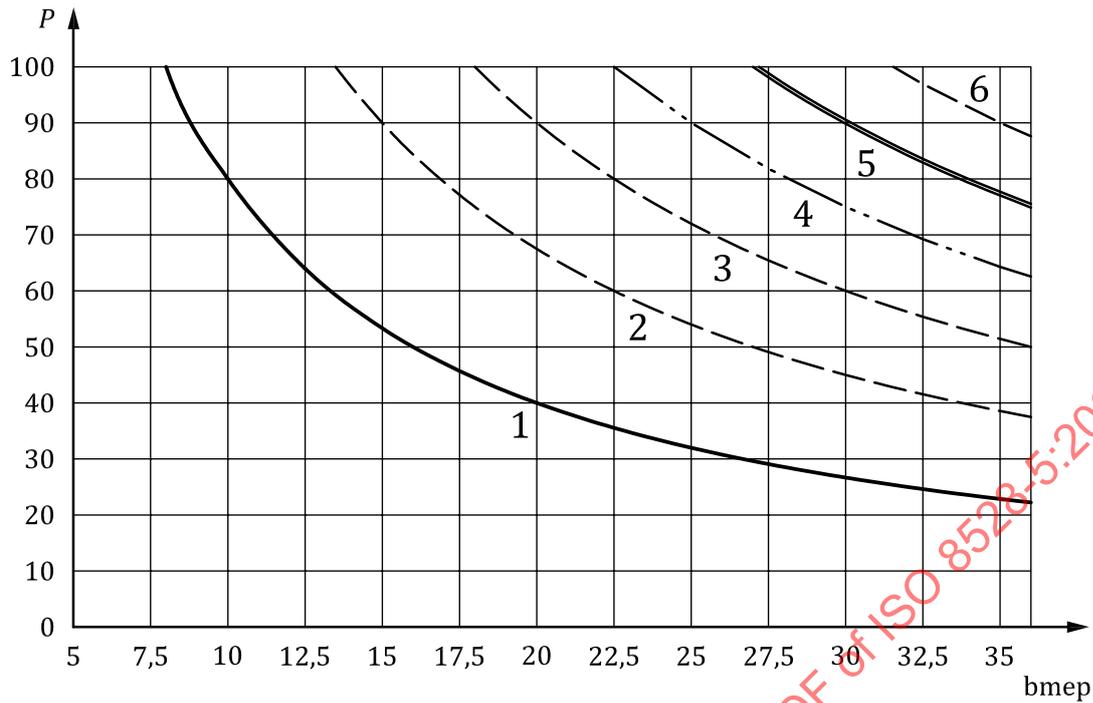
Key

bmep   brake mean effective pressure of declared power in bar

P power increase referred to declared power at site conditions

1   first power stage

2   second power stage

3   third power stage

4   fourth power stage

5   fifth power stage

6   sixth power stage

Figure 5 — Reference values for maximum possible sudden power increases as a function of bmep at declared power (four-stroke diesel engines)

For decision-making purposes, the actual power acceptance behaviour of the engine to be used should be considered (see ISO 3046-4).

Key

bmep brake mean effective pressure of declared power in bar

P power increase referred to declared power at site conditions

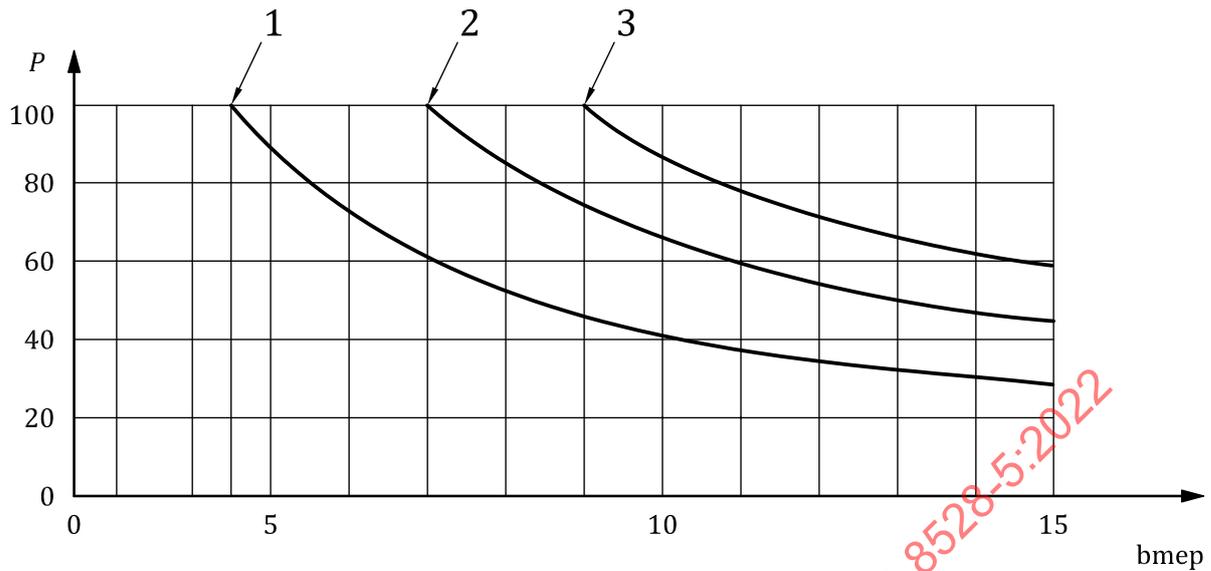1 first power stage

2 second power stage

3 third power stage

Figure 6 — Reference values for maximum possible sudden power increases as a function of bmep at declared power (two-stroke high-speed engines)

9 Cyclic irregularity

The cyclic irregularity, δ_s, is the periodic fluctuation of speed caused by the rotational irregularity of the prime mover. It is the ratio of the difference between the maximum and minimum angular velocity to the mean angular velocity at the generator shaft at any constant load. In the case of single operation, the cyclic irregularity takes effect in a corresponding modulation in generator voltage and is therefore determined by measuring the variation in generated voltage and is given by Formula (1):

$$\delta_s = \frac{\hat{U}_{max,s} - \hat{U}_{min,s}}{\hat{U}_{mean,s}} \tag{1}$$

Voltage modulations cause changes in the luminance of lamps. This can create the visual phenomenon called flicker.

Figure 7 shows a simplified voltage flicker waveform which contains one modulation frequency *f* with an amplitude a_f. The steady-state voltage varies between $\hat{U}_{mod,s,max}$ and $\hat{U}_{mod,s,min}$.

The limits for voltage modulation are given in Table 4.

Key
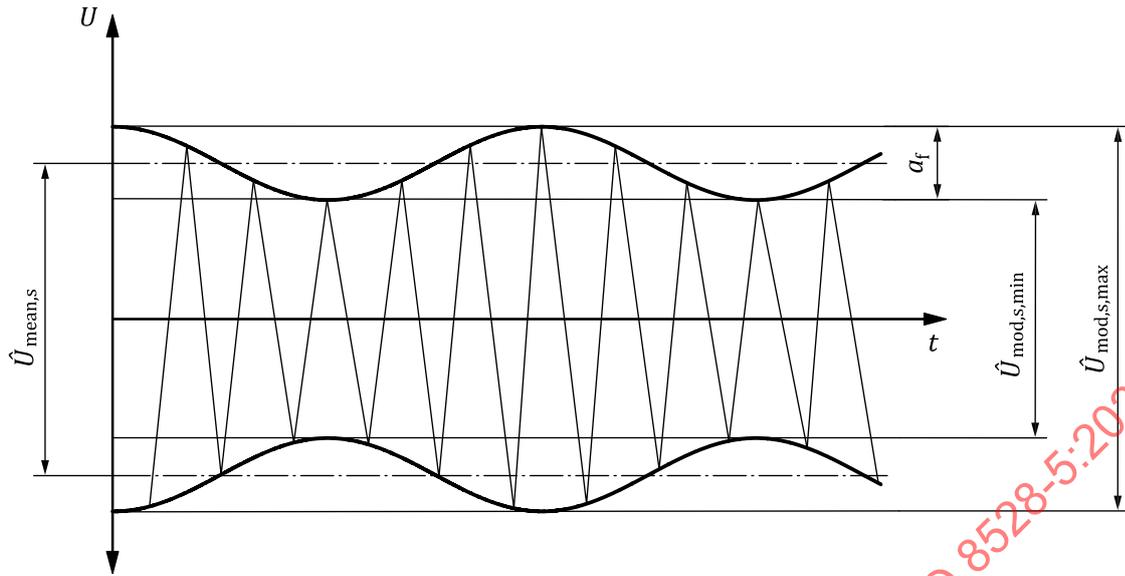
t time

U voltage

Figure 7 — Sinusoidal voltage modulation of an amplitude a_f and frequency f

Voltage flicker in the frequency range around 10 Hz becomes annoying. The annoyance grows very rapidly with the amplitude a_f of the fluctuation. The 10 Hz equivalent voltage flicker value is defined as

$a_{10} = \sqrt{\Sigma(g_f\ a_f)^2}$, whereas g_f denotes the frequency weighting factor corresponding to the modulation frequency component.

Figure 8 plots the distribution curve of the frequency weighting factor. The frequency to which it is most sensitive is 10 Hz, at which the frequency weighting factor is 1.
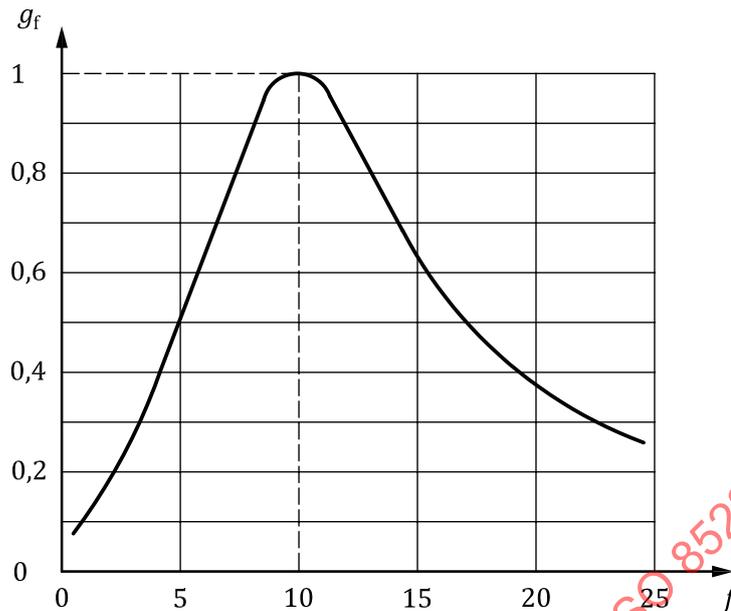
Key

f frequency

g_f frequency weighting factor

Figure 8 — Curve giving equivalent perceptibility due to change in brightness

It is the responsibility of the generating set manufacturer to minimize cyclic irregularities in the frequency range from 6 Hz to 15 Hz.

Special consideration shall be given for generating sets working in parallel with low-speed (100 min^{-1} to 180 min^{-1}) compression ignition (diesel) engine sets in order to avoid resonance between engine torque irregularity and electromechanical frequency oscillation of the set (see ISO 8528-3:2020, 7.4).

NOTE   It is possible to alter the cyclic irregularity of rotational speed at the generator relative to the measured value of the cyclic irregularity at the internal combustion engine by installing a resilient coupling between the internal combustion engine and the generator and/or by modifying the mass moment of inertia.

10 Starting characteristics

The starting characteristics depend on several factors, for example:

a)   ambient air temperature;

b)   temperature of the RIC engine;

c)   starting air pressure;

d)   starter battery condition;

e)   oil viscosity;

f)   total inertia of the generating set;

g)   fuel quality;

h)   state of the starting equipment.

They are subject to agreement between the customer and the generating set manufacturer (see Figure 9).

Key
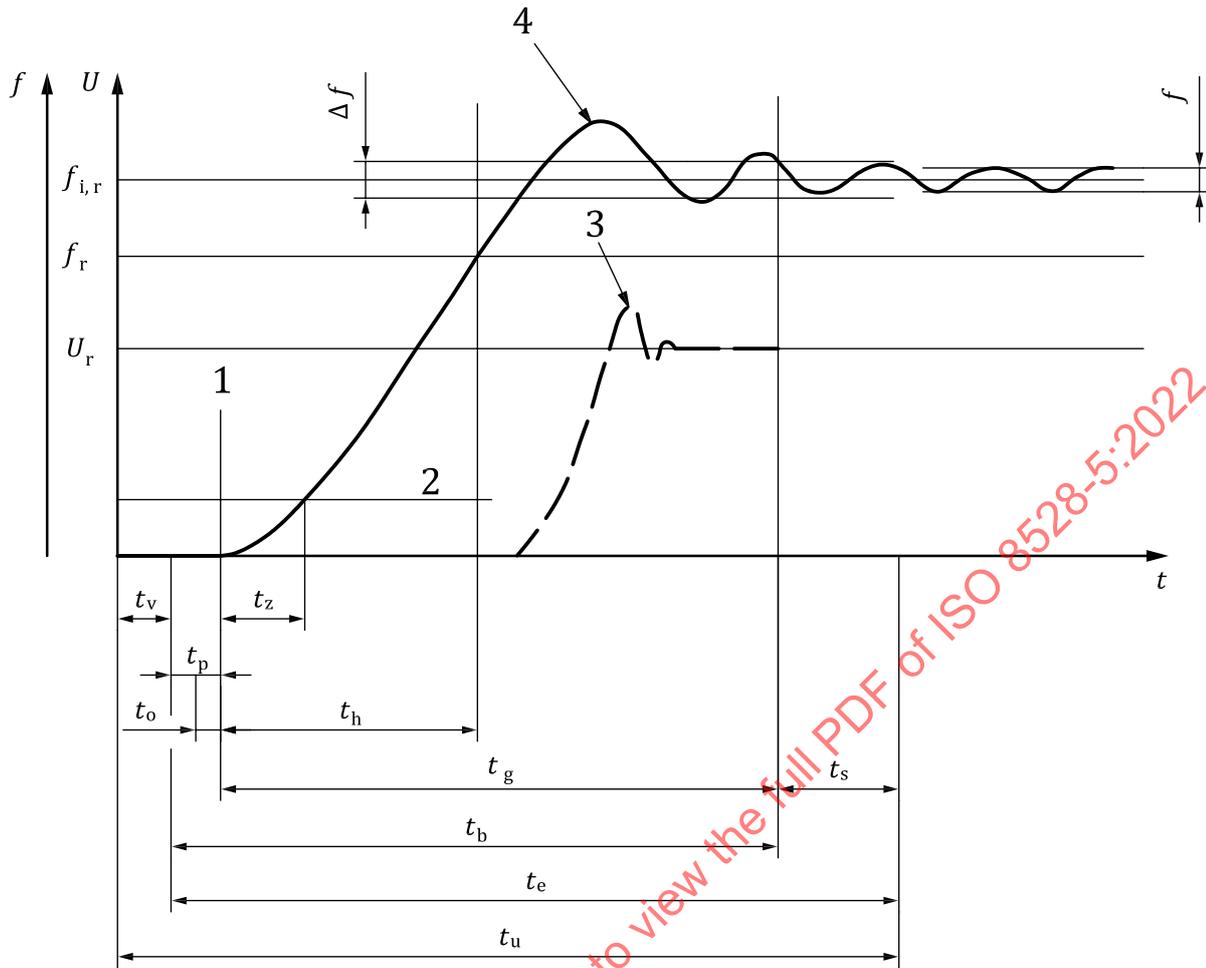
t time

f frequency

U voltage

1   starting pulse

2   level of reaching firing speed

3   voltage curve

4   frequency curve

Figure 9 — Starting characteristics

11 Stop time characteristics

The stop time characteristics in Figure 10 describe the standard shutdown procedure of a generating set. When triggering the stop command (1) for the generating set, the load will be ramped down within the period t_i. At step (2), the circuit breaker opens and causes voltage and frequency to jump to their no-load values. During this period t_c, the generating set is operated at no-load speed until essential components have cooled down below a defined temperature limit. The fuel supply stop signal is sent at step (3) and the generating set coasts during the interval t_d until completely stopping.

Key
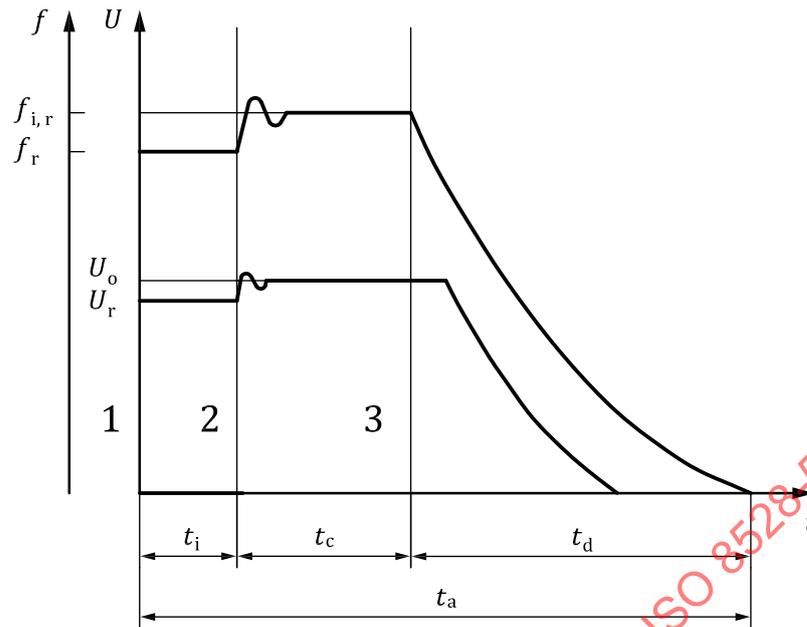
t time

f frequency

U voltage

1   stop command

2   power removed

3   fuel stop signal

Figure 10 — Stopping characteristics

The described procedure does not consider a shutdown under full load caused by a protective device.

12 Parallel operation

12.1 Generating sets coupled with each other without grid

12.1.1 Active power sharing

12.1.1.1 Factors influencing active power sharing

Active power sharing (see Figures 11 and 12) can be influenced by one or more of the following:

a) the speed governor droop characteristic;

b) the dynamic behaviour of the RIC engine and its speed governor;

c) the dynamic behaviour of the coupling;

d) the dynamic behaviour of the AC generator, taking into account the characteristics of the network or the consumer's equipment;

e) the automatic voltage regulator characteristics.

Key
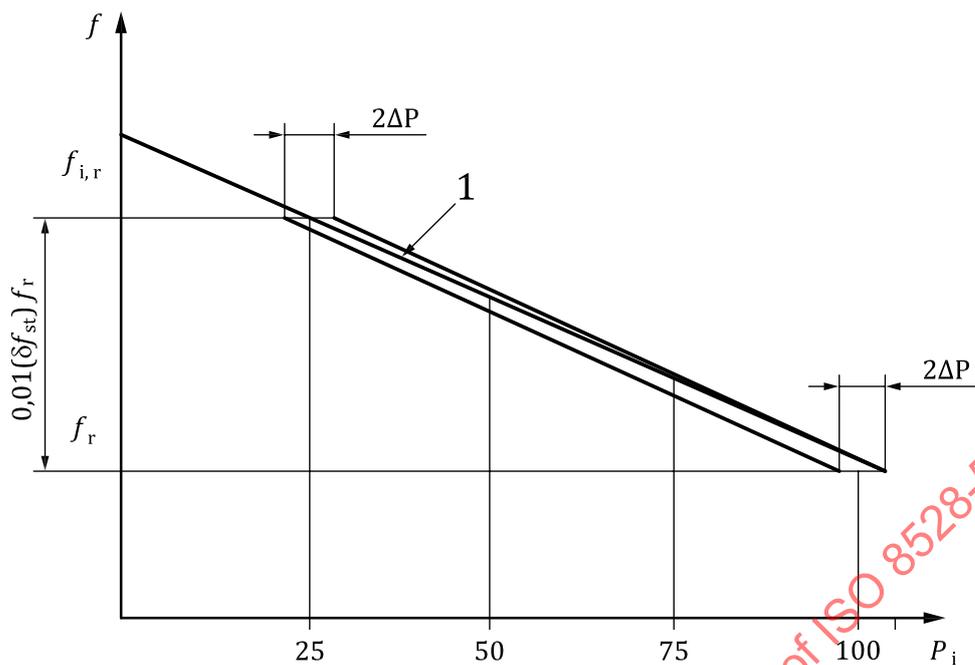
P power

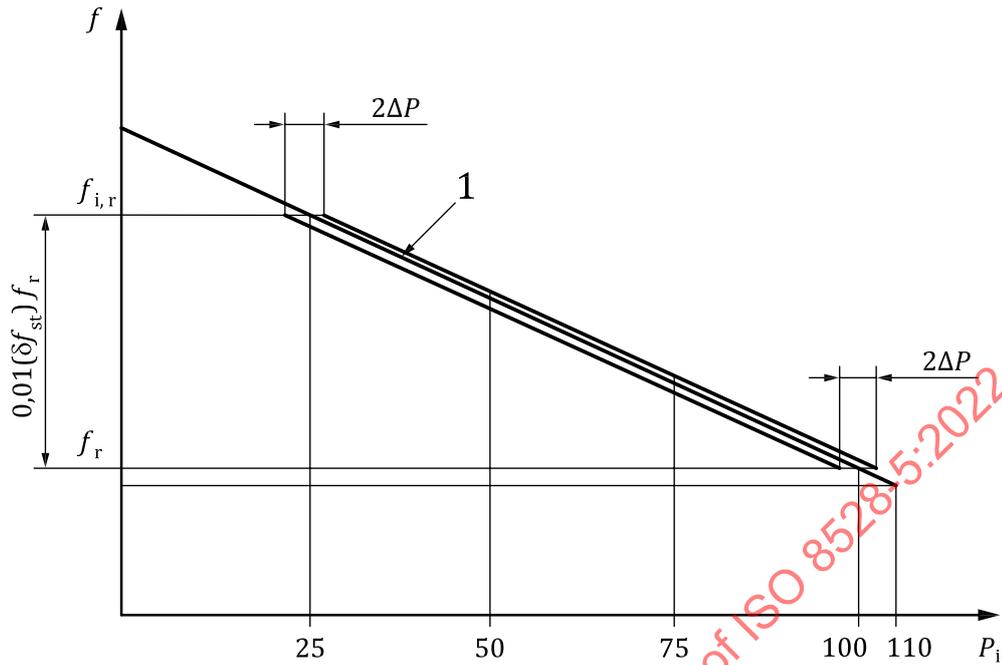f frequency

1 tolerance band

Figure 11 — Example of power sharing in parallel running operation when power limit is 100 % load

Key

P power

f frequency

1   tolerance band

Figure 12 — Example of power sharing in parallel running operation when power limit is not 100 % load

12.1.1.2 Calculation method

The difference, ΔP_i, expressed as the percentage between the proportion of power supplied by an individual generating set and the proportion of the total power supplied by all generating sets at ideal frequency characteristic, is given by Formula (2):

$$\Delta P_i = \left[\frac{P_i}{P_{r,i}} - \frac{\sum_{j=1}^{n} P_j}{\sum_{j=1}^{n} P_{r,j}} \right] \times 100 \tag{2}$$

where

n is the number of parallel-operating generating sets;

i is the index for identifying the individual generating set which is considered within the group of all parallel-operating generating sets;

P_i is the partial active power of the individual generating set considered;

$P_{r,i}$ is the rated active power of the individual generating set considered;

ΣP_j is the sum of the partial active power of all parallel-operating generating sets;

$\Sigma P_{r,j}$ is the sum of the rated active power of all parallel-operating generating sets.

If optimum active power sharing is achieved at the total rated active power, then the maximum deviation in active power sharing for a particular generating set, in the active power range from minimum load to 100 % of its rated active power, occurs when the engine speed governor settings remain unchanged. If automatic active power sharing systems are employed, active power deviation can be reduced, compared with the values obtained through the engine speed governor characteristics alone. In order to avoid a motoring operation in the event of power deviations between generating sets operating in parallel, appropriate precautions, for example reverse power relays, are required.

12.1.1.3 Examples of active power sharing

The examples shown in Table 1 are given assuming a value of cos φ = 0,8.

Table 1 — Examples of active power sharing

Example	Genset	Related power $P_{r,i}$	$\sum_{j=1}^{n} P_{r,j}$	Partial power P_i	$\sum_{j=1}^{n} P_j$	$P_{i,p} = \dfrac{P_i}{P_{r,i}}$	$P_{s,p} = \dfrac{\sum_{j=1}^{n} P_j}{\sum_{j=1}^{n} P_{r,j}}$	ΔP_i
		kW	kW	kW	kW	%	%	%
1	1	400		275		68,7		−6,3
	2	400	1 200	300	900	75	75	0
	3	400		325		81,3		+6,3
2	1	400		335		83,7		+8,7
	2	300	900	210	675	70	75	−5
	3	200		130		65		−10

NOTE Power deviation resulting from constant hunting is included in the tolerances for active power sharing. In the event of sudden load changes, the values for constant deviation and hunting in active power sharing can be temporarily exceeded.

12.1.2 Reactive power sharing

12.1.2.1 Factors influencing reactive power sharing

Reactive power sharing can be influenced by one or more of the following:

a)   the grade of the quadrature-current compensation voltage droop (δ_{QCC});

b)   whether stabilization by equalizer links is present;

c)   the automatic reactive power sharing control characteristic;

d)   the automatic voltage regulator characteristic.

12.1.2.2 Calculation method

The difference, ΔQ_i, expressed as the percentage between the proportion of reactive power supplied by an individual generating set and the proportion of the total reactive power supplied by all the generating sets at ideal voltage droop characteristic, is given by Formula (3):

$$\Delta Q_i = \left[\frac{Q_i}{Q_{r,j}} - \frac{\sum_{j=1}^{n} Q_j}{\sum_{j=1}^{n} Q_{r,j}} \right] \times 100 \tag{3}$$

where

n is the number of parallel-operating generating sets;

i is the index for identifying the individual generating set which is considered within the group of all parallel-operating generating sets;

Q_i is the partial reactive power of the individual generating set considered;

$Q_{r,i}$ is the rated reactive power of the individual generating set considered;

ΣQ_j is the sum of the partial reactive power of all parallel-operating generating sets;

$\Sigma Q_{r,j}$ is the sum of the rated reactive power of all parallel-operating generating sets.

If optimum reactive power sharing is achieved at the total rated reactive power, then the maximum deviation in reactive power sharing for a particular generating set, in the reactive power range from 20 % to 100 % of its rated reactive power, occurs when the voltage control reference value settings remain unchanged. Exact reactive power sharing is made possible, for example, by:

a) the grade of the quadrature-current compensation voltage droop;

b) whether stabilization equalizer links are present;

c) the automatic reactive power sharing control characteristic.

12.1.2.3 Examples of reactive power sharing

The examples shown in Table 2 are given assuming a value of cos φ = 0,8.

Table 2 — Examples of reactive power sharing

Example	Genset	Rated reactive power $Q_{r,i}$	$\sum_{j=1}^{n} Q_{r,j}$	Partial reactive power Q_i	$\sum_{j=1}^{n} Q_j$	$\dfrac{Q_i}{Q_{r,i}} \times 100$	$\dfrac{\sum_{j=1}^{n} Q_j}{\sum_{j=1}^{n} Q_{r,j}} \times 100$	ΔQ_i
		kvar	kvar	kvar	kvar	%	%	%
1	1	300	900	206	675	68,7	75	−6,3
	2	300		225		75		0
	3	300		244		81,3		+6,3
2	1	300	675	251	507	83,7	75	+8,7
	2	225		158		70,2		−4,8
	3	150		98		65,3		−9,7

NOTE In the event of sudden power changes, the permissible values for constant deviation and hunting in reactive power sharing can be temporarily exceeded.

12.1.2.4 Influence on parallel-operating behaviour

The following can have an influence on parallel-running behaviour:

a) the speed governor droop characteristic;

b) the dynamic behaviour of the RIC engine and its speed governor;

c) the dynamic behaviour of the coupling;

d) the dynamic behaviour of the AC generator, taking into account the relevant reaction of the connected mains or the other parallel-operating generators;

e) the automatic voltage regulator characteristic;

f) the grade of quadrature-current compensation voltage droop (δ_{QCC}) of the automatic voltage regulator (AVR);

g) the setting of the no-load voltage of each of the automatic voltage regulators.

12.2 Generating sets connected to the grid

12.2.1 General

When generating sets are connected to the grid, it is necessary to provide protection facilities with grid connected operation.

This clause describes the guidance for power plants with such facilities.

12.2.2 Influence on operating behaviour

The following can have an influence on the behaviour of the generating set when coupled to a grid:

a) the speed governor droop characteristic, which can be null in the case of isochronous regulation;

b) the dynamic behaviour of the RIC engine and its load governor;

c) the dynamic behaviour of the coupling;

d) the dynamic behaviour of the AC generator, taking into account the relevant reaction of the connected mains or the other parallel-operating generators;

e) the automatic voltage regulator characteristic and the chosen regulation mode;

f) the grade of quadrature-current compensation voltage droop (δ_{QCC}) of the automatic voltage regulator (AVR) if the regulation mode voltage is selected and the voltage setpoint is constantly controlled.

12.2.3 Design features

12.2.3.1 General

— Coupling voltage range;

— Coupling frequency range;

— Angular range for coupling.

The coupling to the grid shall be made with an angular variation as weak as possible to avoid any disturbance to the grid.

The typical limit setting for coupling window limit shall be set in accordance with ISO 8528-3:2020, 7.3.1.

12.2.3.2 Reactive power capacity

Any power plant with voltage control and connected to a public grid shall be able to provide or absorb reactive power. When voltage at connection point to the grid deviates from the rated voltage the power plant shall be able to modulate its production or its absorption of reactive power.

The design features of the power plant for the production or the absorption of reactive power is defined according to the operating range of power factor (PF) (i.e. the AC generator's capability of reactive power

P/Q diagram) and/or *U/Q* diagram. The zone of operation represented by the *U/Q* diagram in Figure 13 shall take into account the maximum stator current, the maximum excitation current, maximum stator voltage and the limit of voltage stability of the considered unit or power plant.

The running minimal field shall be agreed with the client according to the local conditions of connection to the grid.
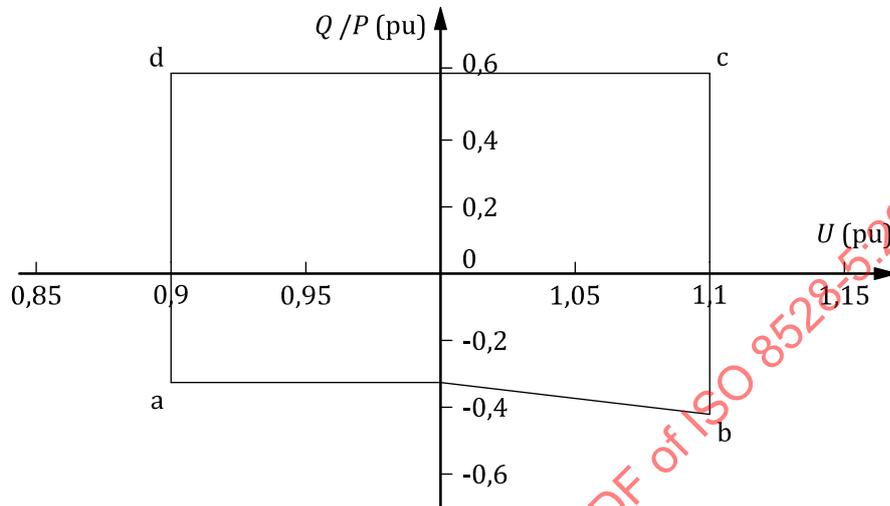

**Figure 13 — Example of *U/Q* diagram**

This diagram represents reactive power capacity of generating unit against ratio voltage/rated voltage.

Whatever the output active power, the generating is able to provide or absorb reactive power in the field defined by the *U/Q* diagram. At the rated power, the generating set is able to:

— at point a and b, absorb reactive power;

— at point c and d, provide reactive power.

The shape of the *U/Q* diagram depends on the characteristics of the considered generating set.

The power capability diagram (see Figure 14) defines the active and reactive power range of the considered generating set.
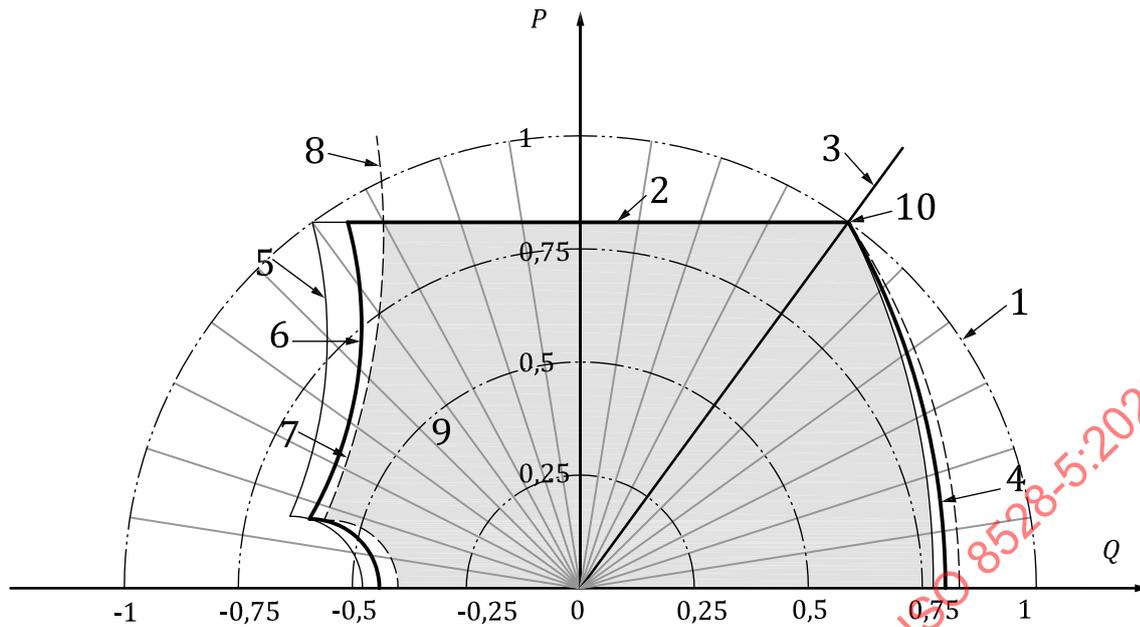
Key

P	active power	7	stability limit for $U_r = 0{,}9 \times U_n$
Q	reactive power	8	alternator reactive power limit
1	stator temperature limit	9	alternator safe operating area
2	active power limit of prime mover	10	rated operation set point at cos phi 0,8
3	cos φ = 0,8		PQ diagram for $U = 0{,}9 \times U_r$
4	rotor temperature limit		PQ diagram for $U = U_r$
5	stability limit for $U_r = 1{,}1 \times U_n$		PQ diagram for $U = 1{,}1 \times U_r$
6	stability limit for $U_r = U_n$		

Figure 14 — Example of PQ diagram

12.2.3.3 Fault voltage ride through

This design feature can be required for coupling to the grid. Voltage against time profile describes the voltages lower limits during a two phases fault or a three phases fault as from the initial moment (t_o). Values of each point of voltage against time profile at terminals of the generating set are communicated by the client to the manufacturer.

The generation set should remain coupled to the grid during voltage dip. Under voltage ride through capacity [see Figure 15 a)] should be demonstrated by measurement or using simulation tools based on the use of validated models or by tests.

The generation set should remain coupled to the grid during voltage swell. Over voltage ride through capacity see [Figure 15 b)] should be demonstrated by measurement or using simulation tools based on the use of validated models or by tests.

Simulation or tests shall make it possible to demonstrate:

— the stability of operation during voltage dip and the ability to remain coupled to the grid during the fault event;

— the stability of operation during voltage swell and the ability to remain coupled to the grid during the fault event;

— the active and reactive power after fault;

— the reactive power during the fault;

— the correct function of auxiliary systems and controls to manage the performance of the generating set during the fault.

The results of the simulation or tests of the fault ride through shall be demonstrated by the production of output graphs showing:

— active power;

— reactive power;

— output voltage of the generating set.
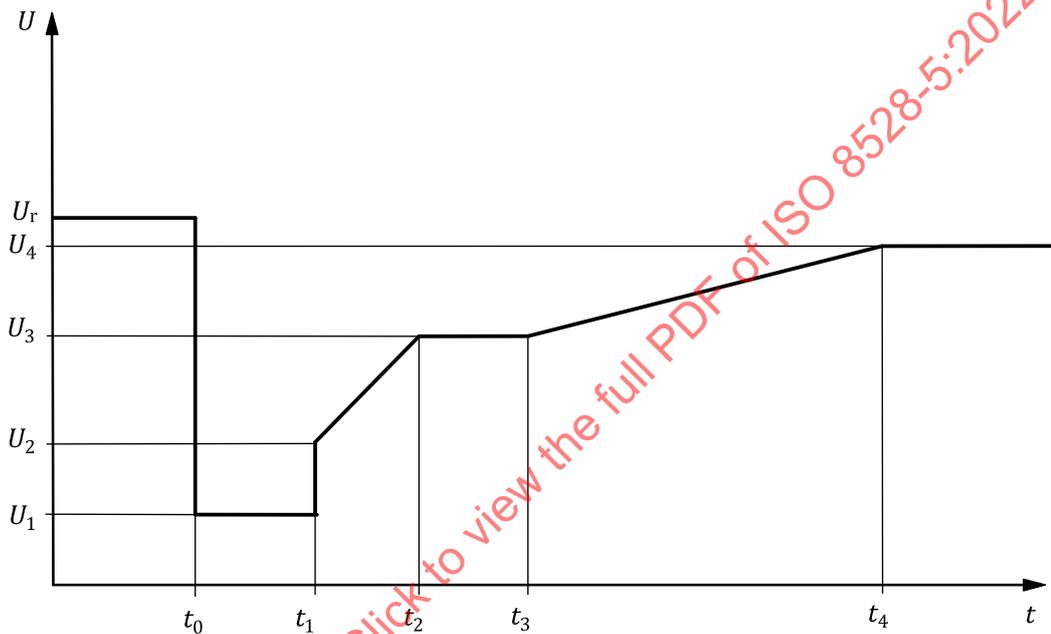
a) Under voltage ride through profile
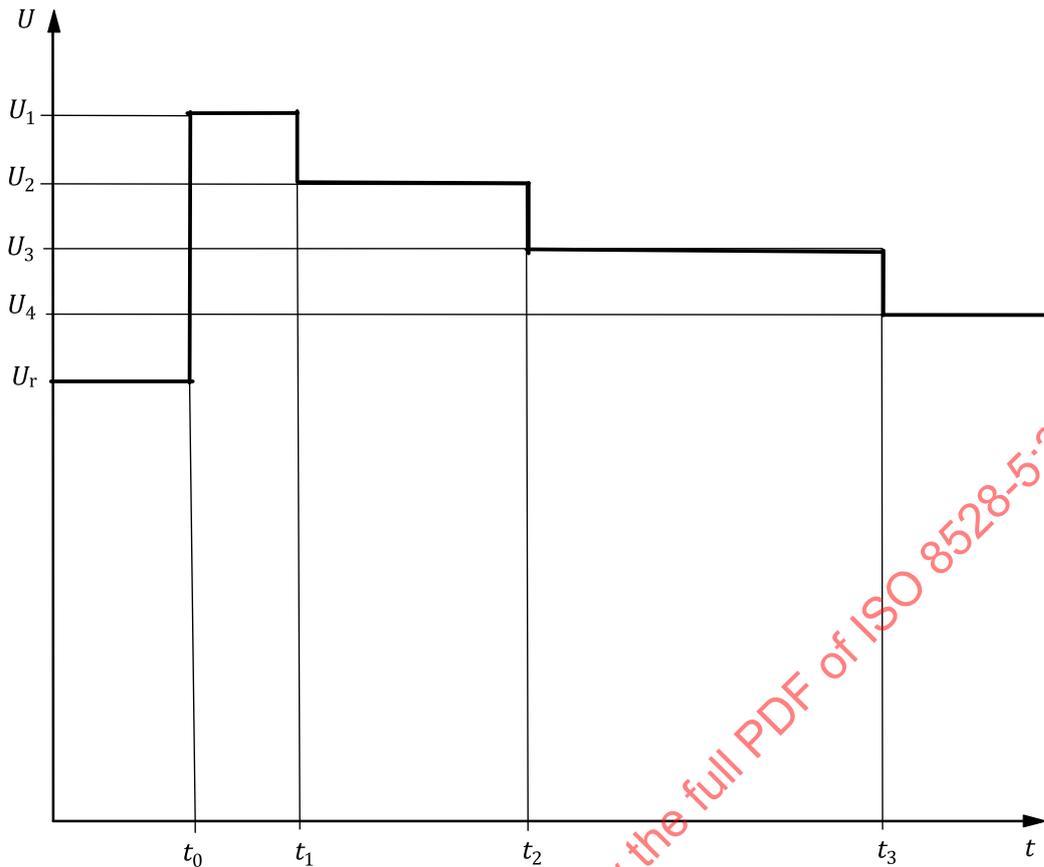
b) Over voltage ride through profile

Key

t time

U voltage

Figure 15 — Examples of voltage ride through profile

The generating unit shall be able to stay connected with the grid according to local grid codes or system requirements. If no requirements are defined and communicated between client and manufacturer and the fault ride through capability is requested, then the proposal values should be taken from grid code requirements at the point of installation.

12.2.3.4 Active power response according to frequency variation

According to local conditions of connection to the grid, the generating sets coupled to a grid can be held coupled to the grid during the exceptional rate of frequency. Power generating sets shall be able to ride through rapid frequency changes without disconnection from the grid. Furthermore, the output power shall be controlled as a function of mains frequency. Typically, assuming an overfrequency, the output decrease shall assume a rate of x % of Pref/Hz.

13 Rating plates

Generating sets shall bear the following rating plates:

a)   generating set rating plate. This shall give at least the following information:

    1)   the words "Generating set ISO 8528";

2) the manufacturer's name or mark;

3) the set serial number;

4) the set year of manufacture; however, by agreement between purchaser and manufacturer, for low-power generating sets, when the set year of manufacture can be known by the set serial number, it may be omitted;

5) the rated power (kW) with one of the prefixes COP, PRP, LTP, ESP, MAX or DCP in accordance with the requirements of ISO 8528-1:2018, Clause 14, see Figure 16.

6) the set performance class in accordance with the requirements of ISO 8528-1:2018, Clause 8;

7) the rated power factor;

8) the set rated frequency (Hz);

9) the set rated voltage (V);

10) the set rated current (A);

11) the mass (kg);

b) rating plate for the RIC engine;

c) rating plate for generators, in accordance with IEC 60034-1 and ISO 8528-3:2020, Clause 10;

d) rating plate for switchgear, where the switchgear is an integral part of the generating set.

NOTE 1   Figure 17 shows an example of a rating plate for a generating set.

NOTE 2   With units rated at less than 10 kW, the information can be combined on a single rating plate.

NOTE 3   Information related to the maximum side altitude above sea level (m) and the maximum site ambient temperature (°C) are not relevant for the rating plate but can be made available in technical documentation.

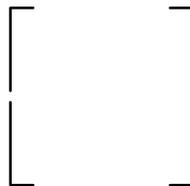Insert power output category according to Table 3 into the cell.

Figure 16 — Space for indicating the power output category (see ISO 8528-1) selected from Table 3

Table 3 — Power output category

COP	Continuous operating power
PRP	Prime power
LTP	Limited time running power
ESP	Emergency standby power
MAX	Maximum power for low-power generating sets
DCP	Data centre power