INTERNATIONAL STANDARD

ISO 8528-5

Fourth edition
2018-10

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

Contents

Page

iii

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).

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*.

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.

This fourth edition cancels and replaces the third edition (ISO 8528-5:2013), which has been technically revised. The main changes compared to the previous edition are as follows:

— Clause 3 has been updated to take into account the minimum and maximum safety frequency;

— new Subclause 14.2 has been added;

— new Annex A has been created.

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

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 (a.c.) generator when operating as a unit. This unit can run paralleling or not to the grid.

It applies to a.c. 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 be necessary. 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 8528-3:2005, *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 and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
frequency
f
reciprocal of the period

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

3.2
maximum transient frequency rise frequency
overshoot frequency
$f_{d,max}$
maximum frequency which occurs on sudden change from a higher to a lower power

Note 1 to entry: The symbol is different from that given in ISO 3046-4:2009.

3.3
maximum transient frequency drop frequency
undershoot frequency
$f_{d,min}$
minimum frequency which occurs on sudden change from a lower to a higher power

Note 1 to entry: The symbol is different from that given in ISO 3046-4:2009.

3.4
operating frequency of over frequency limiting device
f_{do}[a]
frequency at which, for a given setting frequency, the over frequency limiting device starts to operate

3.5
setting frequency of over frequency limiting device
f_{ds}
frequency of the generating set, the exceeding of which activates the over frequency limiting device

Note 1 to entry: In practice, instead of the value for the setting frequency, the value for the permissible over frequency is stated (also see ISO 8528-2:2005, Table 1).

3.6
no-load frequency
f_i
frequency at which the generating set is operating without load

3.7
rated no-load frequency
$f_{i,r}$
frequency at which the generating set is designed to operate without load

3.8
maximum permissible frequency
f_{max}[b]
frequency specified by the generating set manufacturer which lays a safe amount below maximum safety frequency

Note 1 to entry: See ISO 8528-2:2005, Table 1.

3.9
declared frequency
rated frequency
f_r
frequency at which the generating set is designed to operate

3.10
maximum no-load frequency
$f_{i,max}$
maximum frequency at which the generating set is operating without load

3.11
minimum no-load frequency

$f_{i\min}$

minimum frequency at which the generating set is operating without load

3.12
frequency at actual power

f_{arb}

frequency at which the generating set is actually operating

3.13
maximum safety frequency

$f_{\max s}$

frequency which causes a stop of production

3.14
minimum safety frequency

$f_{\min s}$

frequency which causes a stop of production

3.15
envelope width oscillation of generating set

$\overset{\wedge}{\underset{\vee}{f}}$

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

3.16
steady short-circuit current

$I_{\mathbf{k}}$

steady-state current in the armature winding when after short-circuited, the speed being maintained at its nominal value

3.17
duration

t

range of a time interval

Note 1 to entry: The duration of a time interval is a non-negative quantity equal to the difference between the dates of the final instant and the initial instant of the time interval, when the dates are quantitative marks. Different time intervals may have the same duration, e.g. the period of a time-dependent periodic quantity is a duration that is independent of the choice of the initial instant.

Note 2 to entry: The duration is one of the base quantities in the International System of Quantities (ISQ) on which the International System of Units (SI) is based. The term "time" instead of "duration" is often used in this context and also for an infinitesimal duration.

Note 3 to entry: The coherent SI unit of duration and time is second, s (see IEC 60050-112). The units minute (1 min = 60 s), hour (1 h = 60 min = 3 600 s), and day (1 d = 24 h = 86 400 s) are accepted for use with the SI.

Note 4 to entry: "Time" is used as a synonym for continuous time scales.

3.18
total stopping time

t_{a}

time interval from the stop command until the generating set has come to a complete stop

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

3.19
load pick-up readiness time

t_b

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

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

3.20
off-load run-on time
cooling run-on time

t_c

time interval from the removal of the load until generating set off signal is given to the generating set

3.21
run-down time

t_d

time from the generating set off signal to when the time when generating set has come to a complete stop

3.22
load pick-up time

t_e

time interval from start command until the agreed load is connected

Note 1 to entry: $t_e = t_p + t_g + t_s$.

3.23
frequency recovery time after load decrease

$t_{f,de}$

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

Note 1 to entry: See Figure 4.

3.24
frequency recovery time after load increase

$t_{f,in}$

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

Note 1 to entry: See Figure 4.

3.25
total run-up time

t_g

time interval from the beginning of cranking until ready for supplying an agreed power, taking into account a given frequency and voltage tolerance

3.26
time of coupling to the grid

t_{cg}

time interval between the starting order and the moment when the generating set is coupled to the grid

3.27
run-up time

t_h

time interval from the beginning of cranking until the declared speed is reached for the first time

3.28
on-load run-on time

t_i

time interval from a stop command being given until the load is disconnected (automatic sets)

3.29
start preparation time

t_p

time interval from the start command until the beginning of cranking

3.30
load switching time

t_s

time from readiness to take up an agreed load until this load is connected

3.31
interruption time

t_u

time interval from the appearance of the criteria initiating a start until the agreed load is connected

Note 1 to entry: $t_u = t_v + t_p + t_g + t_s$.

$$= t_v + t_e.$$

Note 2 to entry: Recovery time (ISO 8528-12) is a particular case of interruption time.

3.32
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

Note 1 to entry: See Figure 5.

3.33
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

Note 1 to entry: See Figure 5.

3.34
start delay time

t_v

time interval from the appearance of the criteria initiating a start to the starting command (particularly for automatically started generating units)

Note 1 to entry: This time does not depend on the applied generating set. The exact value of this time is the responsibility of and is determined by the customer or by special requirements of legislative authorities. For example, this time is provided to avoid starting in case of a very short mains failure.

3.35
cranking time

t_z

time interval from the beginning of cranking until the firing speed of the engine is reached

3.36
pre-lubricating time
t_0
time required for some engines to ensure that oil pressure is established before the beginning of cranking

Note 1 to entry: This time is usually zero for small generating sets, which normally do not require pre-lubrication.

3.37
rate of change of frequency setting
v_f
rate of change of frequency setting under remote control

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

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

3.38
rate of change of voltage setting
v_u
rate of change of voltage setting under remote control

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

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

3.39
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

3.40
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

3.41
rated voltage
U_r
line-to-line voltage at the terminals of the generator at rated frequency and at rated output

3.42
recovery voltage
U_{rec}
maximum obtainable steady-state voltage for a specified load condition

Note 1 to entry: Recovery voltage is normally expressed as a percentage of the rated voltage.

Note 2 to entry: It normally lies within the steady-state voltage tolerance band (ΔU). For loads in excess of the rated load, recovery voltage is limited by saturation and exciter/regulator field forcing capability.

Note 3 to entry: See Figure 5.

3.43
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

3.44
maximum steady-state voltage
$U_{st,max}$
maximum 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 temperature rise

3.45
minimum steady-state voltage
$U_{st,min}$
minimum 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 temperature rise

3.46
no-load voltage
U_0
line-to-line voltage at the terminals of the generator at rated frequency and no-load

3.47
maximum upward transient voltage on load decrease
$U_{dyn,max}$
maximum voltage which occurs on a sudden change from a higher load to a lower load

3.48
minimum downward transient voltage on load increase
$U_{dyn,min}$
minimum voltage which occurs on a sudden change from a lower load to a higher load

3.49
maximum value of set voltage
$\hat{U}_{max,s}$
maximum obtainable voltage for a specified load condition or line-to-line voltage for defined operation selected by adjustment

3.50
minimum value of set voltage
$\hat{U}_{mini,s}$
miminum obtainable voltage for a specified load condition or line-to-line voltage for defined operation selected by adjustment

3.51
mean value of set voltage
$\hat{U}_{mean,s}$
mean obtainable voltage for a specified load condition or line-to-line voltage for defined operation selected by adjustment

3.52
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: $\hat{U}_{mod,s} = 2 \times \dfrac{\hat{U}_{mod,s,max} - \hat{U}_{mod,s,min}}{\hat{U}_{mod,s,max} + \hat{U}_{mod,s,min}} \times 100$.

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 8 and 9).

3.53
maximum peak of voltage modulation
$\hat{U}_{\text{mod, s, max}}$
quasi-periodic maximum voltage variation (peak-to-peak) about a steady-state voltage

3.54
minimum peak of voltage modulation
$\hat{U}_{\text{mod, s, min}}$
quasi-periodic minimum voltage variation (peak-to-peak) about a steady-state voltage

3.55
width of voltage oscillation
$\overset{\wedge}{\underset{\vee}{U}}$

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

3.56
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

3.57
negative deviation from a linear curve
Δf_{neg}
negative deviation from a linear curve that occurs between no load and rated load

Note 1 to entry: See Figure 2.

3.58
positive deviation from a linear curve
Δf_{pos}
positive deviation from a linear curve that occurs between no load and rated load

Note 1 to entry: See Figure 2.

3.59
maximum frequency deviation from a linear curve
Δf_{c}
larger value of Δf_{neg} and Δf_{pos} that occurs between no load and rated load

Note 1 to entry: See Figure 2.

3.60
range of frequency setting
Δf_{s}
range between the highest and lowest adjustable no-load frequencies

Note 1 to entry: See Figure 1.

Note 2 to entry: $\Delta f_{\text{s}} = f_{\text{i,max}} - f_{\text{i,min}}$.

3.61
downward range of frequency setting
$\Delta f_{\text{s,do}}$
range between the declared no-load frequency and the lowest adjustable no-load

Note 1 to entry: See Figure 1.

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

3.62
upward range of frequency setting
$\Delta f_{\text{s,up}}$
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: $\Delta f_{\text{s,up}} = f_{\text{i,max}} - f_{\text{i,r}}$.

3.63
steady-state voltage tolerance band
ΔU
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: $\Delta U = 2\delta U_{\text{st}} \times \dfrac{U_r}{100}$.

3.64
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: $\Delta U_{\text{s}} = \Delta U_{\text{s,up}} + \Delta U_{\text{s,do}}$.

3.65
downward range of voltage setting
$\Delta U_{\text{s,do}}$
range between the rated voltage and downward 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

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

3.66
upward range of voltage setting
$\Delta U_{\text{s,up}}$
range between the rated voltage and upward 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

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

3.67
frequency/power characteristic deviation
$\Delta\delta f_{\text{st}}$
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: $\Delta\delta f_{\text{st}} = \dfrac{\Delta f_{\text{c}}}{f_{\text{r}}} \times 100$.

3.68
frequency/power characteristic curve
curve of steady-state frequencies in power range between no-load and declared power, plotted against active power of generating set

Note 1 to entry: See Figure 2.

3.69
relative steady-state voltage tolerance band
α_U
ratio of magnitude of voltage change to rated voltage

Note 1 to entry: $\alpha_u = \dfrac{\Delta U}{U_r} \times 100$.

3.70
relative steady-state frequency tolerance band
α_f
ratio of the magnitude of frequency change to rated frequency

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

3.71
steady-state frequency band
β_f

envelope width oscillation $\hat{f}$ of generating set frequency at constant power around a mean value

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

Note 2 to entry: See Figure 3.

Note 3 to entry: $\beta_f = \dfrac{\overset{\wedge}{\underset{\vee}{f}}}{f_r} \times 100$.

3.72
transient frequency deviation (from initial frequency) on load increase (−) related to initial frequency
δf_d^-
temporary frequency deviation between undershoot frequency and initial frequency during the governing process following a sudden load increase, related to initial frequency

Note 1 to entry: A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.

Note 2 to entry: $\delta f_d^- = \dfrac{f_{d,min} - f_{arb}}{f_{arb}} \times 100$.

3.73
transient frequency deviation (from initial frequency) on load decrease (+) related to initial frequency
δf_d^+
temporary frequency deviation between overshoot frequency and initial frequency during the governing process following a sudden load decrease, related to initial frequency

Note 1 to entry: A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.

Note 2 to entry: $\delta f_d^+ = \dfrac{f_{d,max} - f_{arb}}{f_{arb}} \times 100$.

3.74
transient frequency deviation (from initial frequency) on load increase (–) related to rated frequency

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

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

Note 1 to entry: A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.

Note 2 to entry: $\delta f_{\text{dyn}}^{-} = \dfrac{f_{\text{d,min}} - f_{\text{arb}}}{f_{\text{r}}} \times 100$.

3.75
transient frequency deviation (from initial frequency) on load decrease (+) related to rated frequency

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

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

Note 1 to entry: A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.

Note 2 to entry: $\delta f_{\text{dyn}}^{+} = \dfrac{f_{\text{d,max}} - f_{\text{arb}}}{f_{\text{r}}} \times 100$.

3.76
transient voltage deviation on load increase

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

voltage drop when the generator, driven at rated frequency and at rated voltage under normal excitation control, is switched onto rated load

Note 1 to entry: A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.

Note 2 to entry: $\delta U_{\text{dyn}}^{-} = \dfrac{U_{\text{dyn,min}} - U_{\text{r}}}{U_{\text{r}}} \times 100$.

3.77
related range of frequency setting
δf_{s}
range of frequency setting

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

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

3.78
related downward range of frequency setting
$\delta f_{\text{s,do}}$
range of downward frequency setting

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

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

3.79
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: $\delta f_{s,up} = \dfrac{f_{i,max} - f_{i,r}}{f_r} \times 100$.

3.80
frequency droop
δf_{st}
frequency difference between rated no-load frequency and the rated frequency f_r at declared power expressed as a percentage of rated frequency at fixed frequency setting

Note 1 to entry: See Figure 1.

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

3.81
range of frequency of use paralleling to grid
δfr
acceptable extent of operation frequency imposed by coupling to a grid

3.82
cyclic irregularity
δ_s
periodic fluctuation of speed caused by irregularity of the prime mover torque

3.83
overfrequency setting ratio
δf_{lim}
difference between the setting frequency of the overfrequency limiting device and the rated frequency divided by the rated frequency, expressed as a percentage

Note 1 to entry: $\delta f_{lim} = \dfrac{f_{ds} - f_r}{f_r} \times 100$.

3.84
steady-state voltage deviation
δU_{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 temperature rise

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

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

3.85
related range of voltage setting
δU_s
range of voltage setting

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

Note 2 to entry: $\delta U_s = \dfrac{\Delta U_{s,up} + \Delta U_{s,do}}{U_r} \times 100$.

3.86
related downward range of voltage setting
$\delta U_{s,do}$
downward range of voltage setting

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

Note 2 to entry: $\delta U_{s,do} = \dfrac{U_r - U_{s,do}}{U_r} \times 100$.

3.87
related upward range of voltage setting
$\delta U_{s,up}$
upward range of voltage setting

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

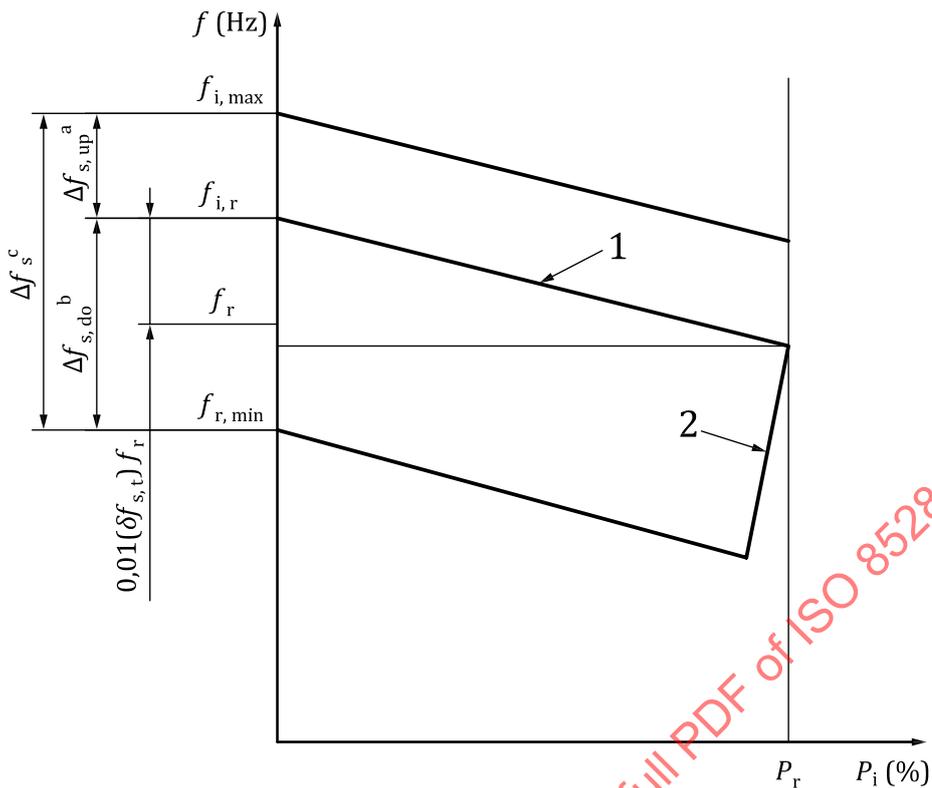Note 2 to entry: $\delta U_{s,up} = \dfrac{U_{s,up} - U_r}{U_r} \times 100$.

3.88
voltage unbalance
$\delta U_{2,0}$
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.

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 a.c. generator)

a   Upward frequency setting range.

b   Downward frequency setting range.

c   Range of frequency setting.

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

Key
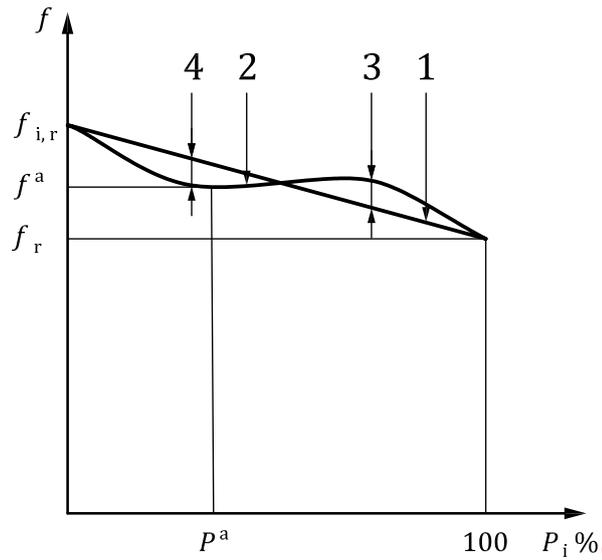
P power
f frequency
1   linear frequency/power characteristic curve
2   frequency/power characteristic curve
3   Δf_{pos}
4   Δf_{neg}
a   Frequency/power characteristic deviation.

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

Key
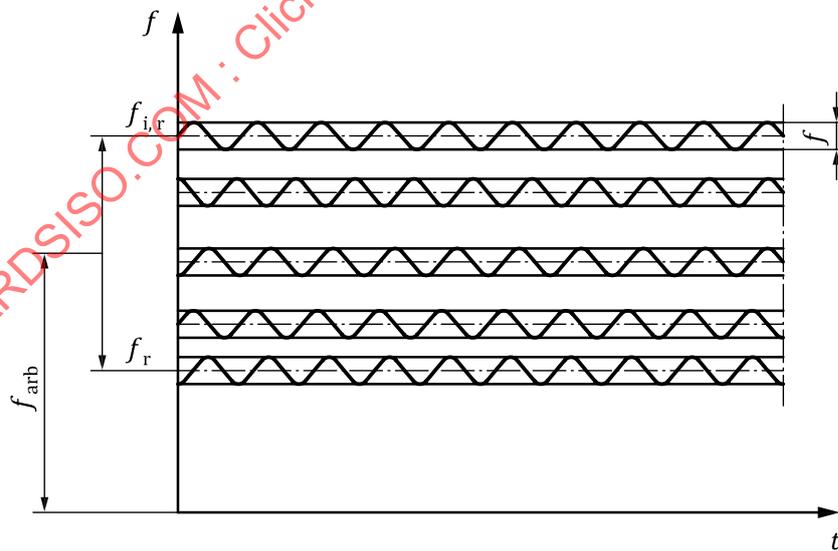
t time
f frequency

Figure 3 — Steady-state frequency band

15

Key

t time

f frequency

1 power increase

2 power decrease

Figure 4 — Dynamic frequency behaviour

Key

t time

U voltage

1 power increase

2 power decrease

Figure 5 — Transient voltage characteristics without quadrature-current compensation voltage droop

4 Other regulations and additional requirements

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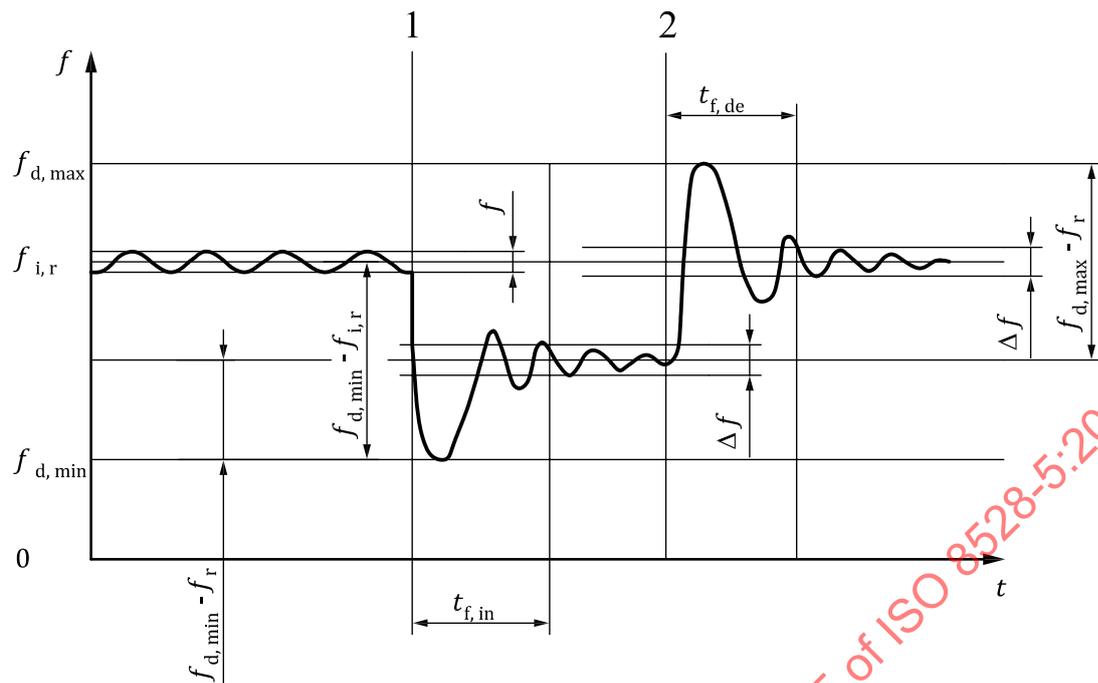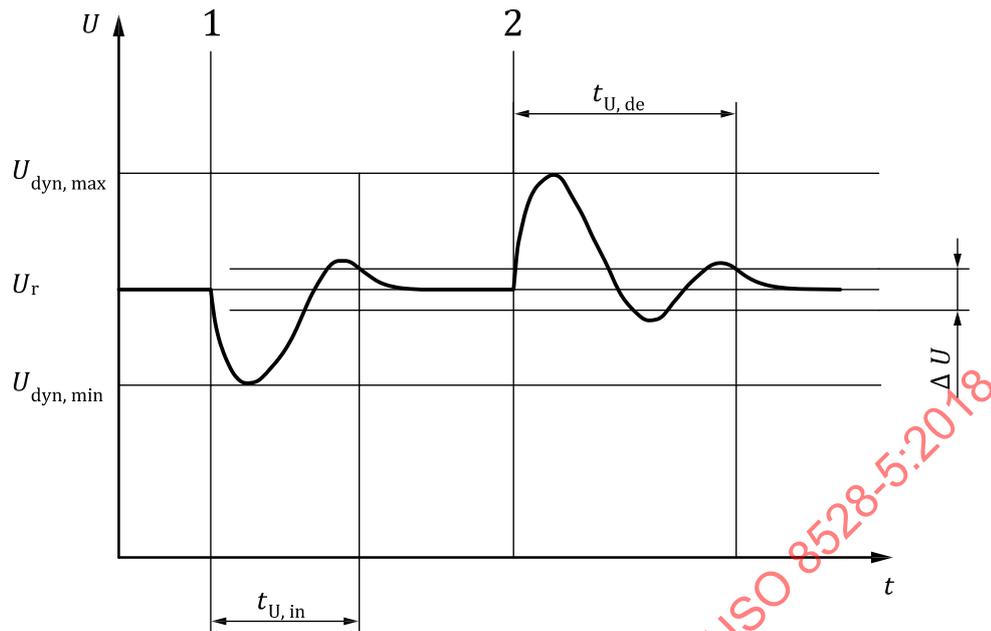ociety, the additional requirements of the classification society shall be observed. The classification society shall be identified by the customer prior to placing of the order.

For a.c. 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 type of turbocharging system, the characteristics of the load, the inertia's and the damping (see Table 1) 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 a.c. 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 5).

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 (also see ISO 8528-3:2005, 10.3).

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, p_{me}, of the RIC engine at declared power;

c) speed governor behaviour;

d) a.c. generator design;

e) a.c. 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 brake mean effective pressure, p_{me}, usually makes loading in several steps necessary. Figures 6 and 7 show reference values for suddenly applied load steps depending on p_{me} 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 brake mean effective pressure;

c) the RIC engine turbo-charging system installed;

d) the type of RIC engine governor installed;

e) the installed voltage regulator characteristics; and

f) the rotational inertia of the complete generating set/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:

g) the permitted drop in frequency;

h) the cyclic irregularity; and

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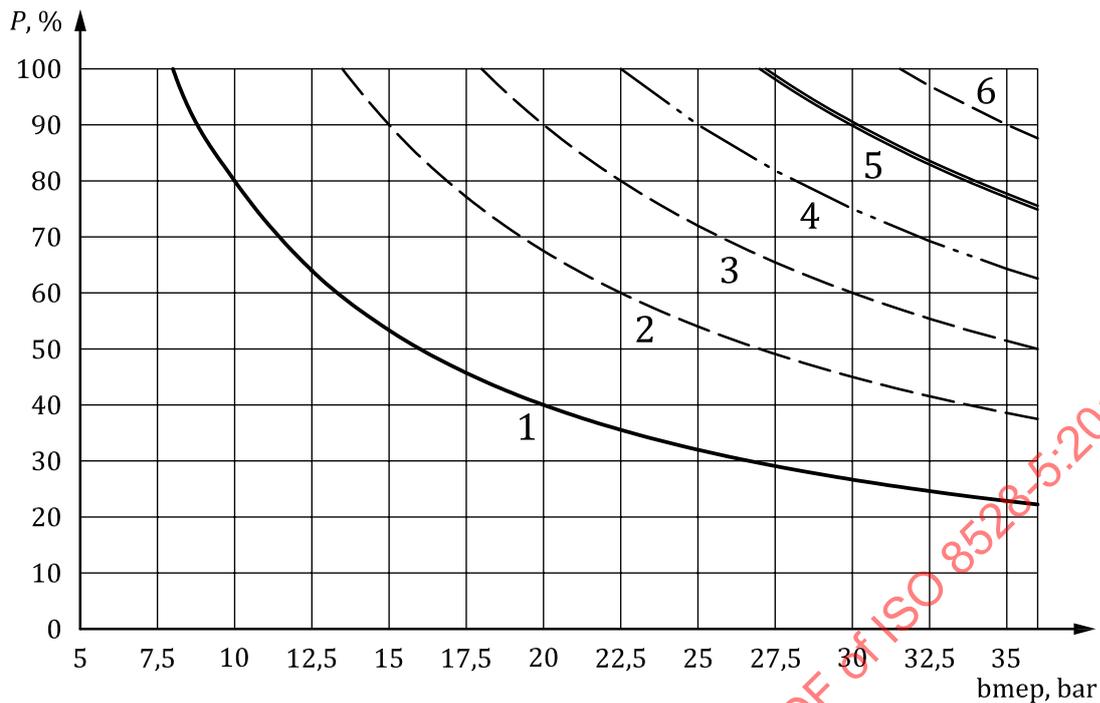
Key

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 6 — Reference values for maximum possible sudden power increases as a function of brake mean effective pressure, bmep, at declared power (four-stroke engines)
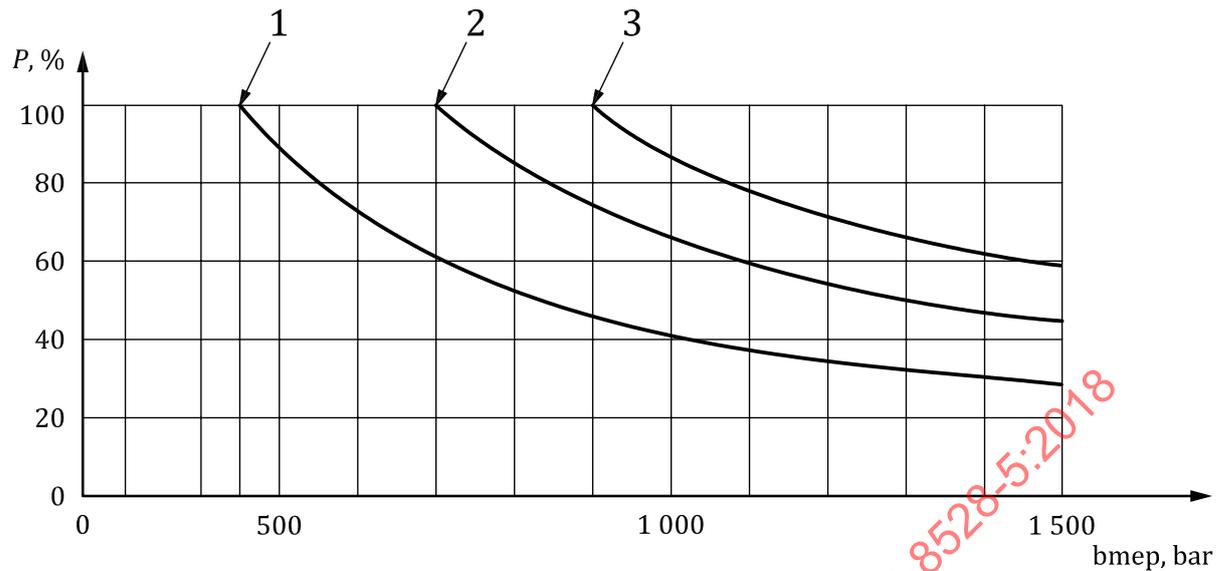
For decision-making purposes, the actual power acceptance behaviour of the engine to be used should be considered (see ISO 3046-4).

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 7 — Reference values for maximum possible sudden power increases as a function of brake mean effective pressure, bmep, at declared power (two-stroke high-speed engines)

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

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):

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

(1)

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 8528-3:2005, Clause 11).

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.
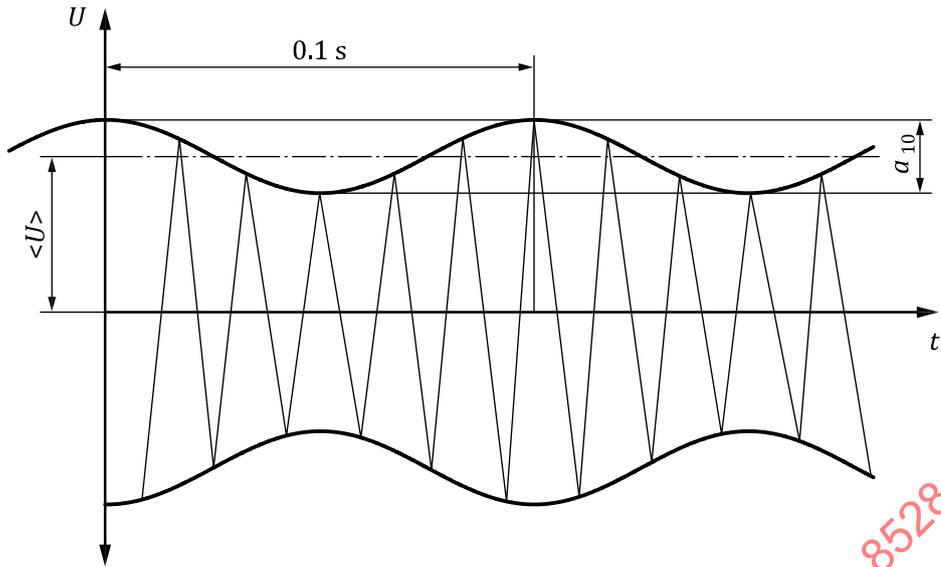
Key

t time

U voltage

Figure 8 — Sinusoidal voltage modulation of an amplitude a_{10} and a regular frequency of 10 Hz
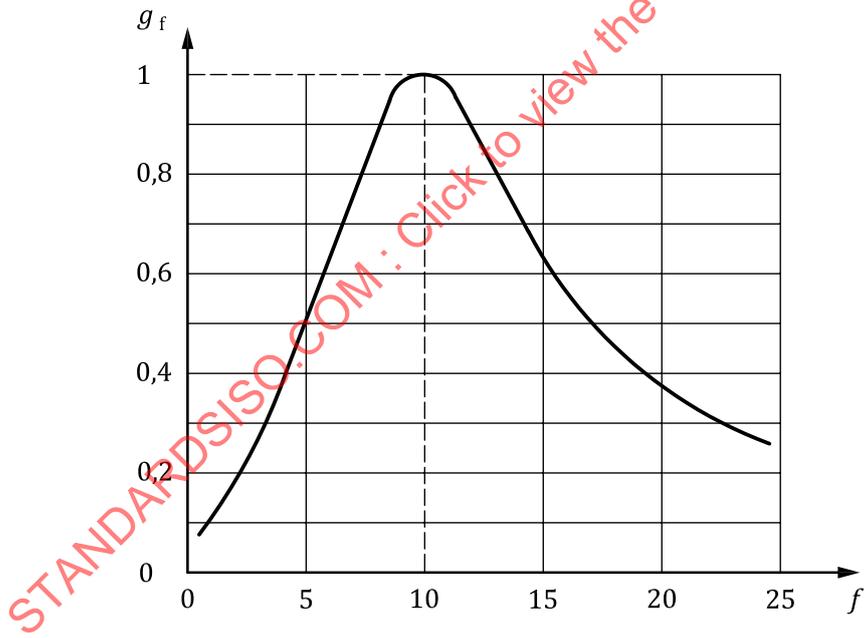
Key

f frequency

g_f frequency weighting factor corresponding to a_f

Figure 9 — Curve giving equivalent perceptibility due to change in brightness

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; and

h)   state of the starting equipment.

They are subject to agreement between the customer and the generating set manufacturer (see Figure 10).

Key

t	time
f	frequency
U	voltage
1	starting pulse
2	firing speed
3	voltage curve
4	frequency curve

Figure 10 — Starting characteristics

11 Stop time characteristics

Key
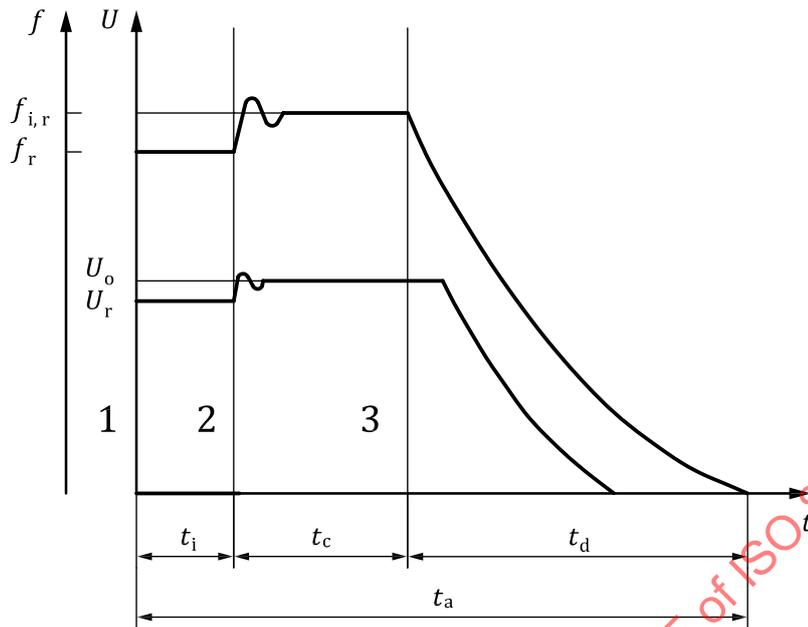
t time

f frequency

U voltage

1   stop command

2   power removed

3   fuel stop signal

Figure 11 — Stopping characteristics

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 Figure 12) can be influenced by any 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 a.c. generator taking into account the characteristics of the network or the consumer's equipment;

e)   the automatic voltage regulator characteristics.

Key
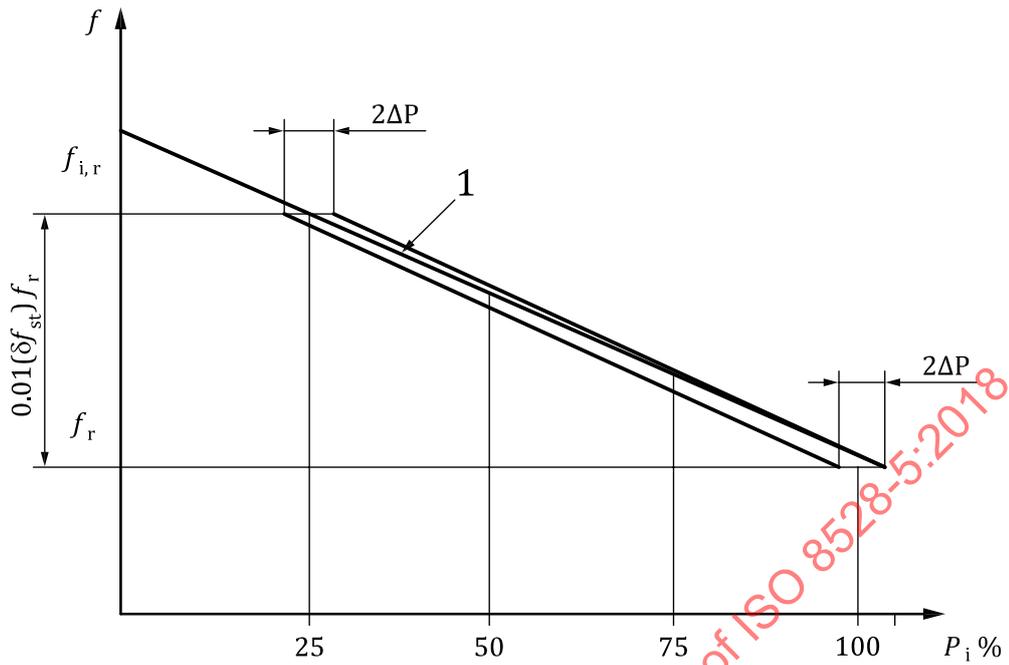
P power

f frequency

1   tolerance band

Figure 12 — Example of power sharing in parallel running operation when power limit is 100 % load

Key

P power

f frequency

1   tolerance band

Figure 13 — 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):
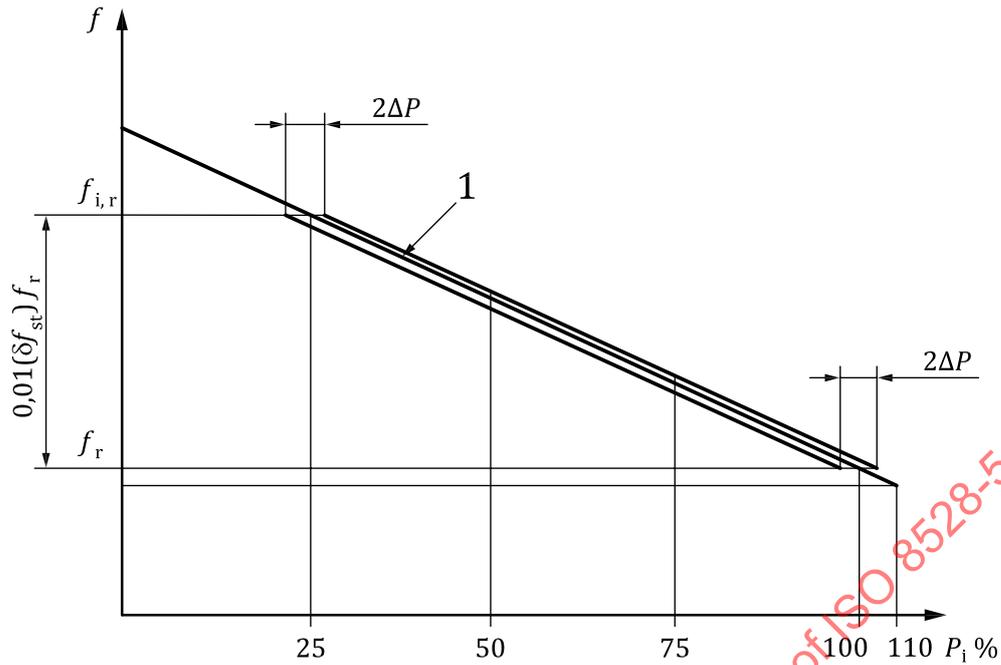
$$\Delta P_i = \left[\frac{P_i}{P_{r,i}} - \frac{\sum\limits_{j=1}^{n} P_j}{\sum\limits_{j=1}^{n} P_{r,j}} \right] \times 100 \qquad (2)$$

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 20 % 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 $P_{r,i}$ kW	$\sum_{j=1}^{n} P_{r,j}$ kW	Partial power P_i kW	$\sum_{j=1}^{n} P_j$ kW	$P_{i,p} = \dfrac{P_i}{P_{r,i}}$ %	$P_{s,p} = \dfrac{\sum_{j=1}^{n} P_j}{\sum_{j=1}^{n} P_{r,j}}$ %	ΔP_i %
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 any 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):

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

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 sets 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; and

c)   the automatic reactive power sharing control characteristic.

12.1.2.2.1 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 $Q_{r,i}$	$\displaystyle\sum_{j=1}^{n} Q_{r,j}$	Partial reactive power Q_i	$\displaystyle\sum_{j=1}^{n} Q_j$	$\dfrac{Q_i}{Q_{r,i}} \times 100$	$\dfrac{\displaystyle\sum_{j=1}^{n} Q_j}{\displaystyle\sum_{j=1}^{n} Q_{r,j}} \times 100$	ΔQ_i
		kvar	kvar	kvar	kvar	%	%	%
	1	300		206		68,7		−6,3
1	2	300	900	225	675	75	75	0
	3	300		244		81,3		+6,3
NOTE In the event of sudden power changes, the permissible values for constant deviation and hunting in reactive power sharing can be temporarily exceeded.								

Table 2 *(continued)*

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	%	%	%
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.								

12.1.2.2.2 Influence on parallel-operating behaviour

The following can have 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 a.c. 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 influence behaviour of generating set when coupled to a grid:

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

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 a.c. 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.

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 deviated 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 to the operating range of power factor (PF) (i.e., the a.c. generator's capability of reactive power P/Q diagram) and/or U/Q diagram. The zone of operation represented by diagram U/Q shall take into account the maximum statoric current, the maximum excitation current, maximum statoric voltage and of 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.
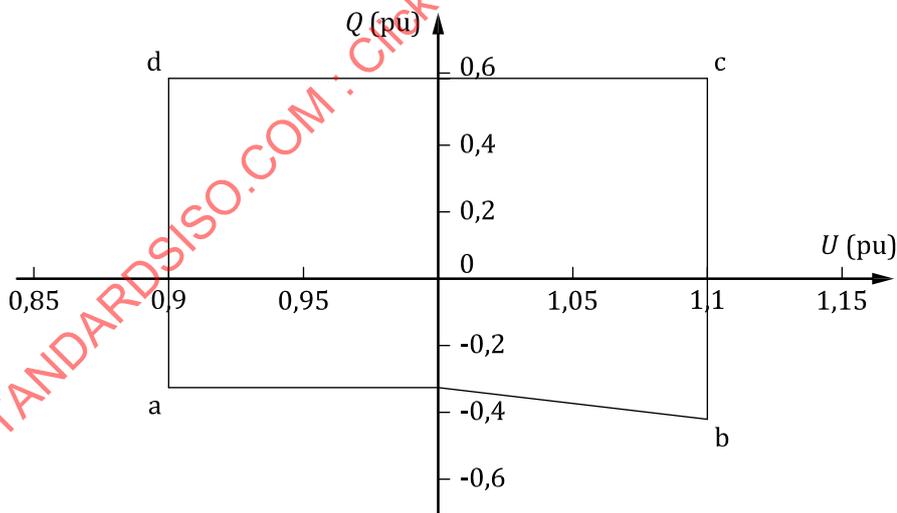

Figure 14 — Example of *U/Q* diagram

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 d, absorb reactive power; and

— at point d and c, provide reactive power.

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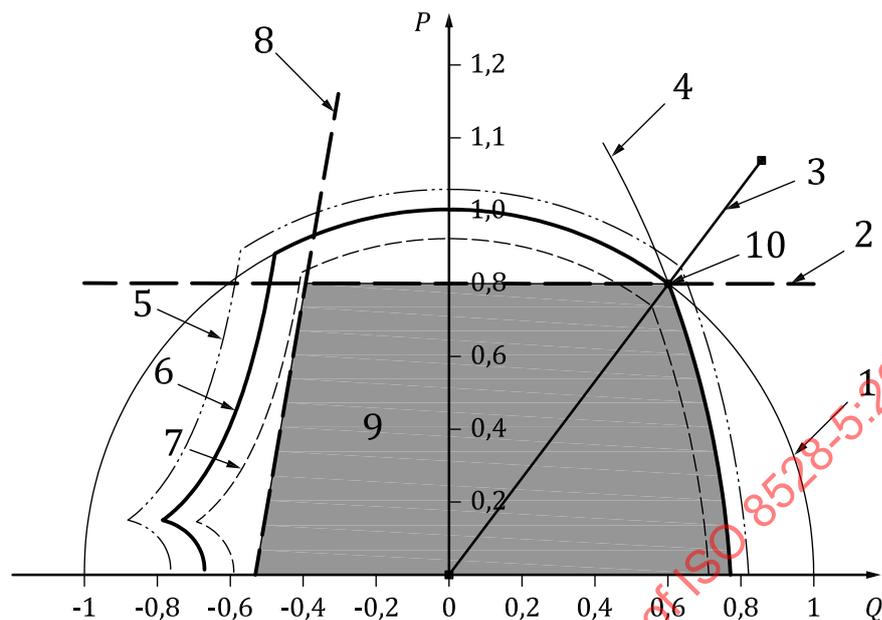
Key

P	active power	7	stability limit for U_r = 0,9 Un
Q	reactive power	8	AVR reactive power limit
1	stator temperature limit	9	AVR 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 U_r
4	rotor temperature limit	——	PQ diagram for U = U_r
5	stability limit for U_r = 1,1 Un	—··—	PQ diagram for U = 1,1 U_r
6	stability limit for U_r = Un		

Figure 15 — 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 three phases fault as from the initial moment (t_0); 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 maintained coupled to the grid during voltage dip. Fault voltage ride through capacity can demonstrated by measurement or using simulation tools base 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 holding of the coupling to the grid;

— the active and reactive power after fault;

— the reactive power during the fault;

— the holding of auxiliaries necessary to the correct performance of the generating set during the fault;

— that the simulation, or the tests results, of facing to fault ride through are published in the way of curves recorded for the following electrical items:

— active power;

— reactive power;

— output voltage of the generating set;

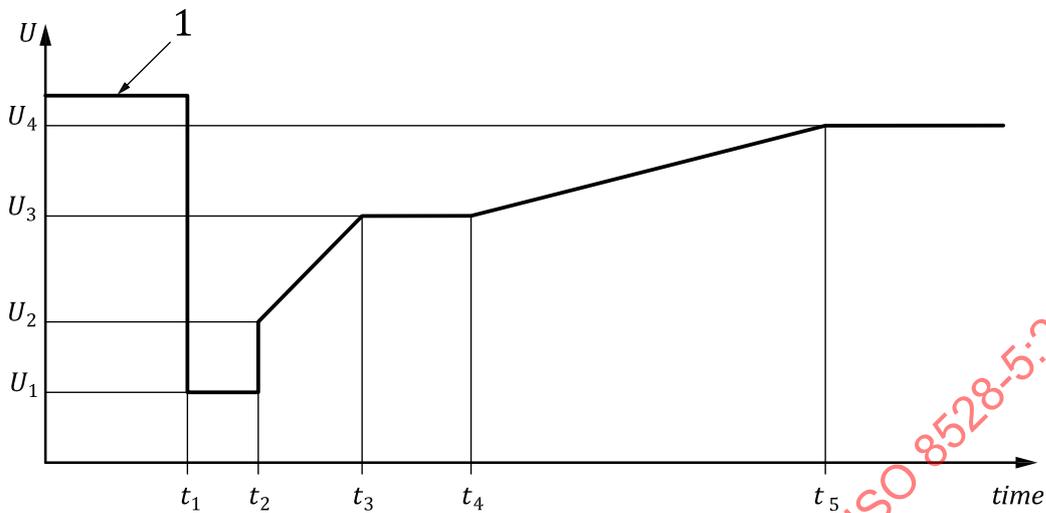— internal angle of the alternator (in case of calculation).

Figure 16 — Example of Voltage against time profile

Generating unit can 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 that fault ride through capability is requested then proposal values should be taken from Annex A (informative).

12.2.3.4 Voltage response according to under frequency

According to local conditions of connection to the grid, the generating sets coupled to a grid can be hold coupled to the grid during the exceptional rate of frequency although the frequency beyond higher or lower range relative of adjustment of the frequency ($\delta f_{s,do}$. $\delta f_{s,up}$). The power during the exceptional rate of frequency is able to vary, for example according to the figure below.
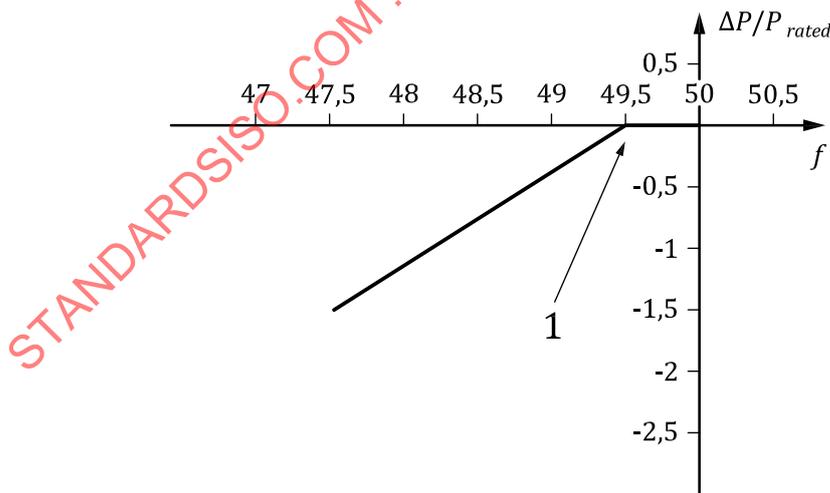

Figure 17 — Example of power reduction according to the frequency

Key

1   f_{db}

f_{db} point is decided in agreement with the client. The duration of operation at a frequency different of rated frequency shall be agreed by the client.

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 and DCP in accordance with the requirements of ISO 8528-1:2018, Clause 13;

6) the set performance class in accordance with the requirements of ISO 8528-1:2018, Clause 7 can be omitted by agreement between purchaser and manufacturer;

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 8528-3:2005, Clause 14;

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

NOTE 1   Figure 21 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 a technical documentation.

Generating set			
Manufacturer			—
Serial No.			—
Year of manufacture			—
Rated power	[ ] [ ]		kW
Rated power factor			—
Maximum site altitude of installation			m
Maximum ambient temperature			°C
Rated frequency			Hz
Rated voltage			V
Rated current			A
Mass			kg
Performance class			—

Figure 18 — Example of an RIC engine driven generating set rating plate

Figure 19 — 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 center power

14 Additional factors influencing generating set performance

14.1 Starting methods

Depending on the size, design and application of the generating set, different starting methods, according to energy source, are used. For example:

a)   mechanical (e.g. crank);

b)   electrical (e.g. electric starting motor); and