INTERNATIONAL STANDARD

ISO 8528-5

Third edition
2013-03-15

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

Reference number
ISO 8528-5:2013(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 8528-5 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*.

This third edition cancels and replaces the second edition (ISO 8528-5:2005), which has been technically revised.

ISO 8528 consists of the following parts, under the general title *Reciprocating internal combustion engine driven alternating current generating sets*:

— *Part 1: Application, ratings and performance*

— *Part 2: Engines*

— *Part 3: Alternating current generators for generating sets*

— *Part 4: Controlgear and switchgear*

— *Part 5: Generating sets*

— *Part 6: Test methods*

— *Part 7: Technical declarations for specification and design*

— *Part 8: Requirements and tests for low-power generating sets*

— *Part 9: Measurement and evaluation of mechanical vibrations*

— *Part 10: Measurement of airborne noise by the enveloping surface method*

— *Part 11*[1]*: Rotary uninterruptible power systems — Performance requirements and test methods*

— *Part 12: Emergency power supplies to safety services*

1) Part 11 is published as IEC 88528-11:2004.

Reciprocating internal combustion engine driven alternating current generating sets —

Part 5: Generating sets

1 Scope

This part of ISO 8528 defines terms and 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.

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 part of ISO 8528 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 part of ISO 8528 can be used as a basis for establishing these requirements.

2 Normative references

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

ISO 3046-5:2001, *Reciprocating internal combustion engines — Performance — Part 5: Torsional vibrations*

ISO 8528-1:2005, *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 60034-1:2004, *Rotating electrical machines — Part 1: Rating and performance*

3 Symbols, terms and definitions

For indications of technical data for electrical equipment, IEC uses the term “rated” and the subscript “N”. For indications of technical data for mechanical equipment, ISO uses the term “declared” and the subscript “r”. Therefore, in this part of ISO 8528, the term “rated” is applied only to electrical items. Otherwise, the term “declared” is used throughout.

An explanation of the symbols and abbreviations used in this International Standard are shown in Table 1.

Table 1 — Symbols, terms and definitions

Symbol	Term	Unit	Definition
f	Frequency	Hz	—
$f_{d,max}$	Maximum transient frequency rise (overshoot frequency)	Hz	Maximum frequency which occurs on sudden change from a higher to a lower power. The symbol is different from that given in ISO 3046-4:2009.
$f_{d,min}$	Maximum transient frequency drop (undershoot frequency)	Hz	Minimum frequency which occurs on sudden change from a lower to a higher power. The symbol is different from that given in ISO 3046-4:2009.
f_{do}[a]	Operating frequency of overfrequency limiting device	Hz	The frequency at which, for a given setting frequency, the overfrequency limiting device starts to operate.
f_{ds}	Setting frequency of overfrequency limiting device	Hz	The frequency of the generating set, the exceeding of which activates the overfrequency limiting device. In practice, instead of the value for the setting frequency, the value for the permissible overfrequency is stated (also see Table 1 of ISO 8528-2:2005).
f_i	No-load frequency	Hz	—
$f_{i,r}$	Rated no-load frequency	Hz	—
f_{max}[b]	Maximum permissible frequency	Hz	A frequency specified by the generating set manufacturer which lies a safe amount below the frequency limit (see Table 1 of ISO 8528-2:2005)
f_r	Declared frequency (rated frequency)	Hz	—
$f_{i,max}$	Maximum no-load frequency	Hz	—
$f_{i,min}$	Minimum no-load frequency	Hz	—
f_{arb}	Frequency at actual power	Hz	—
$\overset{\wedge}{\underset{\vee}{f}}$	Width of frequency oscillation	Hz	—
I_k	Sustained short-circuit current	A	—
t	Time	s	—
t_a	Total stopping time	s	Time interval from the stop command until the generating set has come to a complete stop and is given by: $t_a = t_i + t_c + t_d$
t_b	Load pick-up readiness time	s	Time interval from the start command until ready for supplying an agreed power, taking into account a given frequency and voltage tolerance and is given by: $t_b = t_p + t_g$

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
t_c	Off-load run-on time	s	Time interval from the removal of the load until generating set off signal is given to the generating set. Also known as the "cooling run-on time".
t_d	Run-down time	s	Time from the generating set off signal to when the generating set has come to a complete stop.
t_e	Load pick-up time	s	Time interval from start command until the agreed load is connected and is given by: $t_e = t_p + t_g + t_s$
$t_{f,de}$	Frequency recovery time after load decrease	s	The 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 (see Figure 4).
$t_{f,in}$	Frequency recovery time after load increase	s	The 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 (see Figure 4).
t_g	Total run-up time	s	Time interval from the beginning of cranking until ready for supplying an agreed power, taking into account a given frequency and voltage tolerance.
t_h	Run-up time	s	Time interval from the beginning of cranking until the declared speed is reached for the first time.
t_i	On-load run-on time	s	Time interval from a stop command being given until the load is disconnected (automatic sets).
t_p	Start preparation time	s	Time interval from the start command until the beginning of cranking.
t_s	Load switching time	s	Time from readiness to take up an agreed load until this load is connected.
t_u	Interruption time	s	Time interval from the appearance of the criteria initiating a start until the agreed load is connected and is given by: $t_u = t_v + t_p + t_g + t_s$ $= t_v + t_e$ This time shall be particularly taken into account for automatically started generating sets (see Clause 11). Recovery time (ISO 8528-12:1997) is a particular case of interruption time.

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
$t_{U,de}$	Voltage recovery time after load decrease	s	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 (see Figure 5).
$t_{U,in}$	Voltage recovery time after load increase	s	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 (see Figure 5).
t_v	Start delay time	s	Time interval from the appearance of the criteria initiating a start to the starting command (particularly for automatically started generating units). 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, if required, by special requirements of legislative authorities. For example, this time is provided to avoid starting in case of a very short mains failure.
t_z	Cranking time	s	Time interval from the beginning of cranking until the firing speed of the engine is reached.
t_0	Pre-lubricating time	s	Time required for some engines to ensure that oil pressure is established before the beginning of cranking. This time is usually zero for small generating sets, which normally do not require pre-lubrication.
v_f	Rate of change of frequency setting		Rate of change of frequency setting under remote control expressed as a percentage of related range of frequency setting per second and is given by: $v_f = \frac{(f_{i,max} - f_{i,min})/f_r}{t} \times 100$
v_u	Rate of change of voltage setting		Rate of change of voltage setting under remote control expressed as a percentage of the related range of voltage setting per second and is given by: $v_U = \frac{(U_{s,up} - U_{s,do})/U_r}{t} \times 100$
$U_{s,do}$	Downward adjustable voltage	V	—
$U_{s,up}$	Upward adjustable voltage	V	—

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
U_r	Rated voltage	V	Line-to-line voltage at the terminals of the generator at rated frequency and at rated output. Rated voltage is the voltage assigned by the manufacturer for operating and performance characteristics.
U_{rec}	Recovery voltage	V	Maximum obtainable steady-state voltage for a specified load condition. Recovery voltage is normally expressed as a percentage of the rated voltage. 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 (see Figure 5).
U_s	Set voltage	V	Line-to-line voltage for defined operation selected by adjustment.
$U_{st,max}$	Maximum steady-state voltage	V	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.
$U_{st,min}$	Minimum steady-state voltage	V	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.
U_0	No-load voltage	V	Line-to-line voltage at the terminals of the generator at rated frequency and no-load.
$U_{dyn,max}$	Maximum upward transient voltage on load decrease	V	Maximum voltage which occurs on a sudden change from a higher load to a lower load.
$U_{dyn,min}$	Minimum downward transient voltage on load increase	V	Minimum voltage which occurs on a sudden change from a lower load to a higher load.
$\hat{U}_{max,s}$	Maximum peak value of set voltage	V	—
$\hat{U}_{min,s}$	Minimum peak value of set voltage	V	—
$\hat{U}_{mean,s}$	Average value of the maximum and minimum peak value of set voltage	V	—

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
$\hat{U}_{mod,s}$	Voltage modulation	%	Quasi-periodic voltage variation (peak-to-peak) about a steady-state voltage having typical frequencies below the fundamental generation frequency, expressed as a percentage of average peak voltage at rated frequency and constant speed: $$\hat{U}_{mod,s} = 2\frac{\hat{U}_{mod,s,max} - \hat{U}_{mod,s,min}}{\hat{U}_{mod,s,max} + \hat{U}_{mod,s,min}} \times 100$$ 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 11 and 12).
$\hat{U}_{mod,s,max}$	Maximum peak of voltage modulation	V	Quasi-periodic maximum voltage variation (peak-to-peak) about a steady-state voltage
$\hat{U}_{mod,s,min}$	Minimum peak of voltage modulation	V	Quasi-periodic minimum voltage variation (peak-to-peak) about a steady-state voltage
$\overset{\wedge}{\underset{\vee}{U}}$	Width of voltage oscillation	V	—
Δf_{neg}	Downward frequency deviation from linear curve	Hz	—
Δf_{pos}	Upward frequency deviation from linear curve	Hz	—
Δf	Steady-state frequency tolerance band		The agreed frequency band about the steady-state frequency which the frequency reaches within a given governing period after increase or decrease of the load.
Δf_c	Maximum frequency deviation from a linear curve	Hz	The larger value of Δf_{neg} and Δf_{pos} that occur between no load and rated load (see Figure 2)
Δf_s	Range of frequency setting	Hz	The range between the highest and lowest adjustable no-load frequencies (see Figure 1) as given by: $$\Delta f_s = f_{i,max} - f_{i,min}$$
$\Delta f_{s,do}$	Downward range of frequency setting	Hz	Range between the declared no-load frequency and the lowest adjustable no-load frequency (see Figure 1) as given by: $$\Delta f_{s,do} = f_{i,r} - f_{i,min}$$
$\Delta f_{s,up}$	Upward range of frequency setting	Hz	Range between the highest adjustable no-load frequency and the declared no-load frequency (see Figure 1) as given by: $$\Delta f_{s,up} = f_{i,max} - f_{i,r}$$

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
ΔU	Steady-state voltage tolerance band	V	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. Unless otherwise stated it is given by: $\Delta U = 2\delta U_{st} \times \frac{U_r}{100}$
ΔU_s	Range of voltage setting	V	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 as given by: $\Delta U_s = \Delta U_{s,up} + \Delta U_{s,do}$
$\Delta U_{s,do}$	Downward range of voltage setting	V	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 as given by: $\Delta U_{s,do} = U_r - U_{s,do}$
$\Delta U_{s,up}$	Upward range of voltage setting	V	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 as given by: $\Delta U_{s,up} = U_{s,up} - U_r$
$\Delta\delta f_{st}$	Frequency/power characteristic deviation	%	Maximum deviation from a linear frequency/power characteristic curve in the power range between no-load and declared power, expressed as a percentage of rated frequency (see Figure 2) as given by: $\Delta\delta f_{st} = \frac{\Delta f_c}{f_r} \times 100$
—	Frequency/power characteristic curve	—	Curve of steady-state frequencies in the power range between no-load and declared power, plotted against active power of generating set (see Figure 2).
α_U	Related steady-state voltage tolerance band	%	The tolerance band expressed as a percentage of the rated voltage as given by: $\alpha_U = \frac{\Delta U}{U_r} \times 100$

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
α_f	Related frequency tolerance band	%	This tolerance band expressed as a percentage of the rated frequency as given by: $$\alpha_f = \frac{\Delta f}{f_r} \times 100$$
β_f	Steady-state frequency band	%	Envelope width oscillation $\hat{f}\check{}$ of generating set frequency at constant power around a mean value, expressed as a percentage of rated frequency as given by: $$\beta_f = \frac{\hat{\check{f}}}{f_r} \times 100$$ The maximum value of β_f occurring in the range between 20 % power and declared power shall be stated. For powers below 20 %, the steady-state frequency band can show higher values (see Figure 3), but shall allow synchronization.
δf_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, expressed as a percentage as given by: $$\delta f_d^- = \frac{f_{d,min} - f_{arb}}{f_{arb}} \times 100$$ A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease. Transient frequency deviation shall be in the allowable consumer frequency tolerance.

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
δf_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, expressed as a percentage as given by: $\delta f_d^+ = \frac{f_{d,max} - f_{arb}}{f_{arb}} \times 100$ A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease. Transient frequency deviation shall be in the allowable consumer frequency tolerance.
δf_{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, expressed as a percentage as given by: $\delta f_{dyn}^- = \frac{f_{d,min} - f_{arb}}{f_r} \times 100$ Transient frequency deviation shall be in the allowable consumer frequency tolerance. A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.
δf_{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, expressed as a percentage as given by: $\delta f_{dyn}^+ = \frac{f_{d,max} - f_{arb}}{f_r} \times 100$ Transient frequency deviation shall be in the allowable consumer frequency tolerance. A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
δU_{dyn}^{-}	Transient voltage deviation on load increase	%	Transient voltage deviation on load increase is the voltage drop when the generator, driven at rated frequency and at rated voltage under normal excitation control, is switched onto rated load, expressed as a percentage of rated voltage as given by: $\delta U_{dyn}^{-} = \frac{U_{dyn,min} - U_r}{U_r} \times 100$ Transient voltage deviation shall be in the allowable consumer voltage tolerance. A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.
δU_{dyn}^{+}	Transient voltage deviation on load decrease	%	Transient voltage deviation on load decrease is the voltage rise when the generator, driven at rated frequency and at rated voltage under normal excitation control, has a sudden rejection of rated load, expressed as a percentage of rated voltage as given by: $\delta U_{dyn}^{+} = \frac{U_{dyn,max} - U_r}{U_r} \times 100$ Transient voltage deviation shall be in the allowable consumer voltage tolerance. A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.
δf_s	Related range of frequency setting	%	Range of frequency setting, expressed as a percentage of rated frequency as given by: $\delta f_s = \frac{f_{i,max} - f_{i,min}}{f_r} \times 100$
$\delta f_{s,do}$	Related downward range of frequency setting	%	Range of downward frequency setting expressed as a percentage of the rated frequency as given by: $\delta f_{s,do} = \frac{f_{i,r} - f_{i,min}}{f_r} \times 100$
$\delta f_{s,up}$	Related upward range of frequency setting	%	Range of upward frequency setting expressed as a percentage of the rated frequency as given by: $\delta f_{s,up} = \frac{f_{i,max} - f_{i,r}}{f_r} \times 100$

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
δf_{st}	Frequency droop	%	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 (see Figure 1) as given by: $$\delta f_{st} = \frac{f_{i,r} - f_r}{f_r} \times 100$$
δ_{QCC}	Grade of quadrature-current compensation droop	—	—
δ_s	Cyclic irregularity	—	—
δf_{lim}	Overfrequency setting ratio	%	Difference between the setting frequency of the overfrequency limiting device and the rated frequency divided by the rated frequency, expressed as a percentage as given by: $$\delta f_{lim} = \frac{f_{ds} - f_r}{f_r} \times 100$$
δU_{st}	Steady-state voltage deviation	%	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. The steady-state voltage deviation is expressed as a percentage of the rated voltage as given by: $$\delta U_{st} = \pm \frac{U_{st,max} - U_{st,min}}{2U_r} \times 100$$
δU_s	Related range of voltage setting	%	Range of voltage setting expressed as a percentage of the rated voltage as given by: $$\delta U_s = \frac{\Delta U_{s,up} + \Delta U_{s,do}}{U_r} \times 100$$
$\delta U_{s,do}$	Related downward range of voltage setting	%	Downward range of voltage setting expressed as a percentage of the rated voltage as given by: $$\delta U_{s,do} = \frac{U_r - U_{s,do}}{U_r} \times 100$$

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

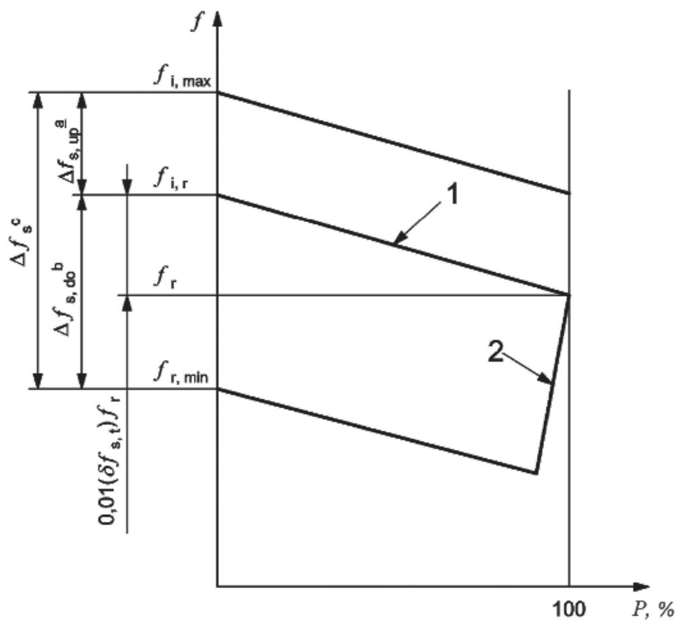
[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.

Table 1 *(continued)*

Symbol	Term	Unit	Definition
$\delta U_{s,up}$	Related upward range of voltage setting	%	Upward range of voltage setting expressed as a percentage of the rated voltage as given by: $$\delta U_{s,up} = \frac{U_{s,up} - U_r}{U_r} \times 100$$
$\delta U_{2,0}$	Voltage unbalance	%	Ratio of the negative-sequence or the zero-sequence voltage components to the positive-sequence voltage components at no-load. Voltage unbalance is expressed as a percentage of rated voltage.

[a] For a given generating set the operating frequency depends on the total inertia of the generating set and the design of the overfrequency protection system.

[b] The frequency limit (see Figure 3 of ISO 8528-2:2005) is the calculated frequency which the engine and generator of the generating set can sustain without risk of damage.



Key

P Power

f Frequency

1 Frequency/power characteristic curve

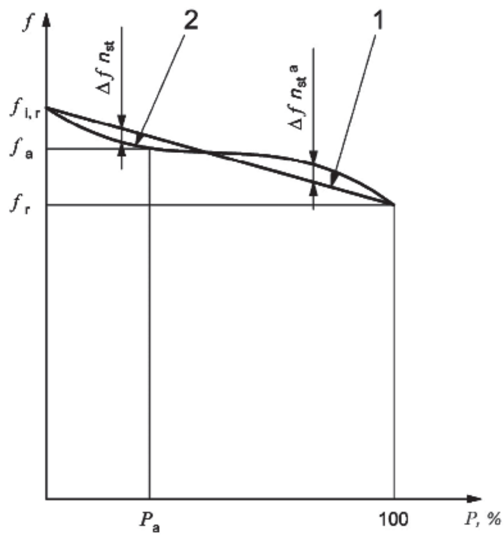
2 Power limit (the power limit of the generating set depends upon the power limit of the RIC engine (e.g. fuel stop power) taking into account the efficiency of the a.c. generator)

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

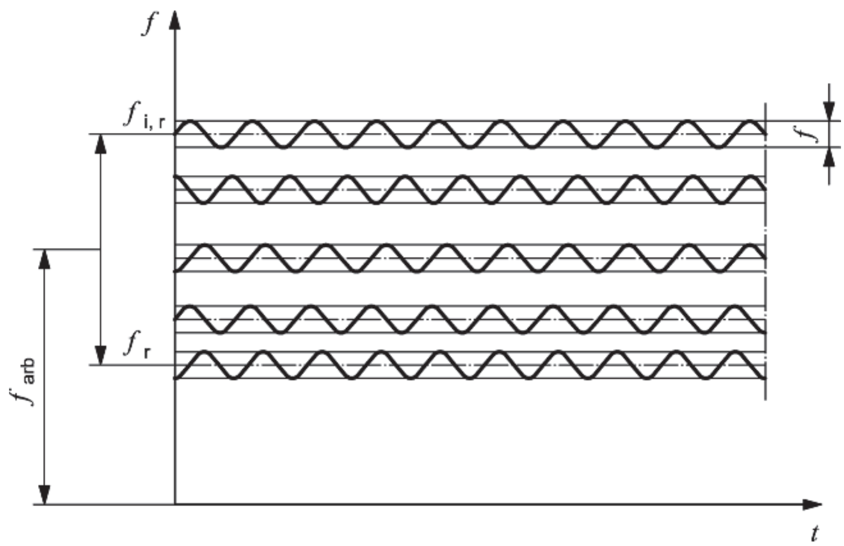
f Frequency

1 Linear frequency/power characteristic curve

2 Frequency/power characteristic curve

a Frequency/power characteristic deviation

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

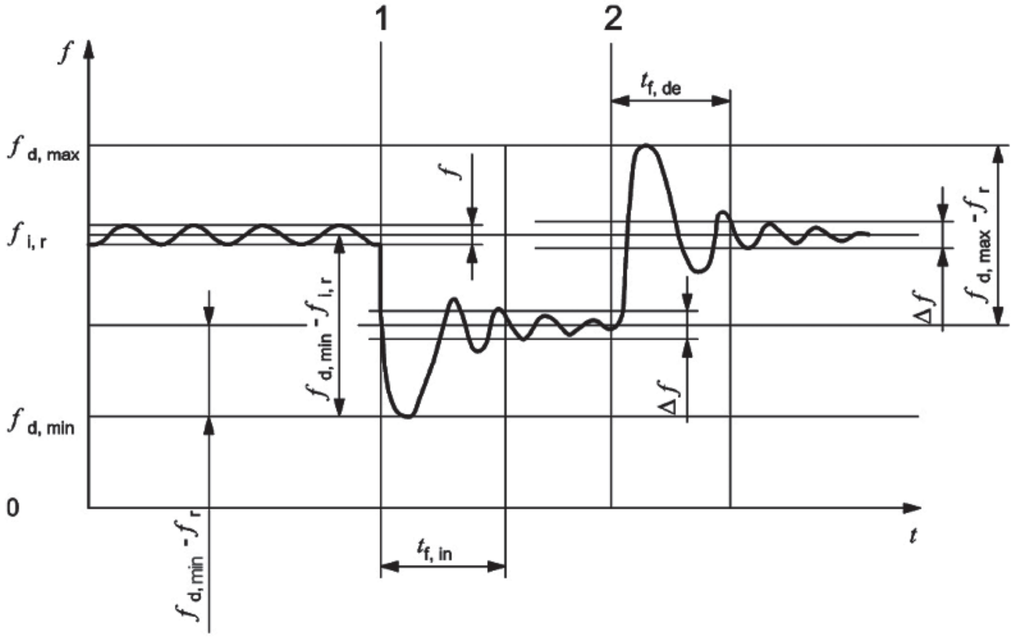


Key

t Time

f Frequency

Figure 3 — Steady-state frequency band



Key

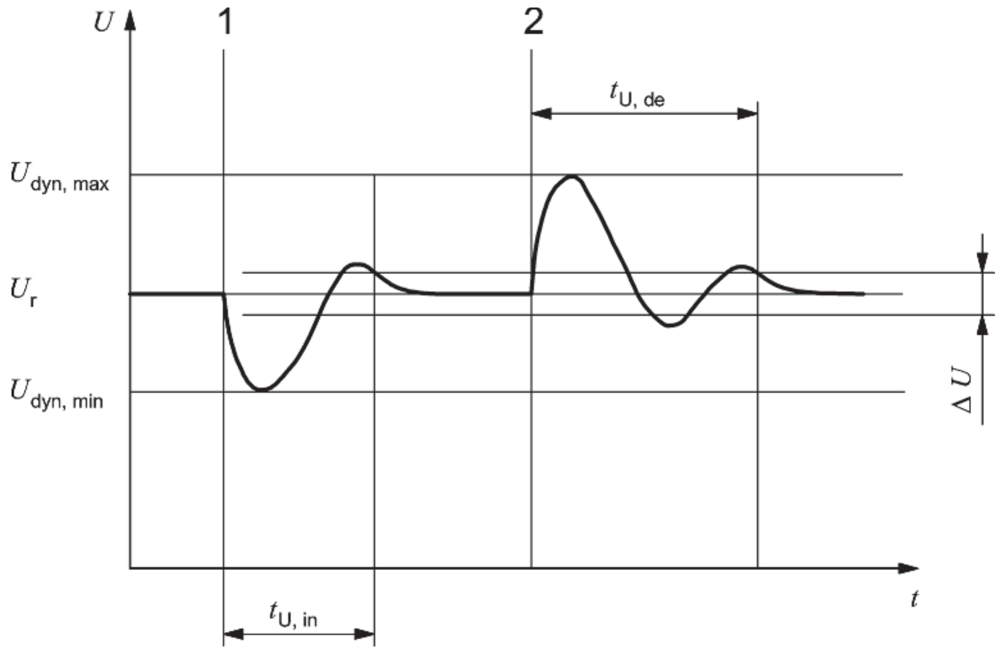
t Time

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 society, the additional requirements of the classification society shall be observed. The classification society name shall be stated 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.

If special requirements from any other regulatory authority (e.g. inspecting and/or legislative authorities) have to be met, the authority name shall be stated by the customer prior to placing the order.

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.

Terms, symbols and definitions related to frequency characteristics are given in Table 1 (see Figures 1, 2, 3 and 4).

6 Overfrequency characteristics

The terms, symbols and definitions related to overfrequency characteristics are given in Table 1.

7 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).

Terms, symbols and definitions related to voltage characteristics are given in Table 1.

8 Sustained short-circuit current

The sustained short-circuit current, I_k, which can be important to current-operated protective devices, can well be lower in service than the "ideal" value specified by the generator manufacturer for a fault at the generator terminals. The actual value will be influenced by the circuit impedance between the generator and the location of the fault (also see 10.3 of ISO 8528-3:2005).

9 Factors affecting generating set performance

9.1 General

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

9.2 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; and

g) effect of nonlinear loads.

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

9.3 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.

9.4 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 diesel engines.

The response behaviour of gas 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.

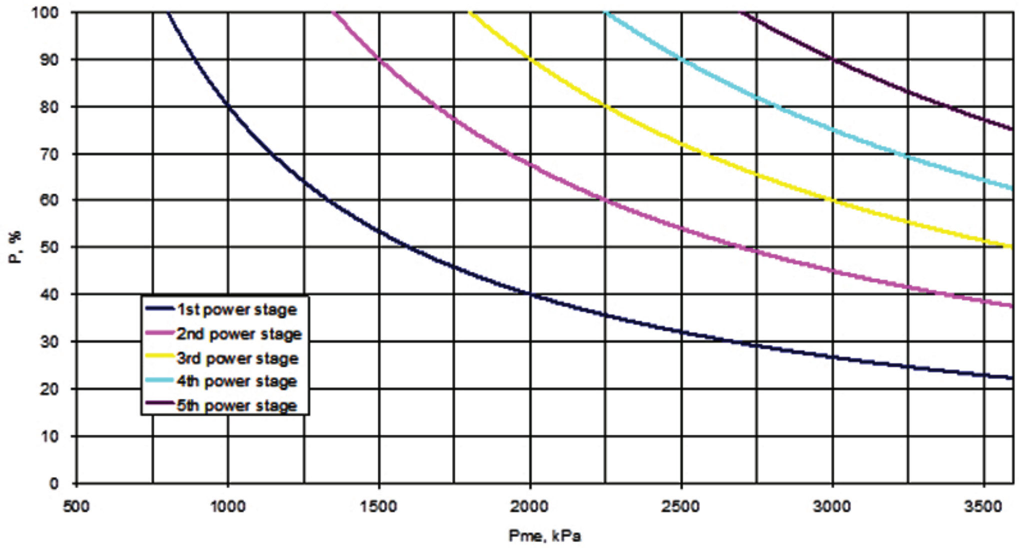
If necessary, these time intervals shall be agreed between the generating set manufacturer and the customer.

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

p_{me} declared power mean effective pressure

P power increase referred to declared power at site conditions

1 first power stage

2 second power stage

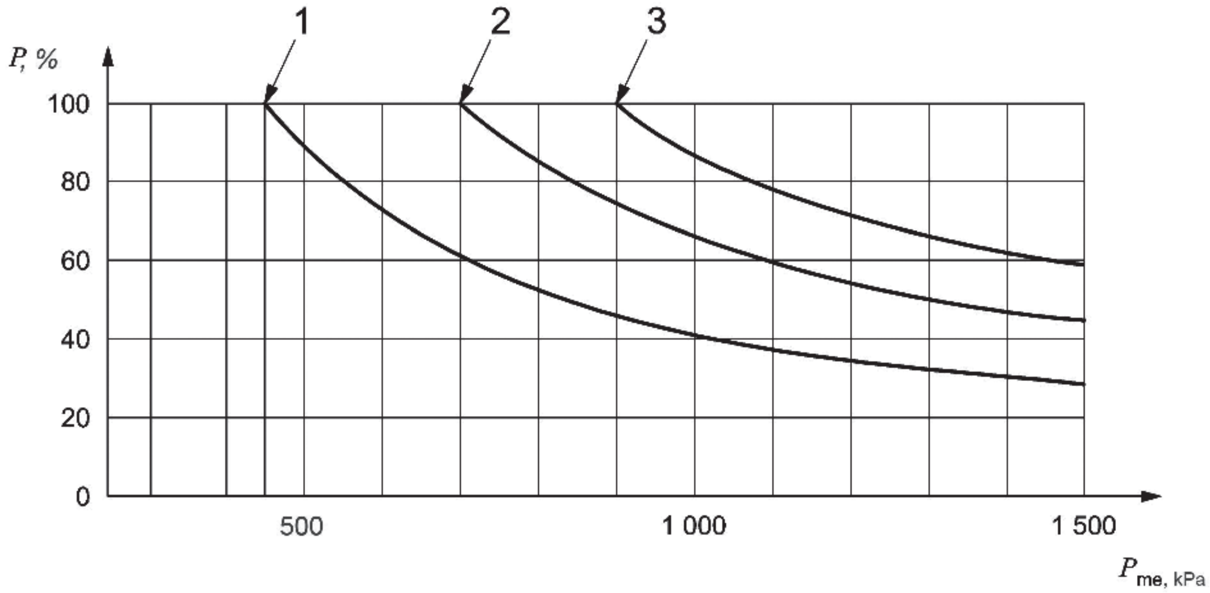
3 third power stage

4 fourth power range

5 fifth power range

Figure 6 — Reference values for maximum possible sudden power increases as a function of brake mean effective pressure, pme, 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 3046-4:2009).



Key

p_{me} declared power mean effective pressure

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, pme, 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 3046-4:2009).

10 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:

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

NOTE 1 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.

NOTE 2 Special consideration is to 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 Clause 11 of ISO 8528-3:2005)

11 Starting characteristics

The starting characteristics depend on several factors, e.g.:

a) ambient air temperature;

b) temperature of the RIC engine;

c) starting air pressure;

d) starter battery condition;

e) oil viscosity;

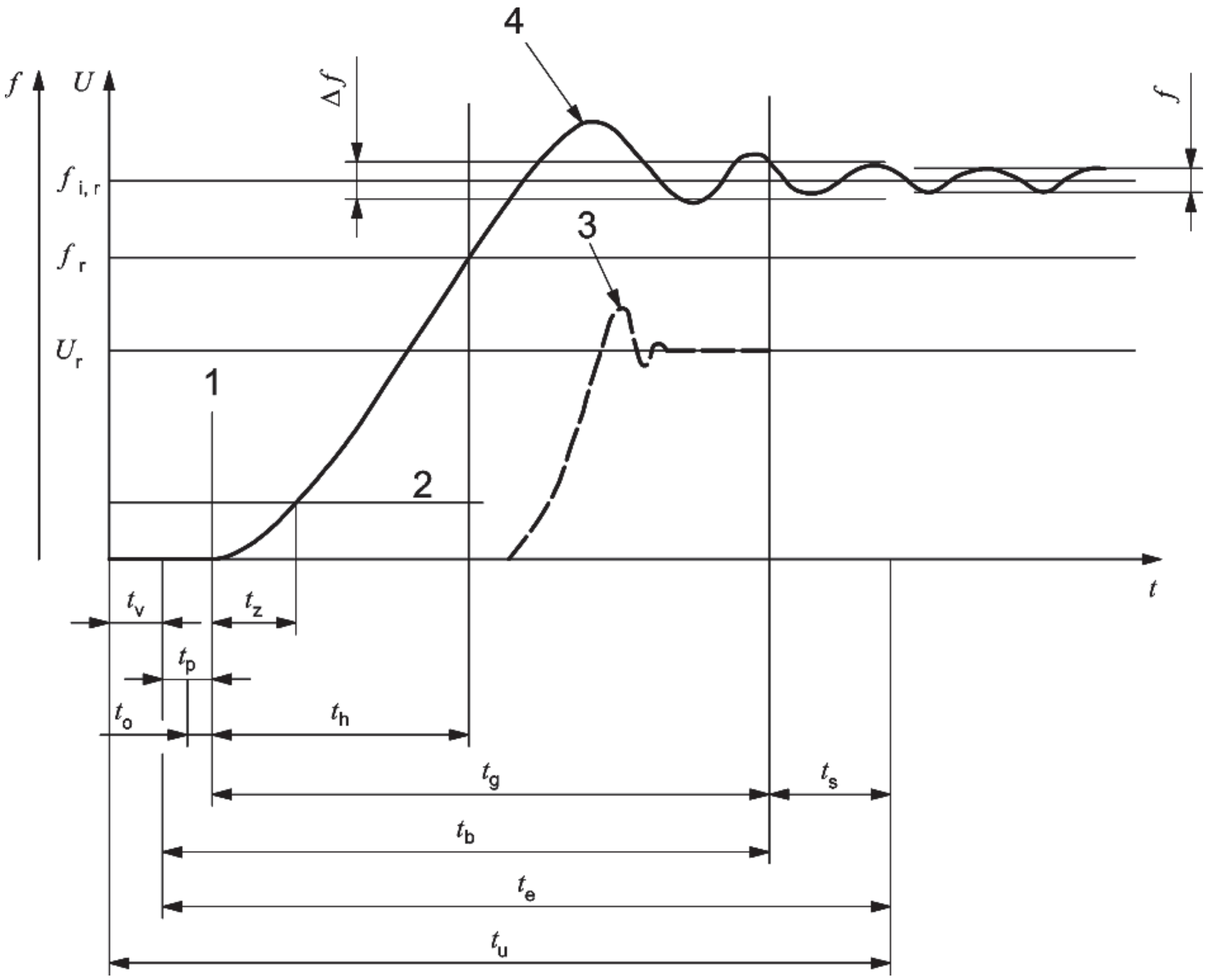
f) total inertia of the generating set;

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 8).

Terms, symbols and definitions related to starting characteristics are given in Table 1.



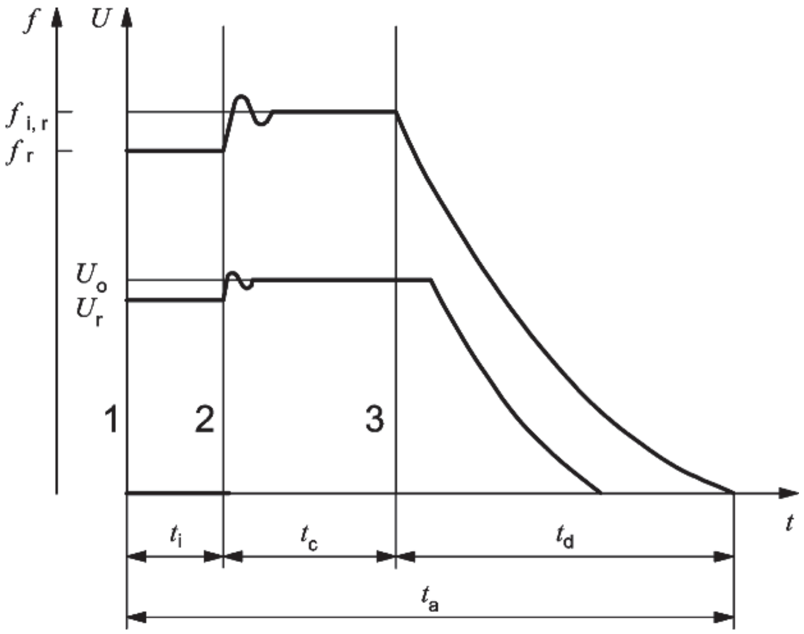
Key

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

Figure 8 — Starting characteristics

12 Stop time characteristics

Terms, symbols and definitions related to the stop time characteristics are given in Table 1 (see Figure 9).



Key

t time
f frequency
U voltage
1 stop command
2 power removed
3 fuel stop signal

Figure 9 — Stopping characteristics

13 Parallel operation

13.1 Active power sharing

13.1.1 Factors influencing active power sharing

Active power sharing (see Figure 10) can be influenced by any one or more of the following:

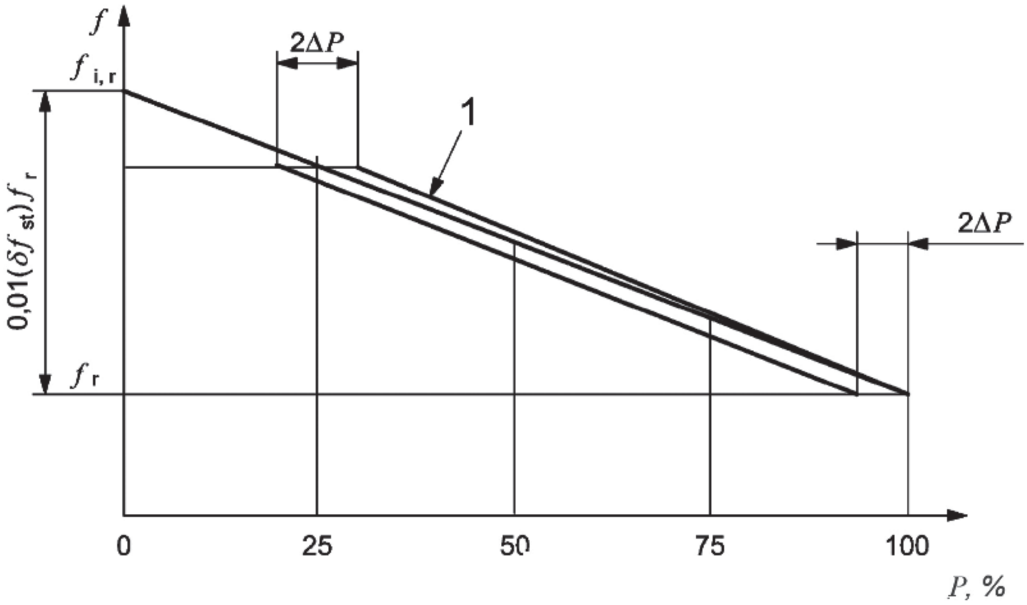
a) the speed governor droop characteristic;

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 10 — Power sharing in parallel running

13.1.2 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:

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

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;
- $\Sigma P_{\text{r},j}$ 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, will occur 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.

13.1.3 Examples of active power sharing

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

Table 2 — Examples of active power sharing

Example	**Genset**	**Related power** $P_{\mathrm{r},i}$	$\sum_{j=1}^{n} P_{\mathrm{r},j}$	**Partial power** P_i	$\sum_{j=1}^{n} P_j$	$P_{i,\mathrm{p}} = \frac{P_i}{P_{\mathrm{r},i}}$	$P_{\mathrm{s,p}} = \frac{\sum_{j=1}^{n} P_j}{\sum_{j=1}^{n} P_{\mathrm{r},j}}$	ΔP_i
		kW	kW	kW	kW	%	%	%
1	1	400	1200	275	900	68,7	75	− 6,3
	2	400		300		75		0
	3	400		325		81,3		+ 6,3
2	1	400	900	335	675	83,7	75	+ 8,7
	2	300		210		70		− 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 may be temporarily exceeded.

13.2 Reactive power sharing

13.2.1 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.

13.2.2 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:

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

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, will occur 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.

13.2.3 Examples of reactive power sharing

The examples shown in Table 3 are worked assuming a value of cos φ = 0,8.

Table 3 — 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	$\sum_{j=1}^{n} Q_j$	$\frac{Q_i}{Q_{r,i}} \times 100$	$\frac{\sum_{j=1}^{n} Q_j}{\sum_{j=1}^{n} Q_{r,j}} \times 100$	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.

13.3 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).

14 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;

5) the rated power (kW) with one of the prefixes COP, PRP, LTP or ESP in accordance with the requirements of Clause 13 of ISO 8528-1:2005;

6) the set performance class in accordance with the requirements of Clause 7 of ISO 8528-1:2005;

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;

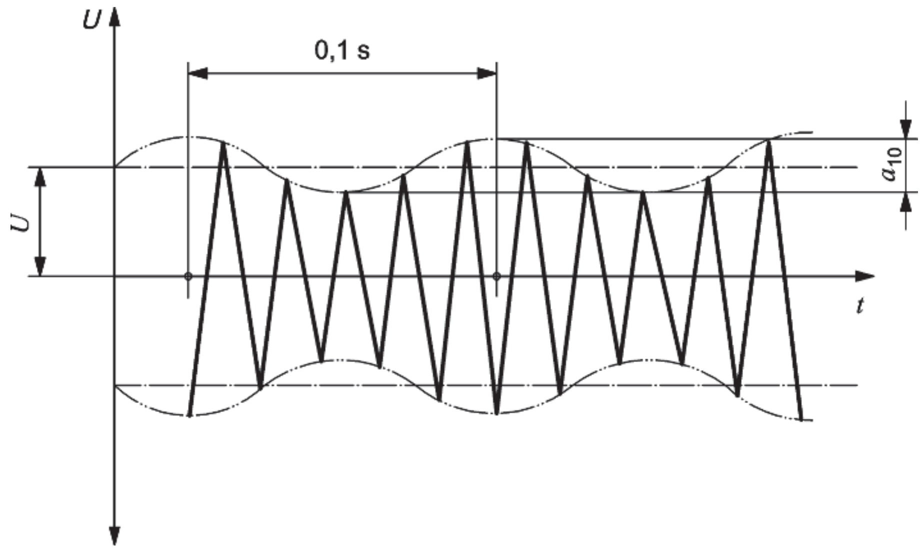
c) Rating plate for generators, in accordance with IEC 60034-1:2004 and Clause 14 of ISO 8528-3:2005;

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

NOTE 1 Figure 13 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.

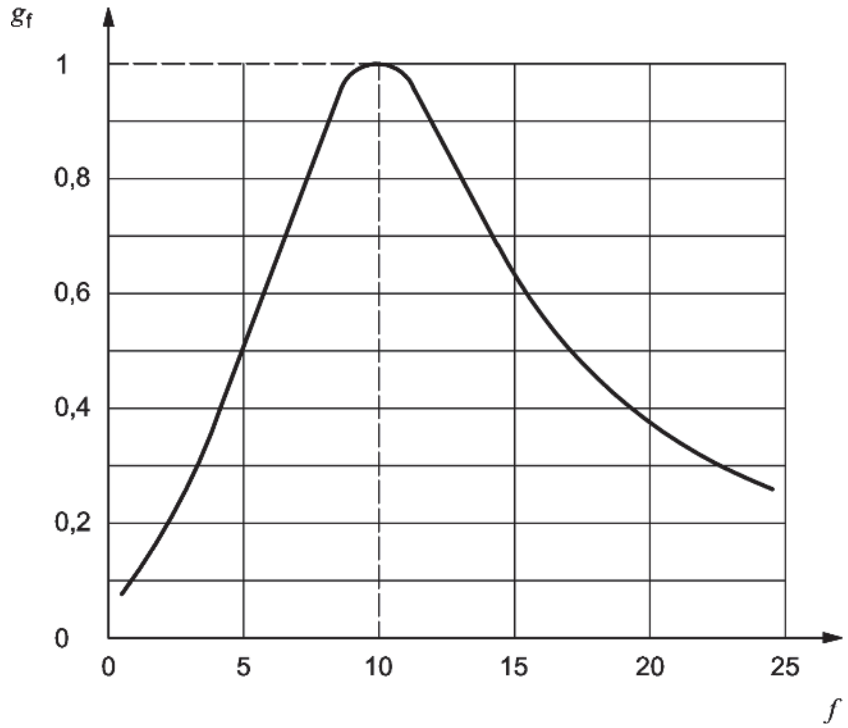


Key

t time

U voltage

Figure 11 — 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 12 — Curve giving equivalent perceptibility due to change in brightness

General 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			—

[ ] Space for indicating the power output category (see ISO 8528-1:2005) selected from:

COP — Continuous Operating Power;

PRP — Prime Power;

LTP — Limited Time running Power;

ESP — Emergency Standby Power

Figure 13 — Example of an RIC engine driven generating set rating plate

15 Further factors influencing generating set performance

15.1 Starting methods

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

a) mechanical (e.g. crank);

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

c) pneumatic (e.g. compressed air introduced to the RIC engine cylinders or pneumatic starting motor).

15.2 Shutdown methods

Depending on design and application, different shutdown methods, according to the type of shutdown signal, are used e.g.:

a) mechanical;

b) electrical;

c) pneumatic;

d) hydraulic.

15.3 Fuel and lubrication oil supply

The fuel and lubrication oil supplies shall be designed so that the generating set is able to operate satisfactorily under all operating conditions. Furthermore, safety requirements (e.g. for fire and explosion protection) shall be taken into account. The appropriate regulations of the legislative authorities of the respective country for fuel and lubricating oil storage shall be complied with.

15.4 Combustion air

The quality of air required for combustion shall be taken into account to determine the degree of filtration required.

15.5 Exhaust system

The exhaust system shall be designed in accordance with the permitted exhaust gas back pressure (stated by the engine manufacturer) and the required noise attenuation. The following criteria can be important in designing the system:

a) whether structure-borne sound insulation is installed/required;

b) whether heat insulation and cladding (radiation, penetrations through walls, protection against contact) is installed/required;

c) whether piping expansion compensation is installed/required;

d) drainage;

e) prevention of water ingress;

f) protection against exhaust gas explosion;

g) configuration of the exhaust outlet (e.g. direction of wind, protection against birds);

h) support;

i) gaseous emissions.

15.6 Cooling and room ventilation

The RIC engine cooling system type, the generator and the switchgear as well as ventilation and air extraction are of particular importance for stationary power plants when designing the site building. In order to design the site building correctly, the required technical data shall be obtained from the generating set manufacturer.

15.7 Monitoring

The extent of monitoring of a power plant depends on, e.g.:

a) the intended application;

b) the mode of operation;

c) the size and type of the generating set;

d) requirements of the consumer’s equipment;

e) the manufacturer’s requirements;

f) the customer’s requirements.

In observing the above criteria, the monitoring equipment shall be chosen to ensure readiness for use and operation.

15.8 Noise emission

If the fixed installation generating set noise emission is to be limited to certain values, then a special agreement shall be made between the manufacturer and the customer at the project stage.

If sound level measurements are agreed for mobile generating sets, then measurements shall be carried out at the manufacturer’s works using short-range field measurements.

NOTE 1 An enveloping surface method is given in ISO 8528-10:1998.

NOTE 2 In practice, the expensive measurements according to the long-range field measurements give no appreciable difference from those of short-range measurements.

As with fixed equipment, treatment for noise attenuation is usually taken on site, and the sound level measurements at the manufacturer’s works can only be carried out without this noise attenuation. If noise attenuation of the generating set is required, the measurement is likely to be carried out as for mobile generating sets.

15.9 Coupling

The generating set/RIC engine coupling selection shall take into account the stresses imposed on it by the torsional vibration of the system which is influenced by, e.g.:

a) up to RIC engine fuel stop power;

b) the inertia of the RIC engine and generator;

c) the short-circuit torque;

d) misalignment;

e) RIC engine misfiring.

The greatest short-circuit torque occurs as a result of a two-phase Iine-to-Iine short circuit at the generator terminals.

The generating set manufacturer is responsible for component compatibility.

15.10 Vibration

15.10.1 General

The generating set manufacturer shall demonstrate that for the vibrating system (engine/coupling/generator/ baseframe) of the generating set, the vibration characteristic in its normal operating range will lie safely outside the range of critical values.

The vibrations caused by other parts of the power station (e.g. exhaust gas system, foundations) shall also be taken into account.

15.10.2 Torsional vibration

The provisions of ISO 3046-5:2001 shall be used to perform the torsional vibration analysis of the generating set.

15.10.3 Linear vibration

15.10.3.1 Dynamic bending deformation

Dynamic bending deformation in the rotating system consisting of the engine/coupling/generator combination can occur due to the effects of combustion and inertial forces in the engine and the magnetic forces in the generator. Dynamic bending deformation shall be taken into account in the design of individual components and of the baseframe.

15.10.3.2 Structural vibrations

15.10.3.2.1 General

Apart from the torsional and linear vibrations, there exist vibrations of the generating set caused by the reciprocating forces and torques present in the RIC engine. The manufacturer of the generating set shall be responsible for the compatibility of the components relative to each other, so that the maximum permitted vibration velocity for individual components is not exceeded.

15.10.3.2.2 Measurement location and measurement conditions

Measurements shall be carried out in the horizontal and/or vertical direction at the generating set bearings. When a bearing is not accessible, or for single-bearing a.c. generators, the measurement shall be carried out on the bearing casing. The measurement of the vibration velocity shall preferably be carried out with the generating set installed on the manufacturer's test-bed and running at its rated output and, if possible, under simulated site installation conditions. Where the rated output cannot be applied for this test, then the highest possible output shall be applied.

15.11 Foundations

In order to be able to establish the dimensions of the generating set baseplate foundations or any supporting surfaces, data on static and dynamic loads to be expected shall be obtained from the generating set manufacturer.

To reduce the effect of free inertia forces on the environment, a suitable resilient mounting can be necessary.

Any openings required for cables, pipelines, etc., at the site shall be taken into account.

If a resilient mounting is provided, then flexible connections shall be provided for cables and pipes.

16 Performance class operating limit values

16.1 General

The operating limit values listed in Table 4 shall be satisfied in order to determine the major characteristics of significance for the voltage and frequency behaviour of a generating set as given in ISO 8528-1:2005.

The numerical values for the individual performance classes shall be selected so that they are matched for the compatibility of their individual component parts.

The appropriate performance class for a generating set shall be selected when all the limit values for this performance class have been fulfilled.

It is recommended that the customer should select the minimum performance class that will fulfil his requirements.

16.2 Recommendation for gas engine operating limit values

The performance of gas engine generating sets should be specified by AMC (Agreement between Manufacturer and Customer). This agreement should consider the impact of the fuel gas Methane Number and lower heating value on transient performance. It should also consider the impact of ambient conditions.

Table 4 — Performance class operating limit values

Parameter		Symbol	Unit	Operating limit values Performance class			
				G1	G2	G3	G4
Frequency droop		δf_{st}	%	≤ 8	≤ 5	≤ 3 [r]	AMC [a]
Steady-state frequency band		β_f	%	≤ 2,5	≤ 1,5 [b]	≤ 0,5	AMC
Related range of downward frequency setting		$\delta_{fs,do}$	%	> (2,5 + δf_{st})			AMC
Related range of upward frequency setting		$\delta_{fs,up}$	%	> + 2,5 [c]			AMC
Rate of change of frequency setting		v_f	%/s	0,2 to 1			AMC
Transient frequency difference from initial frequency	100 % sudden power decrease [p]	δf_d	%	≤ + 18	≤ + 12	≤ + 10	AMC
	sudden power increase [d,e,q]			≤−(15 + δf_{st}) [d]	≤−(10 + δf_{st}) [d]	≤−(7 + δf_{st}) [d]	
Transient frequency deviation from rated frequency	100 % sudden power decrease [p]	δf_{dyn}	%	≤ + 18	≤ + 12	≤ + 10	AMC
	sudden power increase [d,e,q]			≤ − 15 [d]	≤ − 10 [d]	≤ − 7 [d]	
				≤ − 25 [e]	≤ − 20 [e]	≤ − 15 [e]	
Frequency recovery time		$t_{f,in}$	s	≤ 10 [f]	≤ 5 [f]	≤ 3 [f]	AMC
		$t_{f,de}$		≤ 10 [d]	≤ 5 [d]	≤ 3 [d]	
Related frequency tolerance band		α_f	%	3,5	2	2	AMC
Steady-state voltage deviation		δU_{st}	%	≤ ± 5	≤ ± 2,5	≤ ± 1	AMC
				≤ ± 10 [g]	≤ ± 1 [h]		
Voltage unbalance		$\delta U_{2,0}$	%	1 [i]	1 [i]	1 [i]	1 [i]
Related range of voltage setting		δU_s	%	≤ ± 5			AMC
Rate of change of voltage setting		v_U	% s^{-1}	0,2 to 1			AMC
Transient voltage deviation	100 % sudden power decrease	δU^{+}_{dyn}	%	≤ + 35	≤ + 25	≤ + 20	AMC
	sudden power increase [d,e]	δU^{-}_{dyn}		≤ − 25 [d]	≤ − 20 [d]	≤ − 15 [d]	
Voltage recovery time [j] (see Figure 5)		$t_{U,in}$	s	≤ 10	v 6	≤ 4	AMC
		$t_{U,de}$		≤ 10 [d]	≤ 6 [d]	≤ 4 [d]	
Voltage modulation [k,l] (see Figure 11)		$\hat{U}_{mod,s}$	%	AMC	0,3 [m,n]	0,3 [n]	AMC
Active power sharing [o]	between 80 % and 100 % of the nominal rating	ΔP	%	—	≤ + 5	≤ + 5	AMC
	between 20 % and 80 % of the nominal rating				≤ + 10	≤ + 10	AMC

Table 4 *(continued)*

Parameter		Symbol	Unit	Operating limit values			
				Performance class			
				G1	G2	G3	G4
Reactive power sharing	between 20 % and 100 % of the nominal rating	ΔQ	%	—	≤ + 10	≤ + 10	AMC

[a] AMC = by agreement between manufacturer and customer.

[b] In the case of generating sets with single- or two-cylinder engines, the value can be up to 2,5.

[c] To the extent that parallel operation is not necessary, fixed setting of the speed or voltage is permissible.

[d] For generating sets with turbo-charged engines, these data apply with use of the maximum possible power increase according to Figures 6 and 7.

[e] For spark-ignition gas engines.

[f] The stated values are typical only when removing 100 % load; break torque is only provided by mechanical losses of the generating set so the recovery time will depend only on the total inertia and mechanical efficiency of the generating set, which can vary widely due to the application and/or type of engine.

[g] For small units up to 10 kV·A.

[h] Minimum requirements for generating sets with synchronous generators in parallel operation, when the reactive current characteristics shall be taken into consideration; the frequency swing range shall be less than or equal to 0,5 %.

[i] In the case of parallel operation, reduce these values to 0,5.

[j] Unless otherwise stated, the tolerance band used to calculate voltage recovery time will be equal to:

$$2 \times \delta U_{st} \times \frac{U_r}{100}$$

[k] Operating limit values not included in steady-state limits.

[l] If it appears that torsional vibration of the generator, forced by the engine, will cause voltage modulation to exceed the limits, the generator manufacturer shall collaborate as necessary to reduce the vibration, or to provide special excitation control.

[m] For generating sets with single- or two-cylinder engines, the value can be ± 2.

[n] Highest perceptibility of eyes in case of light flickering due to changes in brightness gives a 10 Hz voltage fluctuation with a threshold for irritability of $\hat{U}_{mod10} < 0,3\ \%$.

The given operating limit values for $\hat{U}_{mod10}$ relate to a sinusoidal voltage fluctuation at 10 Hz. For voltage fluctuations at frequencies f having amplitudes a_f, the equivalent 10 Hz amplitude will be: $a_{10} = g_f a_f$

where g_f is the weighting factor for frequency corresponding to a_f according to Figure 12.

Taking into consideration all harmonics of a voltage fluctuation, there is an amplitude corresponding to an equivalent 10 Hz voltage modulation of

$$\hat{U}_{mod10} = \sqrt{\sum_{i=1}^{n} g_{f,i}^2 a_{f,i}^2}$$

[o] When using the tolerances, the amount of the effective nominal load or nominal reactive load of the parallel-operating sets decreases by the tolerance value.

[p] The operating limit values are valid only for $f_{arb} = f_i$ in the case of decreasing load.

[q] The operating limit values are valid only for $f_{arb} = f_r$ in the case of increasing load.

[r] For some applications, the frequency droop is 0 % (isochronous).

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ICS 27.020,29.160.40

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