# 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*

# Contents

# 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*

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[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 (over-shoot 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 (under-shoot 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:<br><br>$t_e = t_p + t_g + t_s$ |
| $t_{f,de}$ | 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:<br><br>$t_u = t_v + t_p + t_g + t_s$<br><br>$= t_v + t_e$<br><br>This time shall be particularly taken into account for automatically started generating sets (see Clause 11).<br><br>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 ($\Delta U$). 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 |
|---|---|---|---|
| $\hat{U}_{\mathrm{mod,s}}$ | 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: $$\hat{U}_{\mathrm{mod,s}} = 2\frac{\hat{U}_{\mathrm{mod,s,max}} - \hat{U}_{\mathrm{mod,s,min}}}{\hat{U}_{\mathrm{mod,s,max}} + \hat{U}_{\mathrm{mod,s,min}}} \times 100$$ 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). |
| $\hat{U}_{\mathrm{mod,s,max}}$ | Maximum peak of voltage modulation | V | Quasi-periodic maximum voltage variation (peak-to-peak) about a steady-state voltage |
| $\hat{U}_{\mathrm{mod,s,min}}$ | 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 | — |
| $\Delta f_{\mathrm{neg}}$ | Downward frequency deviation from linear curve | Hz | — |
| $\Delta f_{\mathrm{pos}}$ | Upward frequency deviation from linear curve | Hz | — |
| $\Delta f$ | 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. |
| $\Delta f_{\mathrm{c}}$ | Maximum frequency deviation from a linear curve | Hz | The larger value of $\Delta f_{\mathrm{neg}}$ and $\Delta f_{\mathrm{pos}}$ that occur between no load and rated load (see Figure 2) |
| $\Delta f_{\mathrm{s}}$ | Range of frequency setting | Hz | The range between the highest and lowest adjustable no-load frequencies (see Figure 1) as given by: $$\Delta f_{\mathrm{s}} = f_{\mathrm{i,max}} - f_{\mathrm{i,min}}$$ |
| $\Delta f_{\mathrm{s,do}}$ | 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: $$\Delta f_{\mathrm{s,do}} = f_{\mathrm{i,r}} - f_{\mathrm{i,min}}$$ |
| $\Delta f_{\mathrm{s,up}}$ | 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: $$\Delta f_{\mathrm{s,up}} = f_{\mathrm{i,max}} - f_{\mathrm{i,r}}$$ |

[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 |
|---|---|---|---|
| $\Delta U$ | 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: $$\Delta U = 2\delta U_{st} \times \frac{U_r}{100}$$ |
| $\Delta U_s$ | 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). |
| $\alpha_U$ | 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 |
|---|---|---|---|
| $\alpha_f$ | Related frequency tolerance band | % | This tolerance band expressed as a percentage of the rated frequency as given by: $$\alpha_f = \frac{\Delta f}{f_r} \times 100$$ |
| $\beta_f$ | Steady-state frequency band | % | Envelope width oscillation $\overset{\wedge}{\underset{\vee}{f}}$ of generating set frequency at constant power around a mean value, expressed as a percentage of rated frequency as given by: $$\beta_f = \frac{\overset{\wedge}{\underset{\vee}{f}}}{f_r} \times 100$$ The maximum value of $\beta_f$ 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. |
| $\delta f_d^-$ | 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 |
|---|---|---|---|
| $\delta f_{\mathrm{d}}^{+}$ | Transient frequency deviation (from initial frequency) on load decrease (+) related to initial frequency | % | Temporary frequency deviation between overshoot frequency and initial frequency during the governing process following a sudden load decrease, related to initial frequency, expressed as a percentage as given by: $$\delta f_{\mathrm{d}}^{+} = \frac{f_{\mathrm{d,max}} - f_{\mathrm{arb}}}{f_{\mathrm{arb}}} \times 100$$ 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. |
| $\delta f_{\mathrm{dyn}}^{-}$ | Transient frequency deviation (from initial frequency) on load increase (-) related to rated frequency | % | Temporary frequency deviation between undershoot (or overshoot) frequency and initial frequency during the governing process following a sudden load change, related to rated frequency, expressed as a percentage as given by: $$\delta f_{\mathrm{dyn}}^{-} = \frac{f_{\mathrm{d,min}} - f_{\mathrm{arb}}}{f_{\mathrm{r}}} \times 100$$ 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. |
| $\delta f_{\mathrm{dyn}}^{+}$ | Transient frequency deviation (from initial frequency) on load decrease (+) related to rated frequency | % | Temporary frequency deviation between overshoot frequency and initial frequency during the governing process following a sudden load change, related to rated frequency, expressed as a percentage as given by: $$\delta f_{\mathrm{dyn}}^{+} = \frac{f_{\mathrm{d,max}} - f_{\mathrm{arb}}}{f_{\mathrm{r}}} \times 100$$ 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 |
|--------|------|------|------------|
| $\delta U_{\mathrm{dyn}}^-$ | 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: $$\delta U_{\mathrm{dyn}}^- = \frac{U_{\mathrm{dyn,min}} - U_{\mathrm{r}}}{U_{\mathrm{r}}} \times 100$$ 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. |
| $\delta U_{\mathrm{dyn}}^+$ | 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: $$\delta U_{\mathrm{dyn}}^+ = \frac{U_{\mathrm{dyn,max}} - U_{\mathrm{r}}}{U_{\mathrm{r}}} \times 100$$ 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. |
| $\delta f_{\mathrm{s}}$ | Related range of frequency setting | % | Range of frequency setting, expressed as a percentage of rated frequency as given by: $$\delta f_{\mathrm{s}} = \frac{f_{\mathrm{i,max}} - f_{\mathrm{i,min}}}{f_{\mathrm{r}}} \times 100$$ |
| $\delta f_{\mathrm{s,do}}$ | Related downward range of frequency setting | % | Range of downward frequency setting expressed as a percentage of the rated frequency as given by: $$\delta f_{\mathrm{s,do}} = \frac{f_{\mathrm{i,r}} - f_{\mathrm{i,min}}}{f_{\mathrm{r}}} \times 100$$ |
| $\delta f_{\mathrm{s,up}}$ | Related upward range of frequency setting | % | Range of upward frequency setting expressed as a percentage of the rated frequency as given by: $$\delta f_{\mathrm{s,up}} = \frac{f_{\mathrm{i,max}} - f_{\mathrm{i,r}}}{f_{\mathrm{r}}} \times 100$$ |

[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 |
|---|---|---|---|
| $\delta f_{st}$ | 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: $$\delta f_{st} = \frac{f_{i,r} - f_r}{f_r} \times 100$$ |
| $\delta_{QCC}$ | Grade of quadrature-current compensation droop | — | — |
| $\delta_s$ | Cyclic irregularity | — | — |
| $\delta f_{lim}$ | 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: $$\delta f_{lim} = \frac{f_{ds} - f_r}{f_r} \times 100$$ |
| $\delta U_{st}$ | 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: $$\delta U_{st} = \pm \frac{U_{st,max} - U_{st,min}}{2U_r} \times 100$$ |
| $\delta U_s$ | 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**
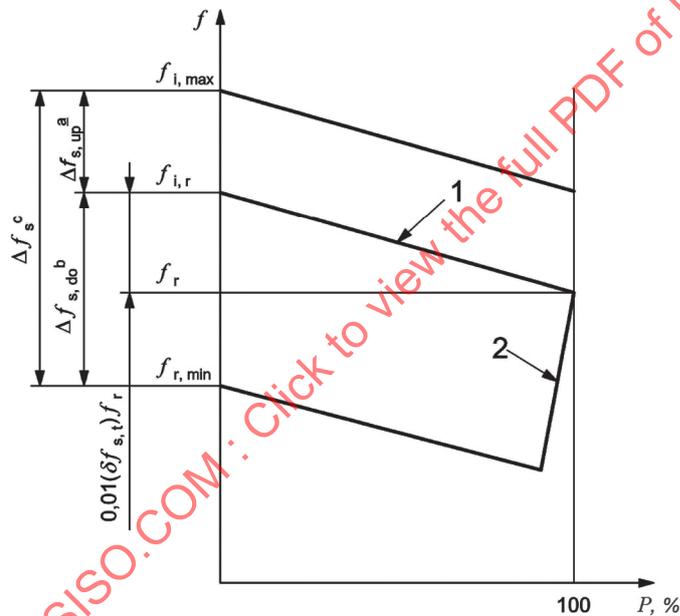
P   Power

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**
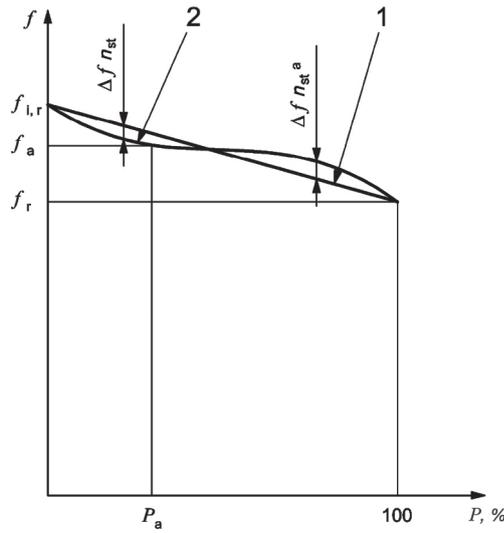
$P$      Power

$f$      Frequency

1     Linear frequency/power characteristic curve

2     Frequency/power characteristic curve

[a]     Frequency/power characteristic deviation
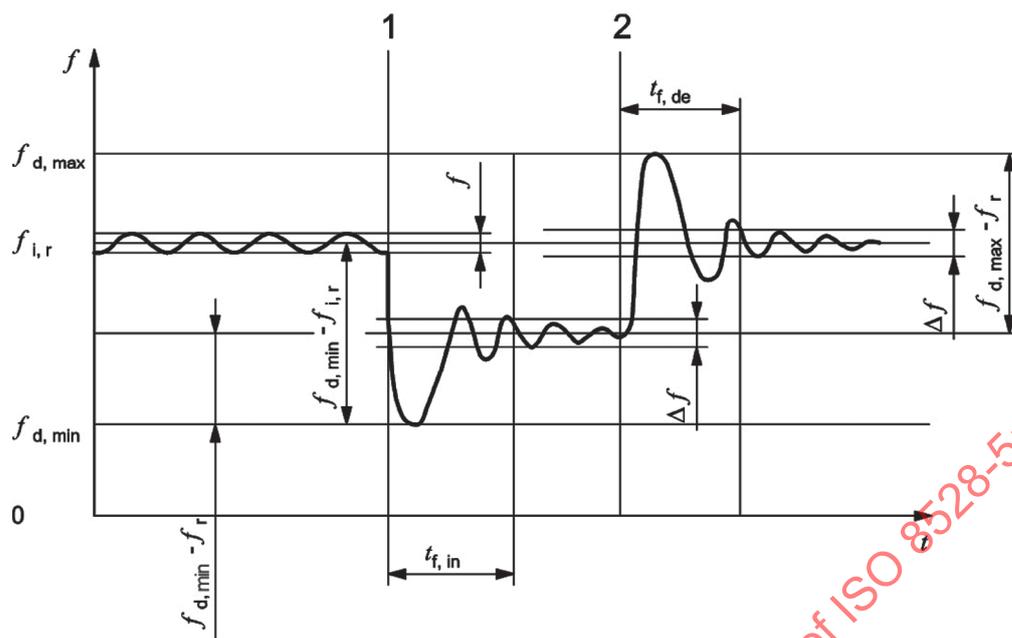
**Figure 2 — Frequency/power characteristic, deviation from the linear curve**



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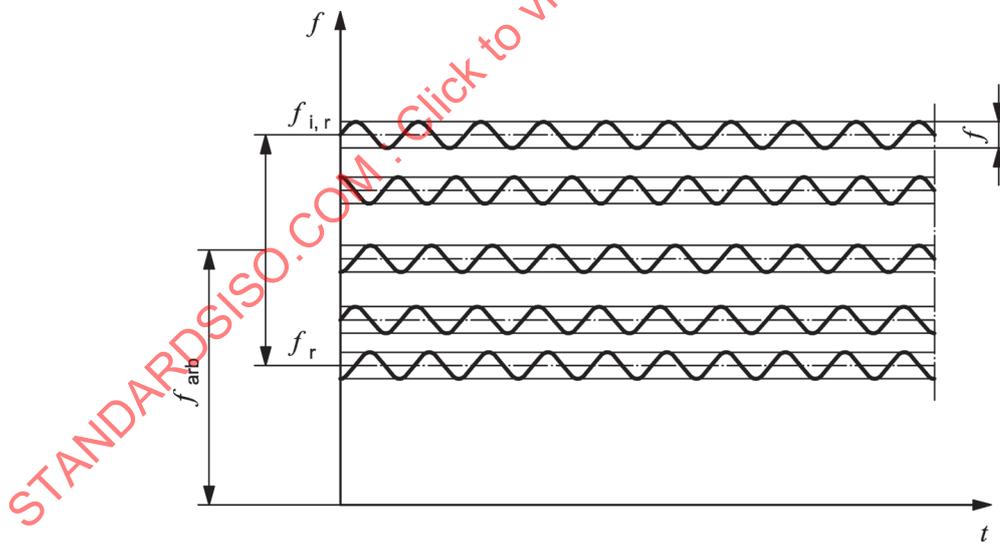
$t$      Time

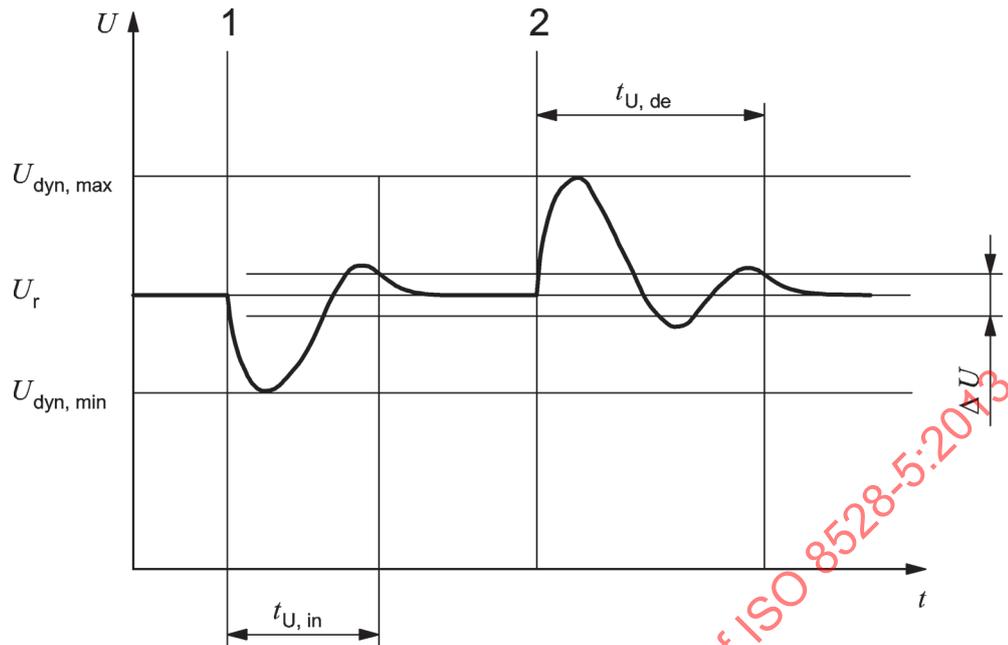$f$      Frequency

**Figure 3 — Steady-state frequency band**

**13**

**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

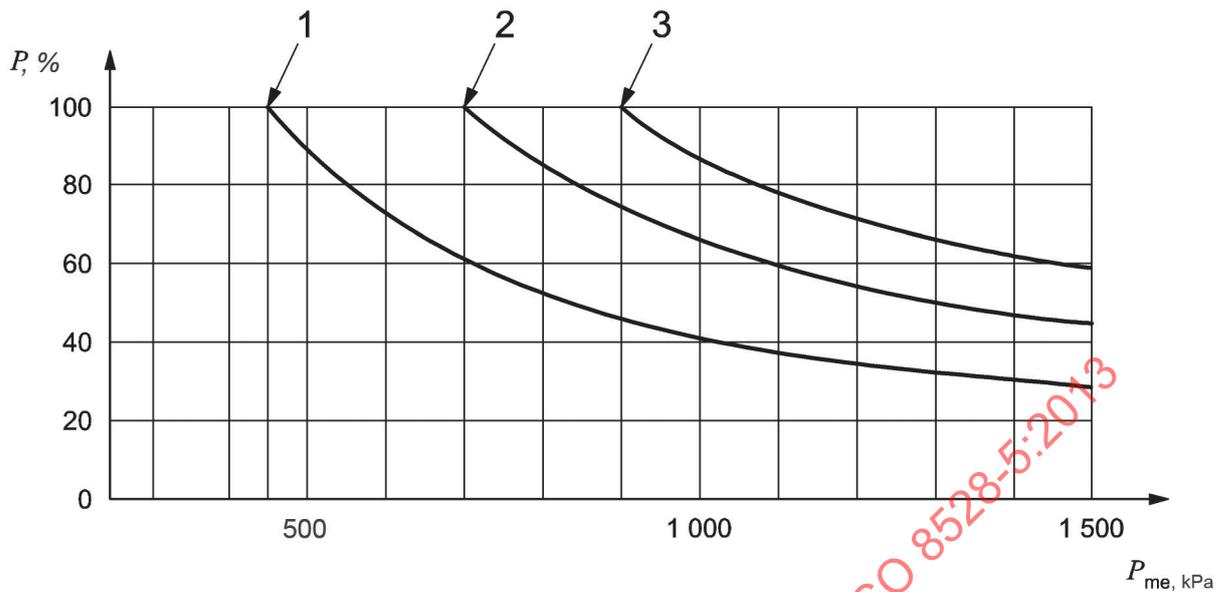i) if appropriate, the behaviour in case of parallel operation.
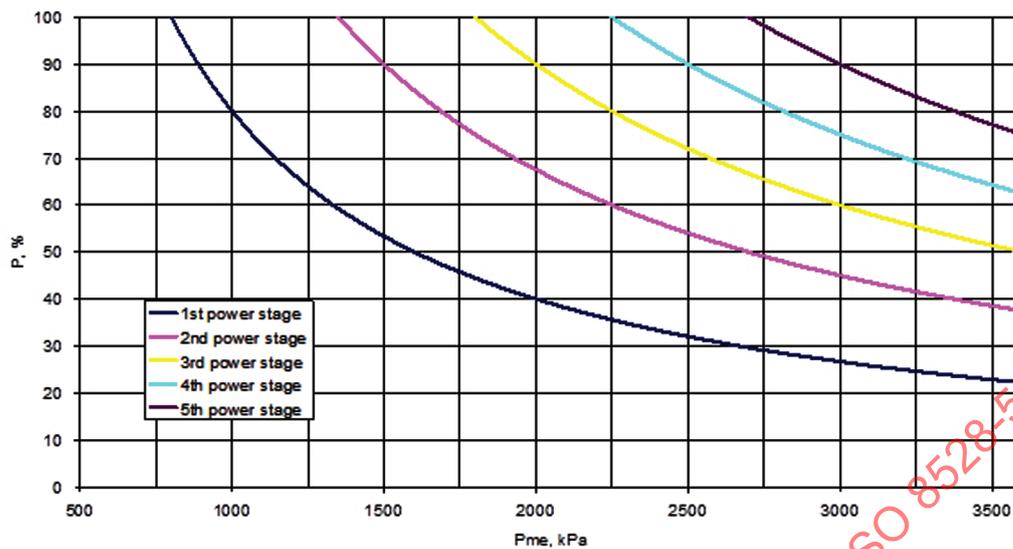
**Key**

$p_{me}$  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 $\delta_s$ 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)
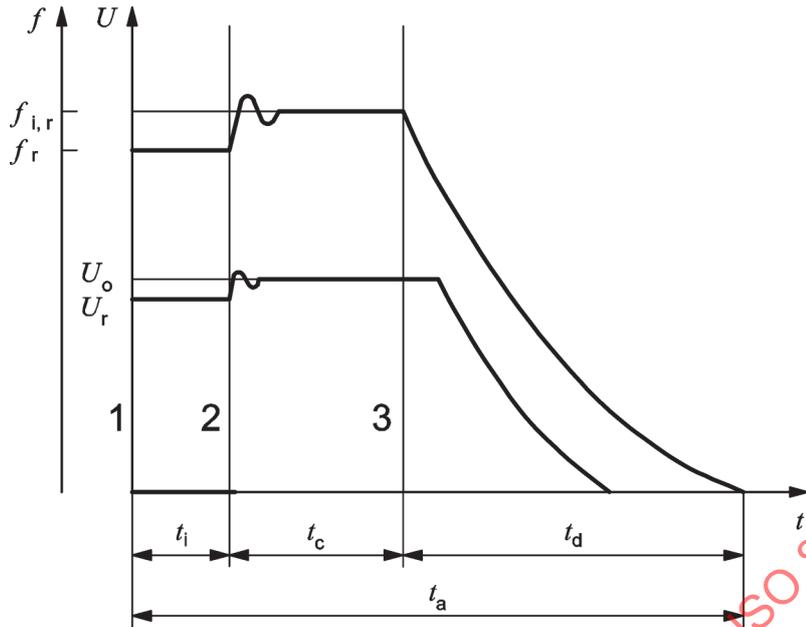
## 11 Starting characteristics

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**
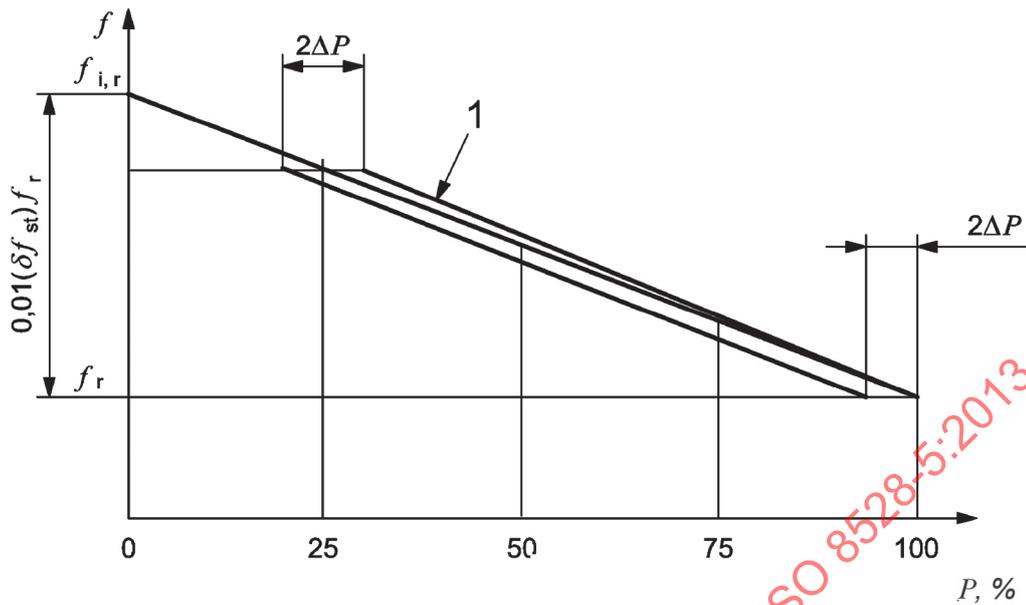
P   power

f   frequency

1   tolerance band

**Figure 10 — Power sharing in parallel running**

### 13.1.2 Calculation method

The difference, $\Delta P_i$, 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:

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

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;

$\Sigma P_j$   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, 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 $\varphi$ = 0,8.

**Table 2 — Examples of active power sharing**

| Example | Genset | Related power $P_{r,i}$ | $\sum_{j=1}^{n} P_{r,j}$ | Partial power $P_i$ | $\sum_{j=1}^{n} P_j$ | $P_{i,p} = \dfrac{P_i}{P_{r,i}}$ | $P_{s,p} = \dfrac{\sum_{j=1}^{n} P_j}{\sum_{j=1}^{n} P_{r,j}}$ | $\Delta P_i$ |
|---|---|---|---|---|---|---|---|---|
| | | kW | kW | kW | kW | % | % | % |
| 1 | 1 | 400 | | 275 | | 68,7 | | − 6,3 |
| | 2 | 400 | 1200 | 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 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 ($\delta_{QCC}$);

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, $\Delta Q_i$, 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:

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

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;

$\Sigma Q_j$     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 $\varphi$ = 0,8.

Table 3 — Examples of reactive power sharing

| Example | Genset | Rated reactive power $Q_{r,i}$ | $\sum\limits_{j=1}^{n} Q_{r,j}$ | Partial reactive power $Q_i$ | $\sum\limits_{j=1}^{n} Q_j$ | $\dfrac{Q_i}{Q_{r,i}} \times 100$ | $\dfrac{\sum\limits_{j=1}^{n} Q_j}{\sum\limits_{j=1}^{n} Q_{r,j}} \times 100$ | $\Delta Q_i$ |
|---|---|---|---|---|---|---|---|---|
| | | kvar | kvar | kvar | kvar | % | % | % |
| 1 | 1 | 300 | | 206 | | 68,7 | | − 6,3 |
| | 2 | 300 | 900 | 225 | 675 | 75 | 75 | 0 |
| | 3 | 300 | | 244 | | 81,3 | | + 6,3 |
| 2 | 1 | 300 | | 251 | | 83,7 | | + 8,7 |
| | 2 | 225 | 675 | 158 | 507 | 70,2 | 75 | − 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 ($\delta_{QCC}$) 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.
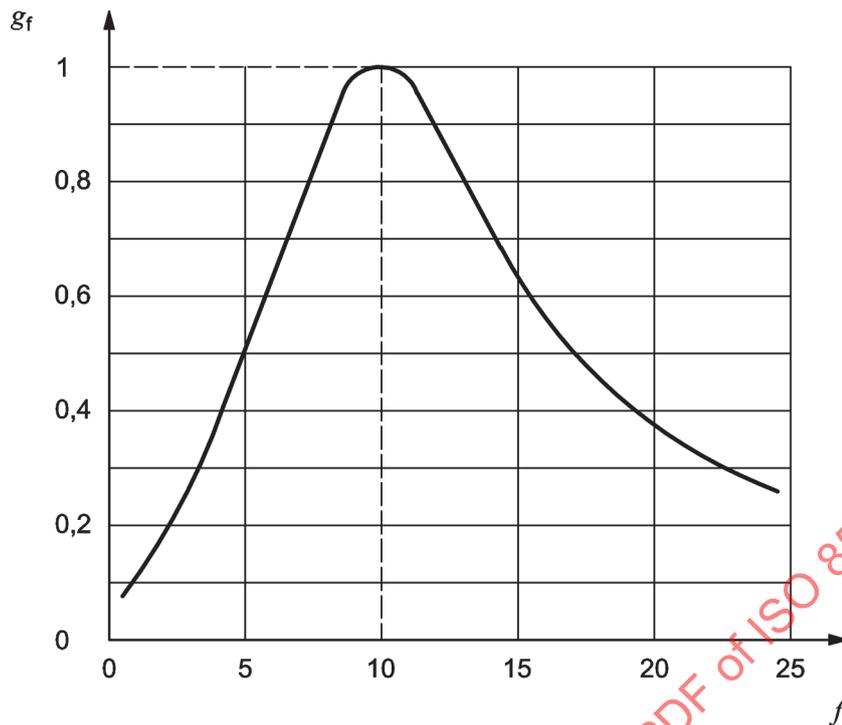
NOTE 3    Information related to the maximum side altitude above sea level (m) and the maximum site ambient temperature (C°) are not relevant for the rating plate but can be made available in a technical documentation.
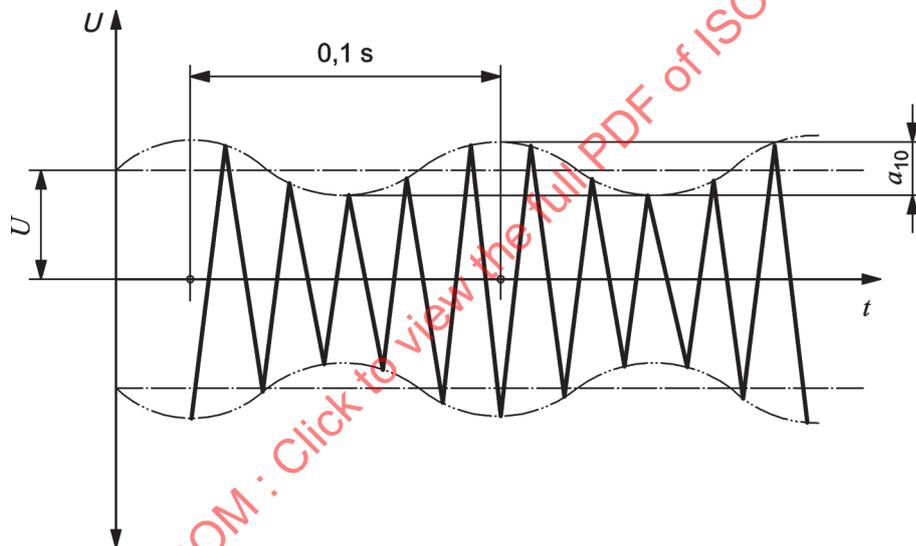


**Key**

$t$    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    [    ] <br> [    ] | | 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).

    