

INTERNATIONAL STANDARD

ISO
8528-5

First edition
1993-04-15

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 8528-5:1993(E)

Foreword

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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.

International Standard ISO 8528-5 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*, Sub-Committee SC 2, *Performance and tests*.

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: Low-power general-purpose generating sets*
- *Part 9: Measurement and evaluation of mechanical vibration*

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International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

- *Part 10: Measurement of airborne noise — Enveloping surface method*
- *Part 11: Security generating sets with uninterruptible power systems*

Parts 7, 8, 9 and 10 are in course of preparation. Part 11 is at an early stage of preparation and may be split into two parts.

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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 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 (for example, essential hospital supplies, high-rise buildings, etc.) supplementary requirements may be necessary. The provisions of this part of ISO 8528 should be regarded as a basis.

For generating sets driven by other reciprocating-type prime movers (e.g. sewage gas engines, steam engines), the provisions of this part of ISO 8528 should be used as a basis.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 8528. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 8528 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 3046-4:1978, *Reciprocating internal combustion engines — Performance — Part 4: Speed governing.*

ISO 3046-5:1978, *Reciprocating internal combustion engines — Performance — Part 5: Torsional vibrations.*

ISO 8528-1:1993, *Reciprocating internal combustion engine driven alternating current generating sets — Part 1: Application, ratings and performance.*

ISO 8528-2:1993, *Reciprocating internal combustion engine driven alternating current generating sets — Part 2: Engines.*

ISO 8528-3:1993, *Reciprocating internal combustion engine driven alternating current generating sets — Part 3: Alternating current generators for generating sets.*

IEC 34-1:1983, *Rotating electrical machines — Part 1: Rating and performance.*

3 Symbols

NOTE 1 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.

f_d	Dynamic frequency (frequency deviation)
$f_{d,max}$	Maximum transient frequency rise
$f_{d,min}$	Maximum transient frequency drop
f_{do}	Operating frequency of overfrequency limiting device
f_{ds}	Setting frequency of overfrequency limiting device
f_i	No-load frequency
$f_{i,r}$	Rated no-load frequency
f_{max}	Maximum permissible frequency
f_r	Declared frequency (rated frequency)
$f_{i,max}$	Maximum no-load frequency
$f_{i,min}$	Minimum no-load frequency
f_{arb}	Frequency at actual power
f_{ov}	Overload frequency
$\hat{f}_v$	Width of frequency oscillation
I_k	Sustained short-circuit current
t	Time
t_a	Total stopping time
t_b	Load pick-up readiness time
t_c	Off-load run-on time
t_d	Run-down time
t_e	Load pick-up time
$t_{f,de}$	Frequency recovery time after load decrease
$t_{f,in}$	Frequency recovery time after load increase
t_g	Total run-up time
t_h	Run-up time
t_i	On-load run-on time
t_p	Start preparation time
t_s	Load switching time
t_u	Interruption time
t_U	Voltage recovery time
$t_{U,de}$	Voltage recovery time after load decrease
$t_{U,in}$	Voltage recovery time after load increase

t_v	Start delay time
t_z	Cranking time
t_0	Pre-lubricating time
v_f	Rate of change of frequency setting
v_U	Rate of change of voltage setting
$U_{s,do}$	Downward adjustable voltage
$U_{s,up}$	Upward adjustable voltage
U_r	Rated voltage
U_{rec}	Recovery voltage
U_s	Set voltage
$U_{st,max}$	Maximum steady-state voltage deviation
$U_{st,min}$	Minimum steady-state voltage deviation
U_0	No-load voltage
$U_{dyn,max}$	Maximum upward transient voltage on load decrease
$U_{dyn,min}$	Minimum downward transient voltage on load increase
$\hat{U}_{max,s}$	Maximum peak value of set voltage
$\hat{U}_{min,s}$	Minimum peak value of set voltage
$\hat{U}_{mean,s}$	Average value of the maximum and minimum peak value of set voltage
$\hat{U}_{mod,s}$	Voltage modulation
$\hat{U}_{mod,s,max}$	Maximum peak of voltage modulation
$\hat{U}_{mod,s,min}$	Minimum peak of voltage modulation
$\hat{U}_v$	Width of voltage oscillation
Δf_{neg}	Downward frequency deviation from linear curve
Δf_{pos}	Upward frequency deviation from linear curve
Δf	Steady-state frequency tolerance band
Δf_c	Frequency deviation from a linear curve
Δf_s	Range of frequency setting
$\Delta f_{s,do}$	Downward range of frequency setting
$\Delta f_{s,up}$	Upward range of frequency setting
ΔU	Steady-state voltage tolerance band
ΔU_s	Range of voltage setting
$\Delta U_{s,do}$	Downward range of voltage setting
$\Delta U_{s,up}$	Upward range of voltage setting
$\Delta \delta f_{st}$	Frequency/power characteristic deviation
α_U	Related steady-state voltage tolerance band

α_f	Related frequency tolerance band
β_f	Steady-state frequency band
δf_d	Transient frequency difference (from initial frequency) [see 5.3.3]
δU_{dyn}	Transient voltage deviation
δf_{dyn}	Transient frequency deviation (from rated frequency) [see 5.3.4]
δf_s	Related range of frequency setting
$\delta f_{s,do}$	Related downward range of frequency setting
$\delta f_{s,up}$	Related upward range of frequency setting
δf_{st}	Frequency droop
δ_{QCC}	Grade of quadrature-current compensation droop
δ_s	Cyclic irregularity
δf_{lim}	Overfrequency setting ratio
δU_{st}	Steady-state voltage deviation
δU_s	Related range of voltage setting
$\delta U_{s,do}$	Related downward range of voltage setting
$\delta U_{s,up}$	Related upward range of voltage setting
$\delta U_{2,0}$	Voltage unbalance

4 Other regulations and additional requirements

4.1 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 shall be stated by the customer prior to placing of the order.

For a.c. generating sets operating in non-classed equipment, such additional requirements are in each case subject to agreement between the manufacturer and customer.

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

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

5 Frequency characteristics

The 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 (for example on the engine torque characteristics, including type of turbocharging system, the characteristics of the load, the inertias, the damping, etc.; see 5.3) and thus on the individual design of all the relevant components. The dynamic frequency behaviour of the generating set may be related directly to the generator speed.

Terms, symbols and definitions for frequency characteristics are given in 5.1 to 5.3.

5.1 Steady-state frequency behaviour

No.	Term	Symbol	Definition
5.1.1	Frequency droop	δf_{st}	Frequency difference between rated no-load frequency and the rated frequency f_r at declared power expressed as a percentage of rated frequency at fixed frequency setting (see figure 1): $\delta f_{st} = \frac{f_{i,r} - f_r}{f_r} \times 100$
5.1.2	Frequency/power characteristic curve	—	Curve of steady-state frequencies in the power range between no-load and declared power, plotted against active power of the generating set (see figure 2).
5.1.3	Frequency/power characteristic deviation	$\Delta \delta f_{st}$	Maximum deviation from a linear frequency/power characteristic curve in the power range between no-load and declared power, expressed as a percentage of rated frequency (see figure 2): $\Delta \delta f_{st} = \frac{\Delta f}{f_r} \times 100$
5.1.4	Steady-state frequency band	β_f	Envelope width oscillation $\hat{f}$ of generating set frequency at constant power around a mean value, expressed as a percentage of rated frequency: $\beta_f = \frac{\hat{f}}{f_r} \times 100$ 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 may show higher values (see figure 3), but should allow synchronization.

5.2 Frequency-setting parameters

No.	Term	Symbol	Definition
5.2.1	Range of frequency setting	Δf_s	The range between the highest and lowest adjustable no-load frequencies (see figure 1): $\Delta f_s = f_{i,max} - f_{i,min}$
	Related range of frequency setting	δf_s	Range of frequency setting, expressed as a percentage of rated frequency: $\delta f_s = \frac{f_{i,max} - f_{i,min}}{f_r} \times 100$

No.	Term	Symbol	Definition
5.2.1.1	Downward range of frequency setting	$\Delta f_{s,do}$	Range between the declared no-load frequency and the lowest adjustable no-load frequency (see figure 1): $\Delta f_{s,do} = f_{i,r} - f_{i,min}$
	Related downward range of frequency setting	$\delta f_{s,do}$	Range of downward frequency setting expressed as a percentage of the rated frequency: $\delta f_{s,do} = \frac{f_{i,r} - f_{i,min}}{f_r} \times 100$
5.2.1.2	Upward range of frequency setting	$\Delta f_{s,up}$	Range between the highest adjustable no-load frequency and the declared no-load frequency (see figure 1): $\Delta f_{s,up} = f_{i,max} - f_{i,r}$
	Related upward range of frequency setting	$\delta f_{s,up}$	Range of upward frequency setting expressed as a percentage of the rated frequency: $\delta f_{s,up} = \frac{f_{i,max} - f_{i,r}}{f_r} \times 100$
5.2.2	Rate of change of frequency setting	v_f	Rate of change of frequency setting under remote control expressed as a percentage of related range of frequency setting per second: $v_f = \frac{(f_{i,max} - f_{i,min})/f_r}{t} \times 100$

5.3 Dynamic frequency behaviour (see figure 4)

No.	Term	Symbol	Definition
5.3.1	Maximum transient frequency rise (overshoot frequency)	$f_{d,max}$	Maximum frequency which occurs on sudden change from a higher to a lower power. NOTE — The symbol is different from that given in ISO 3046-4.
5.3.2	Maximum transient frequency drop (undershoot frequency)	$f_{d,min}$	Minimum frequency which occurs on sudden change from a lower to a higher power. NOTE — The symbol is different from that given in ISO 3046-4.
5.3.3	Transient frequency difference (from initial frequency) on load increase (–) and on load decrease (+), respectively	δf_d δf_d^- δf_d^+	Temporary frequency difference 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: $\delta f_d^- = \frac{f_{d,min} - f_{arb}}{f_r} \times 100$ $\delta f_d^+ = \frac{f_{d,max} - f_{arb}}{f_r} \times 100$ (A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.) NOTE — The operating limit values given in 16.6 and 16.7 are valid only for $f_{arb} = f_i$ in the case of increasing load, and for $f_{arb} = f_r$ in the case of decreasing load.

No.	Term	Symbol	Definition
5.3.4	Transient frequency deviation (from rated frequency) on load increase (–) and on load decrease (+), respectively	δf_{dyn} δf_{dyn}^- δf_{dyn}^+	Temporary frequency difference between undershoot (or overshoot) frequency and rated frequency during the governing process following a sudden load change, relative to rated frequency, expressed as a percentage: $\delta f_{dyn}^- = \frac{f_{d,min} - f_r}{f_r} \times 100$ $\delta f_{dyn}^+ = \frac{f_{d,max} - f_r}{f_r} \times 100$ Transient frequency deviation shall therefore be in the allowable consumer frequency tolerance and shall be particularly stated. (A minus sign relates to an undershoot after a load increase, and a plus sign to an overshoot after a load decrease.)
5.3.5	Frequency recovery time	$t_{f, in}$ $t_{f, de}$	The time interval between the departure from the steady-state frequency band after a sudden specified load change and the permanent re-entry of the frequency into the specified steady-state frequency tolerance band (see figure 4).
5.3.6	Steady-state frequency tolerance band	Δf	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.
	Related frequency tolerance band	α_f	This tolerance band usually is expressed as a percentage of the rated frequency: $\alpha_f = \frac{\Delta f}{f_r} \times 100$

6 Overfrequency characteristics

The terms, symbols and definitions for overfrequency characteristics are given in 6.1 to 6.4.

No.	Term	Symbol	Definition
6.1	Maximum permissible frequency ¹⁾	f_{max}	A frequency specified by the generating set manufacturer which lies a safe amount below the frequency limit (see also ISO 8528-2:1993, 6.5.1).
6.2	Setting frequency of overfrequency limiting device	f_{ds}	The frequency of the generating set, the exceeding of which activates the overfrequency limiting device. NOTE — In practice, instead of the value for the setting frequency, the value for the permissible overfrequency is stated (see also ISO 8528-2:1993, 6.5.2).
6.3	Overfrequency setting ratio	δf_{lim}	Difference between the setting frequency of the overfrequency limiting device and the rated frequency divided by the rated frequency, expressed as a percentage: $\delta f_{lim} = \frac{f_{ds} - f_r}{f_r} \times 100$
6.4	Operating frequency of overfrequency limiting device ²⁾	f_{do}	The frequency at which, for a given setting frequency, the overfrequency limiting device starts to operate.

1) The frequency limit (see also ISO 8528-2:1993, figure 3) is the calculated frequency which the engine and generator of the generating set may sustain without risk of damage.

2) 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.

7 Voltage characteristics (see figure 5)

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 may also influence the generator voltage.

The terms, symbols and definitions of voltage characteristics are given in 7.1 to 7.3.

7.1 Steady-state voltage behaviour

No.	Term	Symbol	Definition
7.1.1	Rated voltage	U_r	Line-to-line voltage at the terminals of the generator at rated frequency and at rated output. NOTE — Rated voltage is the voltage assigned by the manufacturer for operating and performance characteristics.
7.1.2	Set voltage	U_s	Line-to-line voltage for defined operation selected by adjustment.
7.1.3	No-load voltage	U_0	Line-to-line voltage at the terminals of the generator at rated frequency and no-load.
7.1.4	Steady-state voltage deviation	δU_{st}	Maximum deviation from the set voltage under steady-state conditions at rated frequency for all powers between no-load and rated output and at specified power factor, taking into account the influence of temperature rise. The steady-state voltage deviation is expressed as a percentage of the rated voltage: $\delta U_{st} = \pm \frac{U_{st,max} - U_{st,min}}{2U_r} \times 100$
7.1.5	Voltage unbalance	$\delta U_{2,0}$	Ratio of the negative-sequence or the zero-sequence voltage components to the positive-sequence voltage components at no-load. Voltage unbalance is expressed as a percentage of rated voltage.

7.2 Voltage setting characteristics

No.	Term	Symbol	Definition
7.2.1	Range of voltage setting	ΔU_s	Range of maximum possible upward 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: $\Delta U_s = \Delta U_{s,up} + \Delta U_{s,do}$
	Related range of voltage setting	δU_s	Range of voltage setting expressed as a percentage of the rated voltage: $\delta U_s = \frac{\Delta U_{s,up} + \Delta U_{s,do}}{U_r} \times 100$

No.	Term	Symbol	Definition
7.2.2	Downward range of voltage setting	$\Delta U_{s,do}$	Range between the rated voltage and downward adjustment of voltage at the generator terminals at rated frequency, for all loads between no-load and rated output and within the agreed range of power factor: $\Delta U_{s,do} = U_r - U_{s,do}$
	Related downward range of voltage setting	$\delta U_{s,do}$	Downward range of voltage setting expressed as a percentage of the rated voltage: $\delta U_{s,do} = \frac{U_r - U_{s,do}}{U_r} \times 100$
7.2.3	Upward range of voltage setting	$\Delta U_{s,up}$	Range between the rated voltage and upward adjustment of voltage at the generator terminals at rated frequency, for all loads between no-load and rated output and within the agreed range of power factor: $\Delta U_{s,up} = U_{s,up} - U_r$
	Related upward range of voltage setting	$\delta U_{s,up}$	Upward range of voltage setting expressed as a percentage of the rated voltage: $\delta U_{s,up} = \frac{U_{s,up} - U_r}{U_r} \times 100$
7.2.4	Rate of change of voltage setting	v_U	Rate of change of voltage setting under remote control expressed as a percentage of the related range of voltage setting per second: $v_U = \frac{(U_{s,up} - U_{s,do})/U_r}{t} \times 100$

7.3 Dynamic voltage behaviour

No.	Term	Symbol	Definition
7.3.1	Maximum upward transient voltage on load decrease	$U_{dyn,max}$	Maximum voltage which occurs on a sudden change from a higher load to a lower load.
7.3.2	Minimum downward transient voltage on load increase	$U_{dyn,min}$	Minimum voltage which occurs on a sudden change from a lower load to a higher load.
7.3.3	Transient voltage deviation on load increase (–) and on load decrease (+), respectively	δU_{dyn}^- δU_{dyn}^+	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: $\delta U_{dyn}^- = \frac{U_{dyn,min} - U_r}{U_r} \times 100$ 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: $\delta U_{dyn}^+ = \frac{U_{dyn,max} - U_r}{U_r} \times 100$ If the load change differs from the above defined values, then the specified values and the associated power factor should be stated.

No.	Term	Symbol	Definition
7.3.4	Recovery voltage	U_{rec}	Maximum obtainable steady-state voltage for a specified load condition. NOTE — 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).
7.3.5	Voltage recovery time	t_U $t_{U, \text{in}}$ $t_{U, \text{de}}$	Time interval from the point at which a load change is initiated (t_1) until the point when the voltage returns to and remains within the specified steady-state voltage tolerance band (t_2) (see figure 5): $t_U = t_2 - t_1$
7.3.6	Steady-state voltage tolerance band	ΔU	Agreed voltage band about the steady-state voltage that the voltage reaches within a given regulating period after a specified sudden increase or decrease of load. Unless otherwise stated: $\Delta U = 2\delta U_{\text{st}} \times \frac{U_r}{100}$
	Related steady-state voltage tolerance band	α_U	This tolerance band is expressed as a percentage of the rated voltage: $\alpha_U = \frac{\Delta U}{U_r} \times 100$
7.3.7	Voltage modulation	$\hat{U}_{\text{mod},s}$	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: $\hat{U}_{\text{mod},s} = 2 \frac{\hat{U}_{\text{mod},s,\text{max}} - \hat{U}_{\text{mod},s,\text{min}}}{\hat{U}_{\text{mod},s,\text{max}} + \hat{U}_{\text{mod},s,\text{min}}} \times 100$ NOTES 1 This is a cyclic or random disturbance which may be caused by regulators, cyclic irregularity or intermittent loads. 2 Flickering lights are a special case of voltage modulation (see figures 11 and 12).

8 Sustained short-circuit current

The sustained short-circuit current, I_k , which may be important to current-operated protective devices, may 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 (see also ISO 8528-3:1993, 10.2).

9 Factors affecting generating set performance

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

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

- application,
- power requirements of the connected load,

- load power factor,
- starting characteristics of any connected electrical motors,
- diversity factor of the connected load,
- intermittent loads, and
- effect of non-linear loads.

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

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

- the turbo-charging system of the RIC engine,
- brake mean effective pressure, p_{me} , of the RIC engine at declared power,
- speed governor behaviour,
- generator design,
- alternator excitation system characteristics,
- voltage regulator behaviour, and
- rotational inertia of the whole generating set.

In order to indicate 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.

9.3 Since it is really not possible to quantify all influences regarding response to dynamic loading, recommended guide values for load application should be given, based on permissible drop in frequency. A higher brake mean effective pressure, p_{me} , usually makes loading in several steps necessary. Figures 6 and 7 show guide values for suddenly applied load steps depending on p_{me} at declared power. The customer shall therefore specify any particular load types or any load acceptance the generating set manufacturer should consider.

The times between consecutive load steps depend on the size of the RIC engine, the brake mean effective pressure, the turbo-charging system, the kind of governor, voltage regulator and the rotational inertia of the total generating set. If necessary, these times shall be agreed between the generating set manufacturer and the customer. Criteria for the required minimum rotational inertia are the permitted drop in frequency, the cyclic irregularity and, if appropriate, the behaviour in case of parallel operation.

10 Cyclic irregularity

The cyclic irregularity δ_s is the periodic fluctuation of speed caused by the irregularity of the reciprocating-type 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:

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

NOTES

2 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.

3 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 also ISO 8528-3:1993, clause 11).

11 Starting characteristics

The starting characteristics depend on several factors, for example air temperature, temperature of the RIC engine, starting air pressure, condition of starter battery, viscosity of oil, total inertia of the generating set and quality of the fuel, and the state of the starting equipment. They are subject to agreement between the customer and the generating set manufacturer (see also figure 8).

Terms, symbols and definitions of starting characteristics are given in 11.1 to 11.10.

No.	Term	Symbol	Definition
11.1	Load pick-up time	t_e	Time interval from start command until the agreed load is connected: $t_e = t_p + t_g + t_s$
11.2	Start delay time	t_v	Time interval from the appearance of the criteria initiating a start to the starting command (particularly for automatically started generating units). 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.
11.3	Interruption time	t_u	Time interval from the appearance of the criteria initiating a start until the agreed load is connected: $t_u = t_v + t_p + t_g + t_s$ $= t_v + t_e$ This time shall be particularly taken into account for automatically started generating sets (see 11.1).
11.4	Start preparation time	t_p	Time interval from the start command until the beginning of cranking.
11.5	Pre-lubricating time	t_0	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.
11.6	Cranking time	t_z	Time interval from the beginning of cranking until the firing speed of the engine is reached.
11.7	Run-up time	t_h	Time interval from the beginning of cranking until the declared speed is reached for the first time.
11.8	Total run-up time	t_g	Time interval from the beginning of cranking until ready for supplying an agreed power, taking into account a given frequency and voltage tolerance.
11.9	Load pick-up readiness time	t_b	Time interval from the start command until ready for supplying an agreed power, taking into account a given frequency and voltage tolerance: $t_b = t_p + t_g$
11.10	Load switching time	t_s	Time from readiness to take up an agreed load until this load is connected.

12 Stop time characteristics (see also figure 10)

Terms, symbols and definitions for stop time characteristics are given in 12.1 to 12.4.

No.	Term	Symbol	Definition
12.1	On-load run-on time	t_i	Time interval from a stop command being given until the load is disconnected (automatic sets).
12.2	Off-load run-on time	t_c	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".

No.	Term	Symbol	Definition
12.3	Run-down time	t_d	Time from the generating set off signal to when the generating set has come to a complete stop.
12.4	Total stopping time	t_a	Time interval from the stop command until the generating set has come to a complete stop: $t_a = t_i + t_c + t_d$

13 Parallel operation

13.1 Active power sharing (see figure 9)

13.1.1 Factors influencing active power sharing

Active power sharing may be influenced by any one or more of the following:

- the speed governor droop characteristic;
- the dynamic behaviour of the RIC engine and its speed governor;
- the dynamic behaviour of the coupling;
- the dynamic behaviour of the generator, taking into account the characteristics of the network or the consumer's equipment;
- the automatic voltage regulator characteristic.

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:

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

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;
- $\sum P_j$ is the sum of the partial active power of all parallel-operating generating sets;
- $\sum P_{r,j}$ 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 (with $\cos \varphi = 0,8$)

See table 1.

Table 1 — Examples of active power sharing

Example	Genset	Rated power $P_{r,i}$	$\sum_{j=1}^n P_{r,j}$	Partial power P_i	$\sum_{j=1}^n P_j$	$P_{i,p} = \frac{P_i}{P_{r,i}}$	$P_{s,p} = \frac{\sum_{j=1}^n P_j}{\sum_{j=1}^n P_{r,j}}$	ΔP_i
		kW	kW	kW	kW	%	%	%
1	1	400	1 200	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.

13.1.4 Method of testing

With the system operating at full rated power and with $\cos \varphi = 0,8$, make adjustments to minimize the reactive current and to share the power equally, i.e. $P_{i,p} = P_{s,p}$. Then reduce the power from 100 % to 20 % and take the greatest deviation which occurs within this power range as ΔP . Manual adjustments, for example the engine speed/governor control, are not permitted during the test.

13.2 Reactive power sharing

13.2.1 Factors influencing reactive power sharing

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

- grade of quadrature-current compensation voltage droop (δ_{QCC});
- stabilization by equalizer links;
- automatic reactive power sharing control;
- 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:

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

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;
- $\sum Q_j$ is the sum of the partial reactive power of all parallel-operating generating sets;
- $\sum Q_{r,j}$ 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:

- grade of quadrature-current compensation voltage droop;
- equalizer links;
- automatic reactive power sharing control.

13.2.3 Examples of reactive power sharing (with $\cos \phi = 0,8$)

See table 2.

Table 2 — Examples of reactive power sharing

Example	Genset	Rated reactive power $Q_{r,i}$	$\sum_{j=1}^n Q_{r,j}$	Partial reactive power Q_i	$\sum_{j=1}^n Q_j$	$Q_{i,p} = \frac{Q_i}{Q_{r,i}}$	$Q_{s,p} = \frac{\sum_{j=1}^n Q_j}{\sum_{j=1}^n Q_{r,j}}$	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 may be temporarily exceeded.

13.3 Influence on parallel-operating behaviour

The following may have influence on parallel-running behaviour:

- the speed governor droop characteristic;
- the dynamic behaviour of the RIC engine and its speed governor;
- the dynamic behaviour of the coupling;
- the dynamic behaviour of the generator, taking into account the relevant reaction of the connected mains or the other parallel-operating generators;
- the automatic voltage regulator characteristic;
- the grade of quadrature-current compensation voltage droop (δ_{QCC}) of automatic voltage regulator (AVR).

13.4 Power rating

Power rating criteria are specified in ISO 8528-1.

In parallel operation, even when there is no necessity for additional power for governing purposes (mains parallel operation), the generating set rated output should not be exceeded.

14 Rating plates

Generating sets shall bear the following rating plates.

a) Rating plate for set

This shall give at least the following information:

- 1) the words "Generating set ISO 8528";
- 2) the manufacturer's name or mark;
- 3) the serial number of the set;
- 4) the year of manufacture of the set;
- 5) the rated power, in kilowatts, with the prefixes COP, PRP or LTP, in accordance with ISO 8528-1:1993, clause 13;
- 6) the performance class in accordance with ISO 8528-1:1993, clause 7;
- 7) the rated power factor;
- 8) the maximum site altitude above sea-level, in metres;
- 9) the maximum ambient temperature, in degrees Celsius;
- 10) the rated frequency, in hertz;
- 11) the rated voltage, in volts;
- 12) the rated current, in amperes;
- 13) the mass, in kilograms.

b) Rating plate for the RIC engine

c) Rating plate for generators, in accordance with IEC 34-1 and ISO 8528-3:1993, clause 14

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

NOTES

4 Figure 13 shows an example of a rating plate for a generating set.

5 With units rated at less than 10 kW, the information may be combined on a single 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:

- mechanical (e.g. crank);

- electrical (e.g. electric starting motor);
- pneumatic (e.g. compressed air to the cylinder or pneumatic starting motor).

15.2 Shutdown methods

Depending on design and application, different shutdown methods, according to the shutdown signals, are used:

- mechanical;
- electrical;
- pneumatic;
- hydraulic.

15.3 Fuel supply

The fuel supply 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) should be taken into account. The appropriate regulations of the legislative authorities of the respective country for fuel 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.

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 may be important:

- structure-borne sound insulation;
- heat insulation and cladding (radiation, penetrations through walls, protection against contact);
- expansion compensation;
- drainage;
- prevention of water ingress;
- protection against exhaust gas explosion;
- configuration of the end of the exhaust outlet (e.g. depending on direction of wind, protection against birds);
- supports;
- gaseous emissions.

15.6 Cooling and room ventilation

The type of cooling of the RIC engine, 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. For the design of the building, the required technical data of the generating set shall be obtained from the generating set manufacturer.

15.7 Monitoring

The extent of monitoring of a power plant depends on

- the intended application;
- the mode of operation;
- the size and type of the generating set;
- requirements of the consumer's equipment;
- the manufacturer's requirements;
- 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 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 should be carried out at the manufacturer's works by a short-range field.

NOTES

6 An enveloping surface method will be given in ISO 8528-10.

7 In practice, the expensive measurements according to the long-range field measurement give no appreciable difference from those of short-range field 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 may be carried out as for mobile generating sets.

15.9 Couplings

The coupling selection shall take into account those stresses imposed by the torsional vibration influenced by

- power up to fuel stop power;
- the inertia of the RIC engine and generator;
- the short-circuit torque;
- misalignment.

The greatest short-circuit torque occurs as a result of a two-phase line-to-line short circuit at the generator terminals. In many instances, however, the ratio of generator inertia to engine inertia is so large that the torque on the coupling may be little more than, or even less than, the continuous power torque.

The generating set manufacturer is responsible for the design of the component compatibility.

15.10 Vibration

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.

15.10.1 Torsional vibration

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

The manufacturer of the set shall be responsible for ensuring that the torsional vibrations lie safely outside the range of critical values.

When previously agreed by contract, the manufacturer of the set shall be responsible for obtaining calculations and for making measurements of torsional vibrations.

The results of measurements and/or calculations of torsional vibrations shall be agreed between the manufacturer of the generating set, the RIC engine and driven machinery manufacturers and by the inspecting and/or legislative authorities and/or classification societies, when applicable.

15.10.2 Linear vibration

15.10.2.1 Dynamic bending deformation

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

15.10.2.2 Structural vibrations

15.10.2.2.1 General

Apart from the torsional and linear vibrations, there exist vibrations of the generating set caused by the reciprocating forces and torques of 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.

15.10.2.2.2 Measurement location and measurement conditions

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

15.11 Foundations

For the dimensions of the foundations or the supporting surfaces, data on static and dynamic loads may be obtained from the generating set manufacturer.

To reduce the effect of free inertia forces on the environment, a suitable resilient mounting may 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 Operating limit values for performance classes

The operating limit values listed in table 3 shall be satisfied in order to determine the characteristics of major significance for the voltage and frequency behaviour of a generating set as given in ISO 8528-1.

The numerical values for the individual performance classes shall be selected so that they are mutually matched for 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.

NOTE 8 It is recommended that the customer should select the minimum performance class that will fulfil his requirements.

Table 3 — Operating limit values

No.	Parameter	Symbol	Unit	Reference	Operating limit values			
					G1	G2	G3	G4
16.1	Frequency droop	δf_{st}	%	5.1.1	≤ 8	≤ 5	≤ 3	AMC ¹⁾
16.2	Steady-state frequency band	β_f	%	5.1.4	$\leq 2,5$	$\leq 1,5$ 2)	$\leq 0,5$	AMC
16.3	Related range of downward frequency setting	$\delta f_{s,do}$	%	5.2.1.1	$\geq (2,5 + \delta f_{st})$			
16.4	Related range of upward frequency setting	$\delta f_{s,up}$	%	5.2.1.2	$\geq + 2,5$ 3)			
16.5	Rate of change of frequency setting	γ_f	%/s	5.2.2	0,2 to 1			
16.6	Transient frequency difference from initial frequency	δf_d	%	5.3.3	$\leq + 18$	$\leq + 12$	$\leq + 10$	AMC
	100 % sudden power decrease sudden power increase ^{4) 5)}				$\leq (15 + \delta f_{st})$ 4)	$\leq -(10 + \delta f_{st})$ 4)	$\leq -(7 + \delta f_{st})$ 4)	
16.7	Transient frequency deviation from rated frequency	δf_{dyn}	%	5.3.4	$\leq + 18$	$\leq + 12$	$\leq + 10$	AMC
	100 % sudden power decrease sudden power increase ^{4) 5)}				≤ -15 4) ≤ -25 5)	≤ -10 4) ≤ -20 5)	≤ -7 4) ≤ -15 5)	
16.8	Frequency recovery time	$t_{f, in}$ $t_{f, de}$	s	5.3.5	≤ 10 6)	≤ 5 6)	≤ 3 6)	AMC
					≤ 10 4)	≤ 5 4)	≤ 3 4)	
16.9	Related frequency tolerance band	α_f	%	5.3.6	3,5	2	2	AMC
16.10	Steady-state voltage deviation	δU_{st}	%	7.1.4	$\leq \pm 5$ $\leq \pm 10$ 7)	$\leq \pm 2,5$ $\leq \pm 1$ 8)	$\leq \pm 1$	AMC
16.11	Voltage unbalance	$\delta U_{2,0}$	%	7.1.5	1 9)	1 9)	1 9)	1 9)
16.12	Range of voltage setting	δU_s	%	7.2.1	± 5			
16.13	Rate of change of voltage setting	v_U	%/s	7.2.4	0,2 to 1			
16.14	Transient voltage deviation	δU_{dyn}^+ δU_{dyn}^-	%	7.3.3	$\leq + 35$	$\leq + 25$	$\leq + 20$	AMC
	100 % sudden power decrease sudden power increase ^{4) 5)}				≤ -25 4)	≤ -20 4)	≤ -15 4)	
16.15	Voltage recovery time ¹⁰⁾	$t_{U, in}$ $t_{U, de}$	s	7.3.5	≤ 10 ≤ 10 4)	≤ 6 ≤ 6 4)	≤ 4 ≤ 4 4)	AMC
16.16	Voltage modulation ^{11) 12)}	$\hat{U}_{mod,s}$	%	7.3.7	AMC	0,3 13) 14)	0,3 14)	AMC
16.17	Active power sharing ¹⁵⁾	ΔP	%	13.1	—	$\leq \pm 5$	$\leq \pm 5$	AMC
	between 80 % and 100 % of the nominal rating between 20 % and 80 % of the nominal rating					$\leq \pm 10$	$\leq \pm 10$	

No.	Parameter	Symbol	Unit	Reference	Operating limit values			
					G1	G2	G3	G4
16.18	Reactive power sharing between 20 % and 100 % of the nominal rating	ΔQ	%	13.2	—	$\leq \pm 10$	$\leq \pm 10$	AMC

1) AMC = by agreement between manufacturer and customer.

2) In the case of generating sets with single- or two-cylinder engines, the value may be up to 2,5.

3) To the extent that parallel operation is not necessary, fixed setting of the speed or voltage is permissible.

4) For generating sets with turbo-charged engines, these data apply with use of the maximum possible power increase according to figures 6 and 7.

5) For spark-ignition gas engines.

6) 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.

7) For small units up to 10 kV·A.

8) 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 %.

9) In the case of parallel operation, reduce these values to 0,5.

10) Unless otherwise stated, the tolerance band used to calculate voltage recovery time will be equal to:

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

11) Operating limit values not included in steady-state limits.

12) 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.

13) For generating sets with single- or two-cylinder engines, the value may be ± 2 .

14) 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 $\hat{U}_{mod10} \leq 0,3 \%$.

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

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

15) When using the tolerance, the amount of the effective nominal load or nominal reactive load of the parallel-operating generating sets decreases by the tolerance value.

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

1) The power limit of the generating set depends on the power limit of the RIC engine, e.g. fuel stop power, taking into account the efficiency of the a.c. generator.

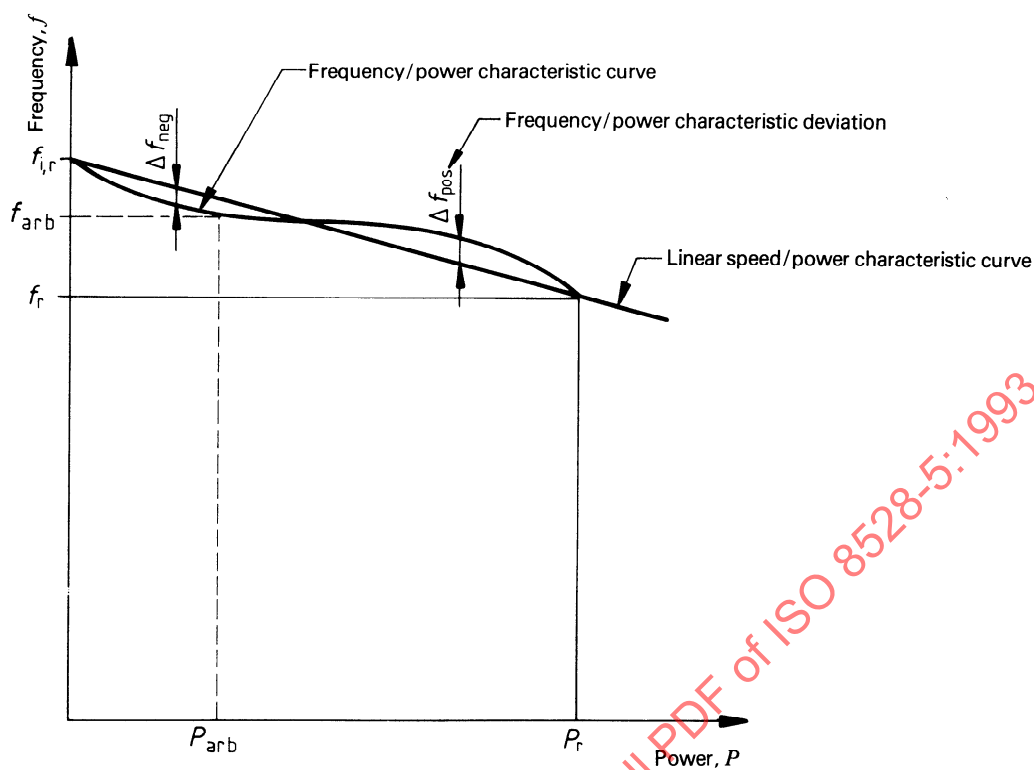


Figure 2 — Frequency/power characteristic deviation from the linear curve

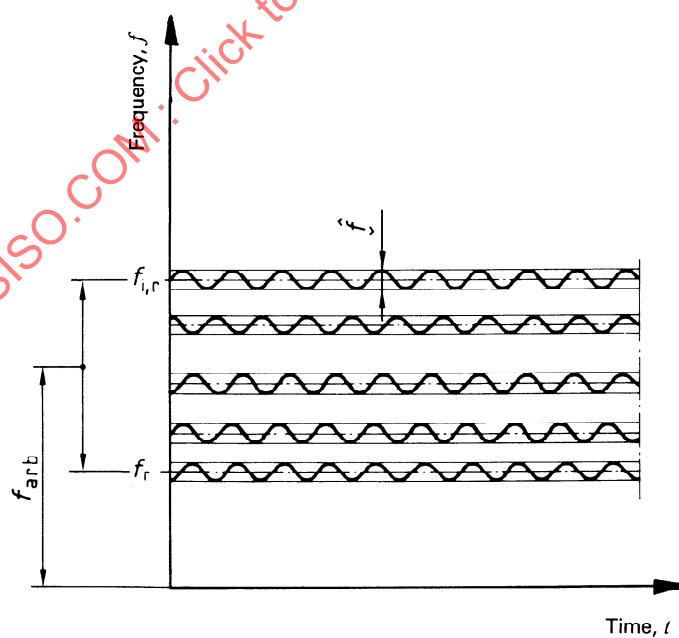


Figure 3 — Steady-state frequency band

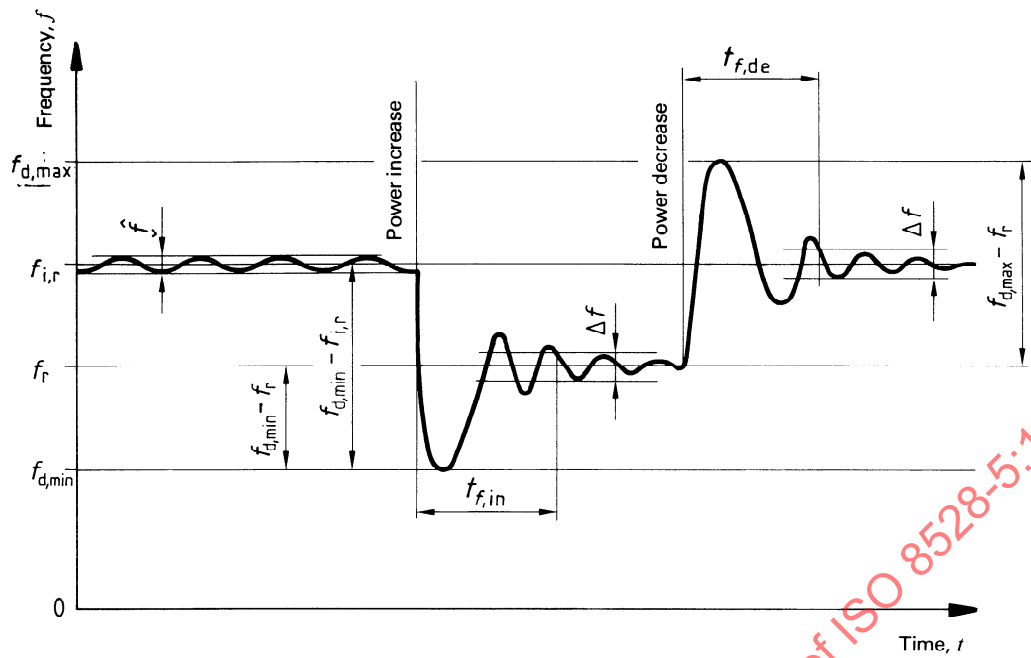


Figure 4 — Dynamic frequency behaviour

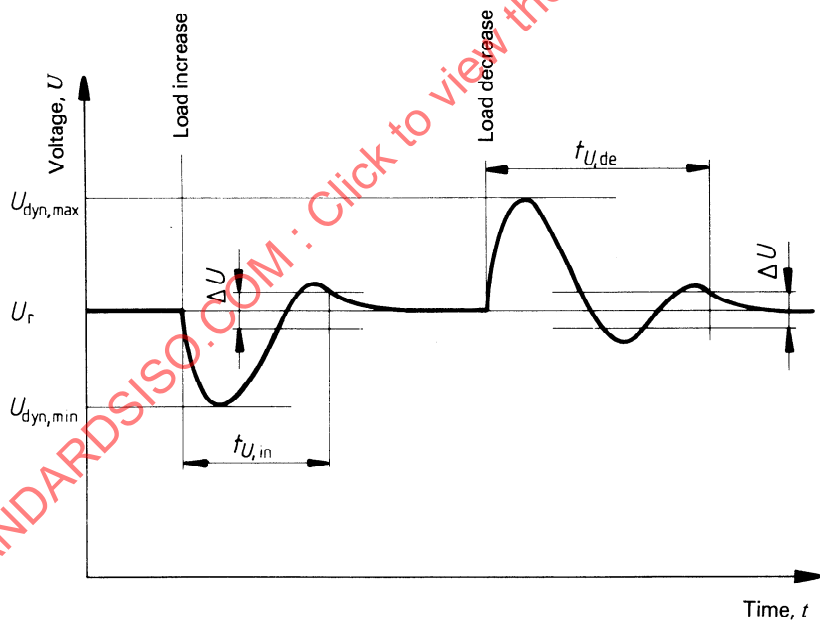


Figure 5 — Transient voltage characteristics without quadrature-current compensation voltage droop