UL 60034-1 (IEC 60034-1:2017)

STANDARD FOR SAFETY

Rotating Electrical Machines – Part 1: Rating and Performance

UL Standard for Safety for Rotating Electrical Machines – Part 1: Rating and Performance, UL 60034-1 (IEC 60034-1:2017)

Second Edition, Dated September 18, 2018

Summary of Topics

This is the Second Edition of the Standard for Rotating Electrical Machines – Part 1: Rating and Performance, UL 60034-1, which is a UL-only identical adoption of IEC 60034-1: 2017 Ed. 13

The new requirements are substantially in accordance with Proposal(s) on this subject dated July 20, 2018.

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UL 60034-1 (IEC 60034-1:2017)

Standard for Rotating Electrical Machines – Part 1: Rating and Performance

First Edition – July, 2016

Second Edition

September 18, 2018

This ANSI/UL Standard for Safety consists of the Second Edition.

The most recent designation of ANSI/UL 60034-1 as an American National Standard (ANSI) occurred on September 11, 2018. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, or Preface. The IEC Foreword is also excluded from the ANSI approval of IEC-based standards.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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Preface (UL)

This UL Standard is based on IEC Publication 60034-1: 13th edition, Rotating electrical machines – Part 1: Rating and performance. IEC publication 60034-1 is copyrighted by the IEC.

This is the UL Standard for Safety for Rotating Electrical Machines – Part 1: Rating and Performance. This UL Part 1 is to be used in conjunction with the appropriate UL Part 2, UL 60034-2-1, which contains clauses to supplement or modify the corresponding clauses in the Part 1, to provide relevant requirements for each type of product.

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Note – Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ROTATING ELECTRICAL MACHINES – Part 1: Rating and performance

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60034-1 has been prepared by IEC technical committee 2: Rotating machinery.

This thirteenth edition cancels and replaces the twelfth edition published in 2010. It constitutes a technical revision.

The main technical changes with regard to the previous edition are as follows:

Clause or subclause	Change
3.25	Shorter time to thermal equilibrium
5.5.2	Note on P-Q capability diagram for synchronous generators
6.4	Clarification added that other conditions can be agreed on
6.6	Clarification added that standstill is explicitly included; note added
7.1	Clarification on bus transfer or fast reclosing
	Capability to withstand impulse voltages in case of machines connected to a U converter
7.2.4	New Table 3 for identification code
7.3	Table 4 corrected to reflect current scope of IEC 60034-3
7.5	Voltage withstand level for machines connected to a converter
8.3.4	Measurement of ambient air temperature in case of open machines
8.6.3.4	Notes on ETD in the end windings of high voltage machines and on ETD use to monitor strand blockage in case of directly liquid cooled windings
8.10	Clarification on temperature limit
	Clarification on temperature difference between method R and method ETD
	Clarification that temperature limit acc. to method R must always be kept
	Note on measured temperature limits between methods R and ETD
	Table 8 and Table 11 extended incorporating thermal class 200 (N)
	Line 4c) of Table 8 restricted to field windings of DC machines
	Temperature limits in Table 8 changed according to 2/1737/DC and the comments received on this document
	Physically correct formula in Table 10, item 1b
9.1	Clarification on machines that are subject to routine testing
9.2	Separate withstand voltage testing of phases
	Clarification on frequency and time instant for withstand voltage test
	Note on leakage current during withstand voltage test
	Note referring to IEC 60027
10.2	Information on IVIC on rating plate or in documentation
	Clarification added to item f
	IC code and design letter for locked-rotor apparent power on rating plate
11.1	Clarification on cross-sectional area of earthing conductor for generators
	Note on grounding for small machines added
12.2	Tolerance on field current of synchronous machines added
	Tolerance on power factor applies also for PM synchronous machines operated directly at the lines
	Contradiction between tolerances on efficiency and on losses clarified
13.1	Changed as proposed by ACEC
	Note for large generators added
13.3	Changed as proposed by ACEC
13.5	Changed as proposed by ACEC
Annex B	DC power supply added

The text of this standard is based on the following documents:

FDIS	Report on voting
2/1857/FDIS	2/1863/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60034 series, published under the general title *Rotating electrical machines*, can be found on the IEC website.

NOTE A table of cross-references of all IEC TC 2 publications can be found in the IEC TC 2 dashboard on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under ″http://webstore.iec.ch″ in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

ROTATING ELECTRICAL MACHINES – Part 1: Rating and performance

1 Scope

This part of IEC 60034 is applicable to all rotating electrical machines except those covered by other IEC standards, for example, IEC 60349.

Machines within the scope of this document may also be subject to superseding, modifying or additional requirements in other standards, for example, IEC 60079 and IEC 60092.

NOTE If particular clauses of this document are modified to meet special applications, for example machines subject to radioactivity or machines for aerospace, all other clauses apply insofar as they are compatible.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60027-1, *Letter symbols to be used in electrical technology – Part 1: General*

IEC 60027-4, *Letter symbols to be used in electrical technology – Part 4: Rotating electric machines*

IEC 60034-2 (all parts), *Rotating electrical machines – Part 2: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)*

IEC 60034-3, *Rotating electrical machines – Part 3: Specific requirements for synchronous generators driven by steam turbines or combustion gas turbines*

IEC 60034-5, *Rotating electrical machines – Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP code) – Classification*

IEC 60034-6, *Rotating electrical machines – Part 6: Methods of cooling (IC code)*

IEC 60034-8, *Rotating electrical machines – Part 8: Terminal markings and direction of rotation*

IEC 60034-12:2016, *Rotating electrical machines – Part 12: Starting performance of singlespeed three-phase cage induction motors*

IEC 60034-15, *Rotating electrical machines – Part 15: Impulse voltage withstand levels of form-wound stator coils for rotating a.c. machines*

IEC 60034-18 (all parts), *Rotating electrical machines – Part 18: Functional evaluation of insulation systems*

IEC 60034-18-41, *Rotating electrical machines – Part 18-41: Partial discharge free electrical insulation systems (Type I) used in rotating electrical machines fed from voltage converters – Qualification and quality control tests*

IEC TS 60034-25, *Rotating electrical machines – Part 25: AC electrical machines used in power drive systems – Application guide*

IEC 60034-29, *Rotating electrical machines – Part 29: Equivalent loading and superposition techniques – Indirect testing to determine temperature rise*

IEC 60034-30-1, *Rotating electrical machines – Part 30-1: Efficiency classes of line operated A.C. motors (IE-code)*

IEC 60038, *IEC standard voltages*

IEC 60050-411:1996, *International Electrotechnical Vocabulary (IEV) – Chapter 411: Rotating machines*

IEC 60060-1, High-voltage test techniques – Part 1: General definitions and test requirements

IEC 60072 (all parts), *Dimensions and output series for rotating electrical machines*

IEC 60085, *Electrical insulation – Thermal evaluation and designation*

IEC 60204-1, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

IEC 60204-11, *Safety of machinery – Electrical equipment of machines – Part 11: Requirements for HV equipment for voltages above 1 000 V a.c. or 1 500 V d.c. and not exceeding 36 kV*

IEC 60335-1:2010, *Household and similar electrical appliances – Safety – Part 1: General requirements*

IEC 60445, *Basic and safety principles for man-machine interface, marking and identification – Identification of equipment terminals, conductor terminations and conductors*

IEC 60664-1, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 61148, *Terminal markings for valve device stacks and assemblies and for power conversion equipment*

IEC 61293, *Marking of electrical equipment with ratings related to electrical supply – Safety requirements*

CISPR 11, *Industrial, scientific and medical equipment – Radiofrequency disturbance characteristics – Limits and methods of measurement*

CISPR 14 (all parts), *Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus*

CISPR 16 (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods*

3 Terms and definitions

For the purposes of this document, the terms and definitions in IEC 60050-411, some of which are repeated here for convenience, and the following apply.

NOTE 1 For definitions concerning cooling and coolants, other than those in 3.17 to 3.22, see IEC 60034-6.

NOTE 2 For the purposes of this document, the term ‘agreement’ means ‘agreement between the manufacturer and purchaser’.

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

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

- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
rated value
quantity value assigned, generally by a manufacturer, for a specified operating condition of a machine

Note 1 to entry: The rated voltage or voltage range is the rated voltage or voltage range between lines at the terminals.

[SOURCE: IEC 60050-411:1996, 411-51-23]

3.2
rating
set of rated values and operating conditions

[SOURCE: IEC 60050-411:1996, 411-51-24]

3.3
rated output
value of the output included in the rating

3.4
load
all the values of the, *in case of a generator*, electrical and, *in case of a motor*, mechanical quantities that signify the demand made on a rotating machine by an electrical circuit or a mechanism at a given instant

[SOURCE: IEC 60050-411:1996, 411-51-01, modified:modification indicated in italics]

3.5
no-load <operation>
state of a machine rotating with zero output power *(but under otherwise normal operating conditions)*

[SOURCE: IEC 60050-411:1996, 411-51-02, modified: modification indicated in italics]

3.6
full load
load which causes a machine to operate at its rating

[SOURCE: IEC 60050-411:1996, 411-51-10]

3.7
full load value
quantity value for a machine operating at full load

Note 1 to entry: This concept applies to power, torque, current, speed, etc.

[SOURCE: IEC 60050-411:1996, 411-51-11]

3.8
de-energized and rest
complete absence of all movement and of all electrical supply or mechanical drive

[SOURCE: IEC 60050-411:1996, 411-51-03]

3.9
duty
statement of the load(s) to which the machine is subjected, including, if applicable, starting, electric braking, no-load and rest and de-energized periods, and including their durations and sequence in time

[SOURCE: IEC 60050-411:1996, 411-51-06]

3.10
duty type
continuous, short-time or periodic duty, comprising one or more loads remaining constant for the duration specified, or a non-periodic duty in which generally load and speed vary within the permissible operating range

[SOURCE: IEC 60050-411:1996, 411-51-13]

3.11
cyclic duration factor
ratio between the period of loading, including starting and electric braking, and the duration of the duty cycle, expressed as a percentage

[SOURCE: IEC 60050-411:1996, 411-51-09]

3.12
locked-rotor torque
smallest measured torque the motor develops at its shaft and with the rotor locked, over all its angular positions, at rated voltage and frequency

[SOURCE: IEC 60050-411:1996, 411-48-06]

3.13
locked-rotor current
greatest steady-state r.m.s. current taken from the line with the motor held at rest, over all angular positions of its rotor, at rated voltage and frequency

[SOURCE: IEC 60050-411:1996, 411-48-16]

3.14
pull-up torque <of an a.c. motor>
smallest steady-state asynchronous torque which the motor develops between zero speed and the speed which corresponds to the breakdown torque, when the motor is supplied at the rated voltage and frequency

Note 1 to entry: This definition does not apply to those asynchronous motors of which the torque continually decreases with increase in speed.

Note 2 to entry: In addition to the steady-state asynchronous torques, harmonic synchronous torques, which are a function of rotor load angle, will be present at specific speeds.

At such speeds, the accelerating torque may be negative for some rotor load angles.

Experience and calculation show this to be an unstable operating condition and therefore harmonic synchronous torques do not prevent motor acceleration and are excluded from this definition.

3.15
breakdown torque <of an a.c. motor>
maximum steady-state asynchronous torque which the motor develops without an abrupt drop in speed, when the motor is supplied at the rated voltage and frequency

Note 1 to entry: This definition does not apply to motors with torques that continually decrease with increase in speed.

3.16
pull-out torque <of a synchronous motor>
maximum torque which the synchronous motor develops at synchronous speed with rated voltage, frequency and field current

3.17
cooling
procedure by means of which heat resulting from losses occurring in a machine is given up to a primary coolant, which may be continuously replaced or may itself be cooled by a secondary coolant in a heat exchanger

[SOURCE: IEC 60050-411:1996, 411-44-01]

3.18
coolant
medium, liquid or gas, by means of which heat is transferred

[SOURCE: IEC 60050-411:1996, 411-44-02]

3.19
primary coolant
medium, liquid or gas, which, being at a lower temperature than a part of a machine and in contact with it, removes heat from that part

[SOURCE: IEC 60050-411:1996, 411-44-03]

3.20
secondary coolant
medium, liquid or gas, which, being at a lower temperature than the primary coolant, removes the heat given up by this primary coolant by means of a heat exchanger or through the external surface of the machine

[SOURCE: IEC 60050-411:1996, 411-44-04]

3.21
direct cooled winding
inner cooled winding
winding mainly cooled by coolant flowing in direct contact with the cooled part through hollow conductors, tubes, ducts or channels which, regardless of their orientation, form an integral part of the winding inside the main insulation

Note 1 to entry: In all cases when ‘indirect’ or ‘direct’ is not stated, an indirect cooled winding is implied.

[SOURCE: IEC 60050-411:1996, 411-44-08]

3.22
indirect cooled winding
any winding other than a direct cooled winding

Note 1 to entry: In all cases when ‘indirect’ or ‘direct’ is not stated, an indirect cooled winding is implied.

[SOURCE: IEC 60050-411:1996, 411-44-09]

3.23
supplementary insulation
independent insulation applied in addition to the main insulation in order to ensure protection against electric shock in the event of failure of the main insulation

3.24
moment of inertia
sum (integral) of the products of the mass elements of a body and the squares of their distances (radii) from a given axis

3.25
thermal equilibrium
state reached when the temperature rises of the several parts of the machine do not vary by more than a gradient of *1 K per half hour*

Note 1 to entry: Thermal equilibrium may be determined from the time-temperature rise plot when the straight lines between points at the beginning and end of two successive intervals of half hour each have a gradient of 1 K or less per half hour or 2 K or less per hour.

[SOURCE: IEC 60050-411:1996, 411-51-08, modified: modification indicated in italics]

3.26
thermal equivalent time constant
time constant, replacing several individual time constants, which determines approximately the temperature course in a winding after a step-wise current change

3.27
encapsulated winding
winding which is completely enclosed or sealed by moulded insulation

[SOURCE: IEC 60050-411:1996, 411-39-06]

3.28
rated form factor of direct current supplied to a d.c. motor armature from a static power converter
ratio of the r.m.s. maximum permissible value of the current $I_{rms,maxN}$ to its average value I_{avN} (mean value integrated over one period) at rated conditions:

$$k_{fN} = \frac{I_{rms,\ maxN}}{I_{avN}}$$

3.29
current ripple factor
ratio of the difference between the maximum value I_{max} and the minimum value I_{min} of an undulating current to two times the average value I_{av} (mean value integrated over one period):

$$q_i = \frac{I_{max} - I_{min}}{2 \times I_{av}}$$

Note 1 to entry: For small values of current ripple, the ripple factor may be approximated by the following expression:

$$q_i = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

Note 2 to entry: The above expression may be used as an approximation if the resulting calculated value of q_i is equal to or less than 0,4.

3.30
tolerance
permitted deviation between the declared value of a quantity and the measured value

3.31
type test
test of one or more machines made to a certain design to show that the design meets certain specifications

Note 1 to entry: The type test may also be considered valid if it is made on a machine which has minor deviations of rating or other characteristics. These deviations should be subject to agreement.

[SOURCE: IEC 60050-411:1996, 411-53-01]

3.32
routine test
test to which each individual machine is subjected during or after manufacture to ascertain whether it complies with certain criteria

[SOURCE: IEC 60050-411:1996, 411-53-02]

3.33
runaway speed
maximum speed attained by the engine/generator set after removal of the full load of the generator if the speed regulator does not function

Note 1 to entry: For motors, the maximum overspeed at loss of supply is meant that a motor might reach driven by the coupled equipment

[SOURCE: IEC 60050-411:1996, 811-17-23]

4 Duty

4.1 Declaration of duty

It is the responsibility of the purchaser to declare the duty. The purchaser may describe the duty by one of the following:

a) numerically, where the load does not vary or where it varies in a known manner;

b) as a time sequence graph of the variable quantities;

c) by selecting one of the duty types S1 to S10 that is no less onerous than the expected duty.

The duty type shall be designated by the appropriate abbreviation, specified in 4.2, written after the value of the load.

An expression for the cyclic duration factor is given in the relevant duty type figure.

The purchaser normally cannot provide values for the moment of inertia of the machine (J_M) or the relative thermal life expectancy (TL), see Annex A. These values are provided by the manufacturer.

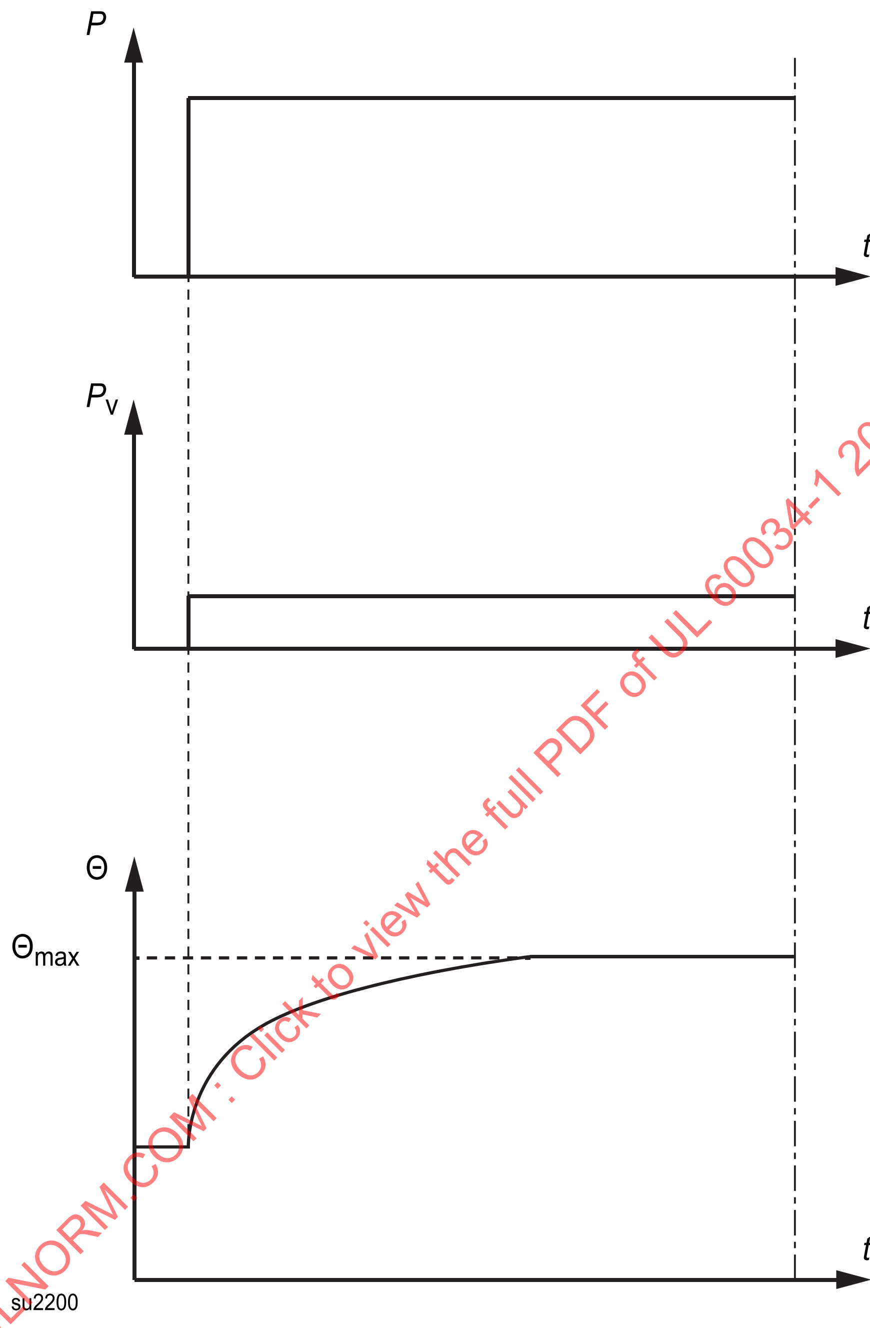
Where the purchaser does not declare a duty, the manufacturer shall assume that duty type S1 (continuous running duty) applies.

4.2 Duty types

4.2.1 Duty type S1 – Continuous running duty

Operation at a constant load maintained for sufficient time to allow the machine to reach thermal equilibrium, see Figure 1.

The appropriate abbreviation is S1.



Key

P	load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained
t	time

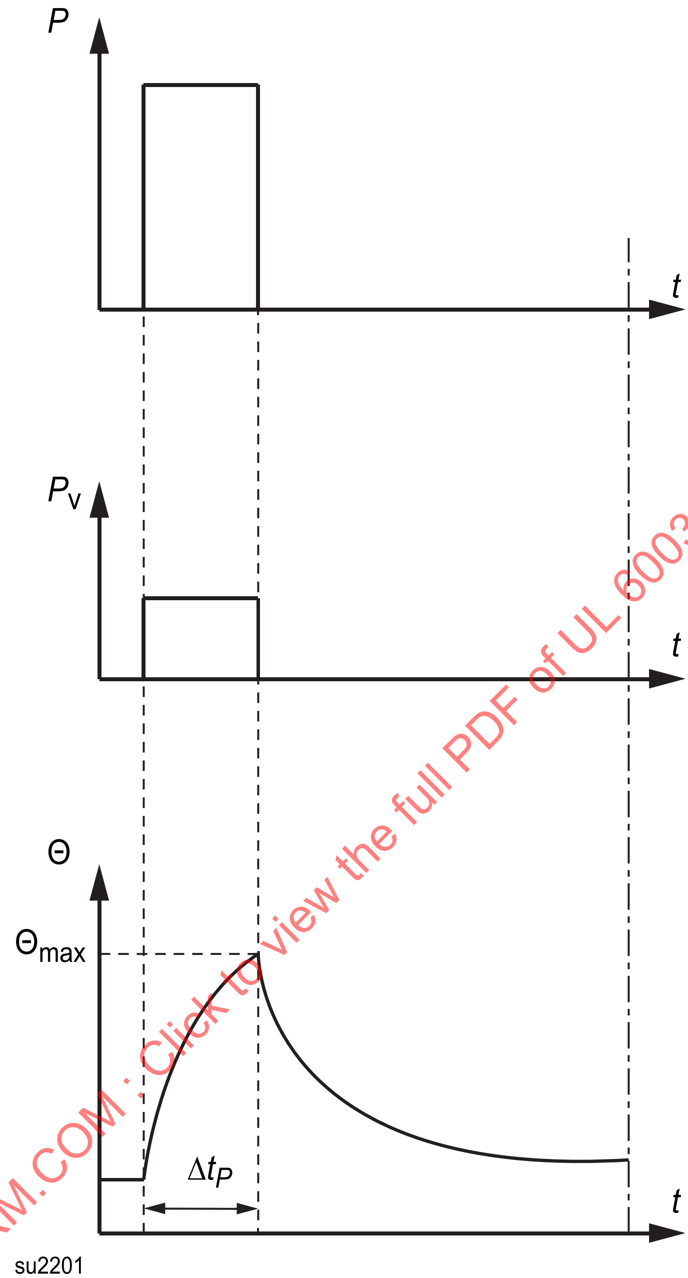
Figure 1 – Continuous running duty – Duty type S1

4.2.2 Duty type S2 – Short-time duty

Operation at constant load for a given time, less than that required to reach thermal equilibrium, followed by a time de-energized and at rest of sufficient duration to re-establish machine temperatures within 2 K of the coolant temperature, see Figure 2.

The appropriate abbreviation is S2, followed by an indication of the duration of the duty,

Example: S2 60 min.



Key

P	load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained
t	time
Δt_P	operation time at constant load

Figure 2 – Short-time duty – Duty type S2

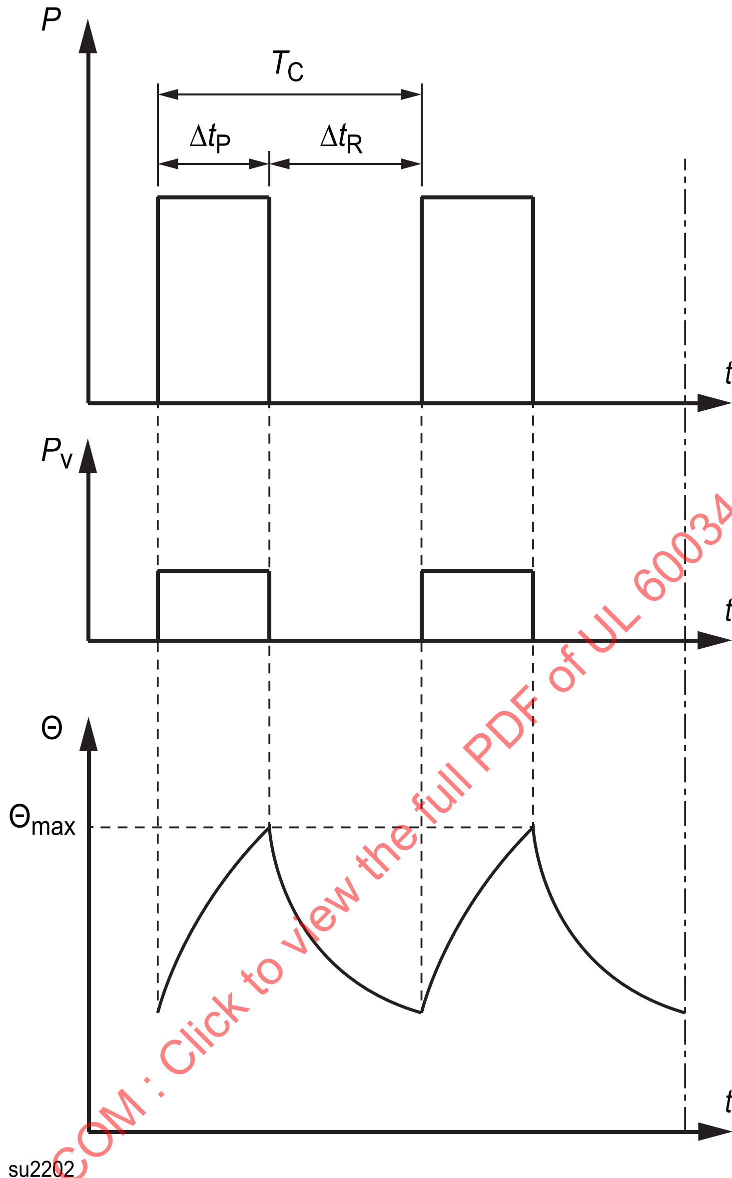
4.2.3 Duty type S3 – Intermittent periodic duty

NOTE Periodic duty implies that thermal equilibrium is not reached during the time on load.

A sequence of identical duty cycles, each including a time of operation at constant load and a time de-energized and at rest, see Figure 3. In this duty, the cycle is such that the starting current does not significantly affect the temperature rise.

The appropriate abbreviation is S3, followed by the cyclic duration factor.

Example: S3 25 %.



Key

P	load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained
t	time
T_C	time of one load cycle
Δt_P	operation time at constant load
Δt_R	time de-energized and at rest

Cyclic duration factor = $\Delta t_P / T_C$

Figure 3 – Intermittent periodic duty – Duty type S3

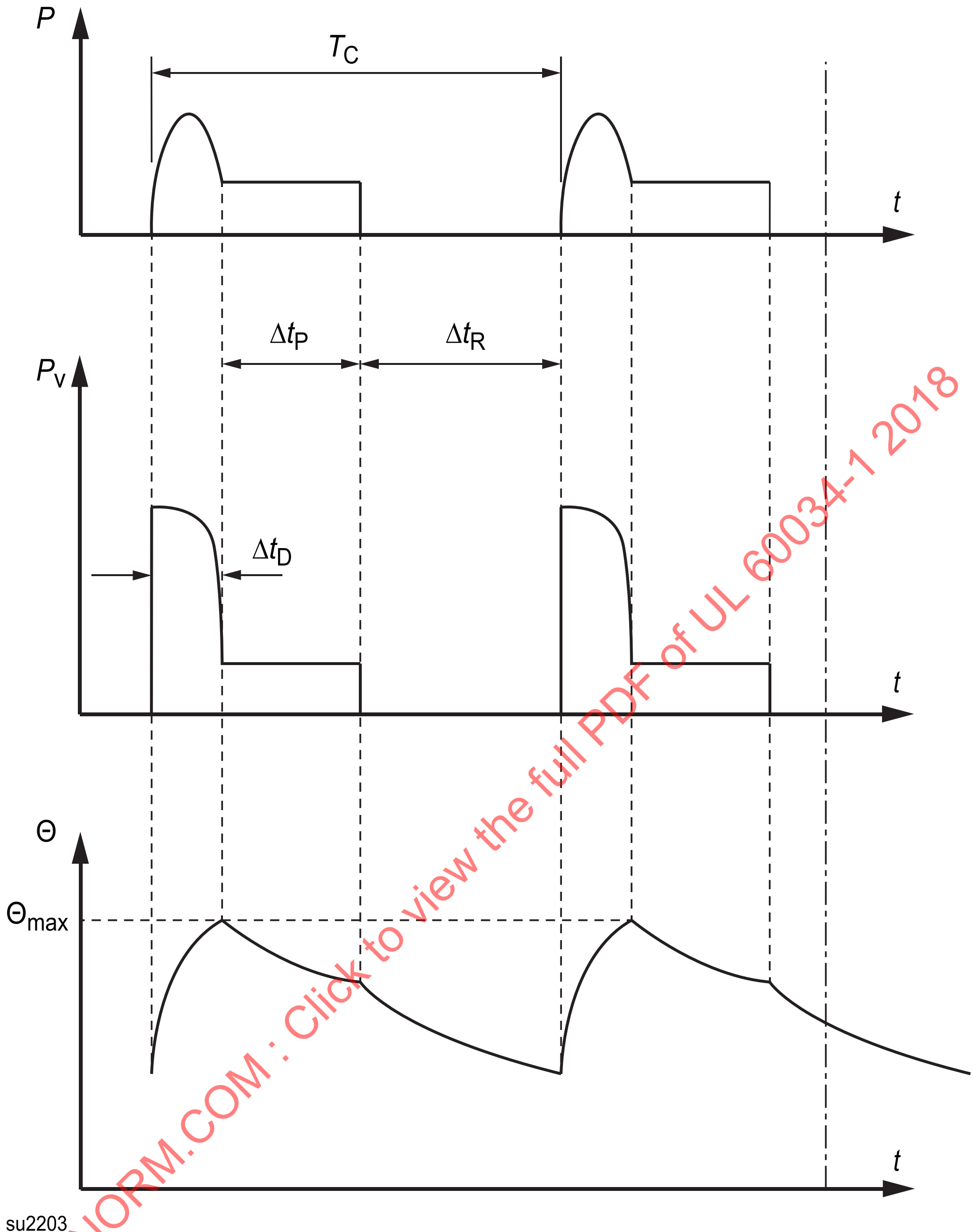
4.2.4 Duty type S4 – Intermittent periodic duty with starting

NOTE Periodic duty implies that thermal equilibrium is not reached during the time on load.

A sequence of identical duty cycles, each cycle including a significant starting time, a time of operation at constant load and a time de-energized and at rest, see Figure 4.

The appropriate abbreviation is S4, followed by the cyclic duration factor, the moment of inertia of the motor (J_M) and the moment of inertia of the load (J_{ext}), both referred to the motor shaft.

Example: S4 25 % J_M = 0,15 kg × m^2 J_{ext} = 0,7 kg × m^2.



Key

P	load	*t*	time
P_V	electrical losses	T_C	time of one load cycle
Θ	temperature	Δt_D	starting/accelerating time
Θ_{max}	maximum temperature attained	Δt_P	operation time at constant load
		Δt_R	time de-energized and at rest

Cyclic duration factor = $(\Delta t_D + \Delta t_P)/T_C$

Figure 4 – Intermittent periodic duty with starting – Duty type S4

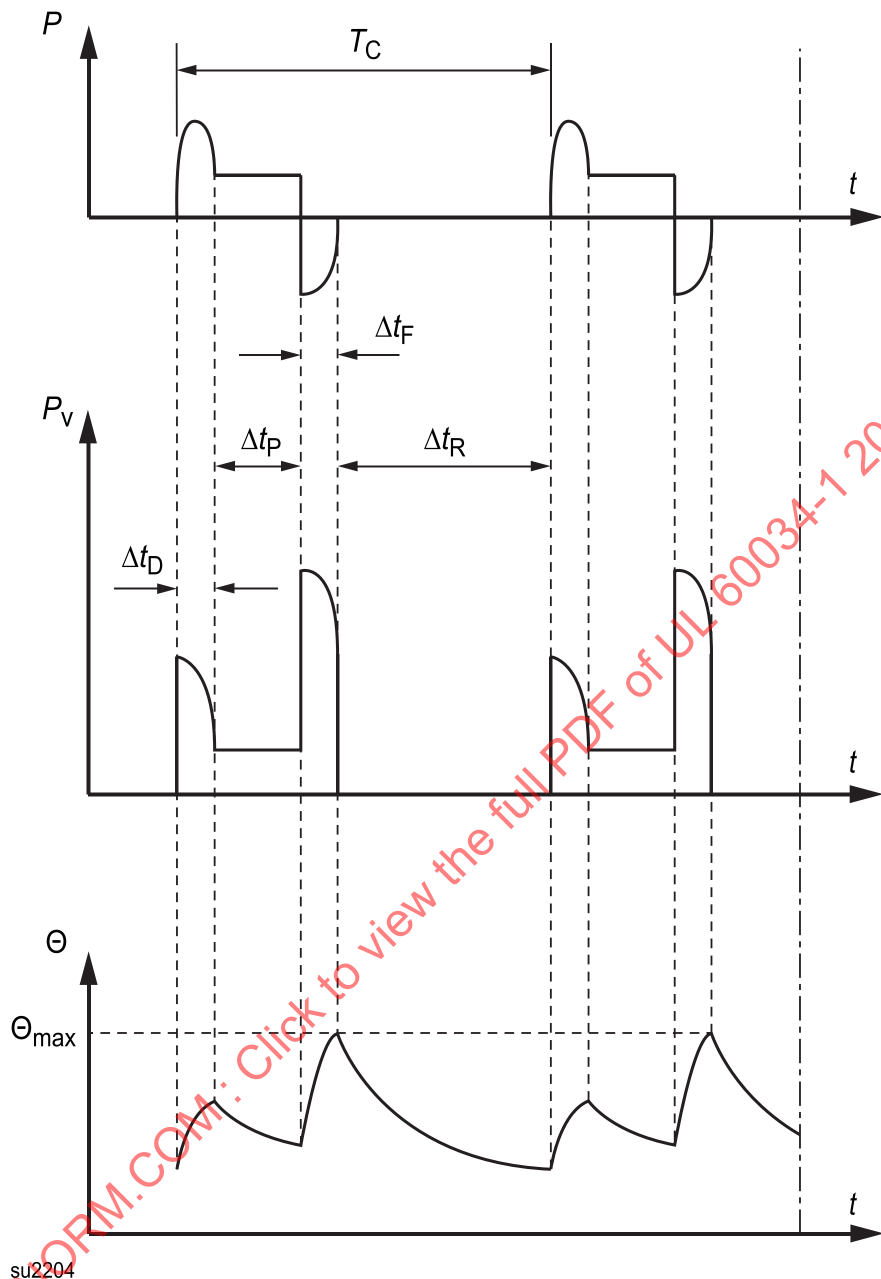
4.2.5 Duty type S5 – Intermittent periodic duty with electric braking

NOTE Periodic duty implies that thermal equilibrium is not reached during the time on load.

A sequence of identical duty cycles, each cycle consisting of a starting time, a time of operation at constant load, a time of electric braking and a time de-energized and at rest, see Figure 5.

The appropriate abbreviation is S5, followed by the cyclic duration factor, the moment of inertia of the motor (J_M) and the moment of inertia of the load (J_{ext}), both referred to the motor shaft.

Example: S5 25 % J_M = 0,15 kg × m^2 J_{ext} = 0,7 kg × m^2



Key

P	load	T_C	time of one load cycle
P_V	electrical losses	Δt_D	starting/accelerating time
Θ	temperature	Δt_P	operation time at constant load
Θ_{max}	maximum temperature attained	Δt_F	time of electric braking
t	time	Δt_R	time de-energized and at rest

Cyclic duration factor = $(\Delta t_D + \Delta t_P + \Delta t_F)/T_C$

Figure 5 – Intermittent periodic duty with electric braking – Duty type S5

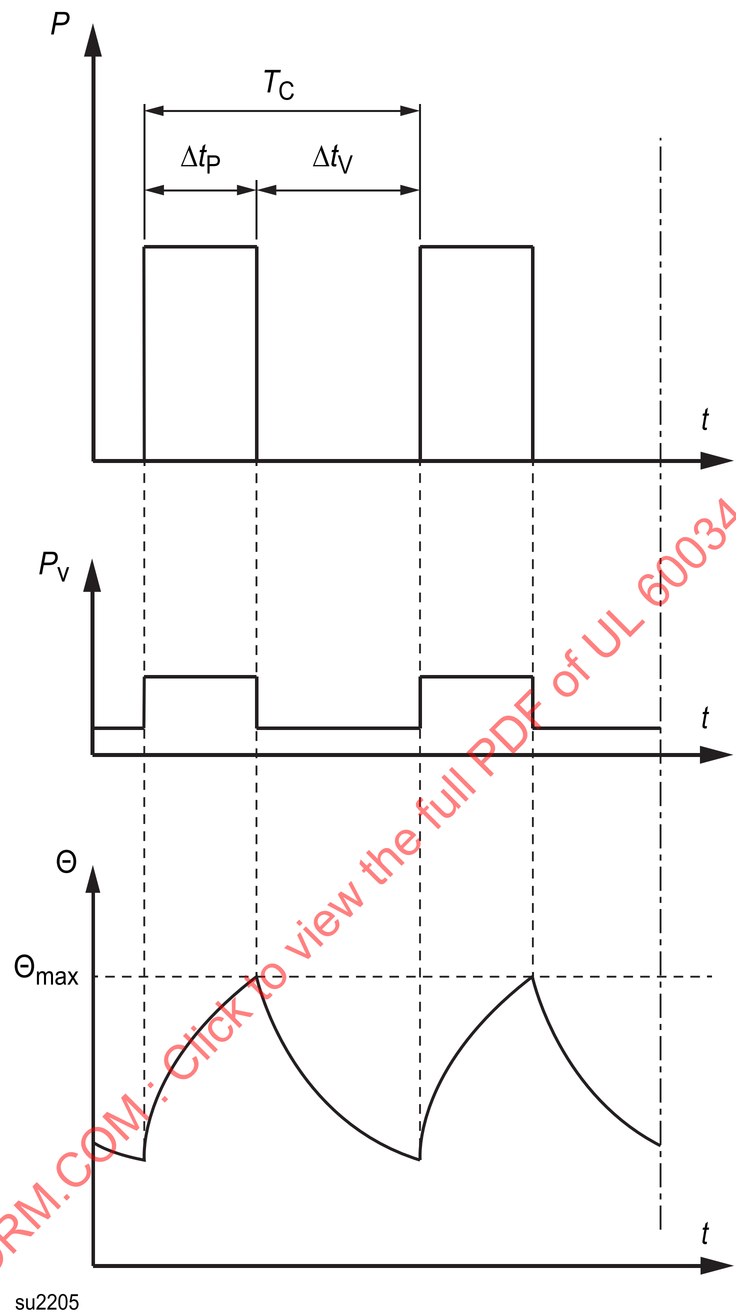
4.2.6 Duty type S6 – Continuous operation periodic duty

NOTE Periodic duty implies that thermal equilibrium is not reached during the time on load.

A sequence of identical duty cycles, each cycle consisting of a time of operation at constant load and a time of operation at no-load. There is no time de-energized and at rest, see Figure 6.

The appropriate abbreviation is S6, followed by the cyclic duration factor.

Example: S6 40 %



Key

P	load	t	time
P_V	electrical losses	T_C	time of one load cycle
Θ	temperature	Δt_P	operation time at constant load
Θ_{max}	maximum temperature attained	Δt_V	operation time at no-load

Cyclic duration factor = $\Delta t_P / T_C$

Figure 6 – Continuous operation periodic duty – Duty type S6

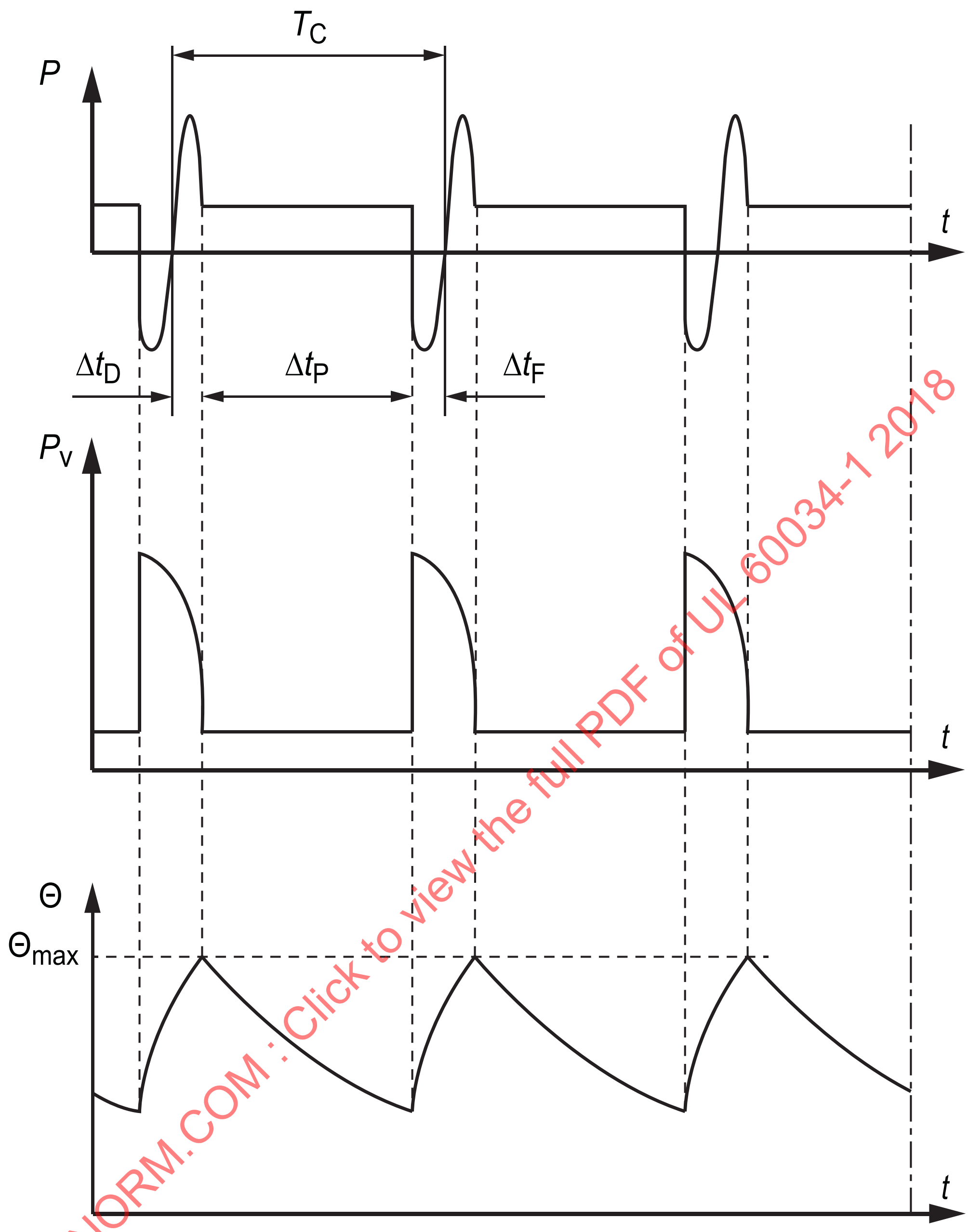
4.2.7 Duty type S7 – Continuous operation periodic duty with electric braking

NOTE Periodic duty implies that thermal equilibrium is not reached during the time on load.

A sequence of identical duty cycles, each cycle consisting of a starting time, a time of operation at constant load and a time of electric braking. There is no time de-energized and at rest, see Figure 7.

The appropriate abbreviation is S7, followed by the moment of inertia of the motor (J_M) and the moment of inertia of the load (J_{ext}), both referred to the motor shaft.

Example: S7 J_M = 0,4 kg × m^2 J_{ext} = 7,5 kg × m^2



Key

P	load	t	time
P_V	electrical losses	T_C	time of one load cycle
Θ	temperature	Δt_D	starting/accelerating time
Θ_{max}	maximum temperature attained	Δt_P	operation time at constant load
Cyclic duration factor = 1		Δt_F	time of electric braking

Figure 7 – Continuous operation periodic duty with electric braking – Duty type S7

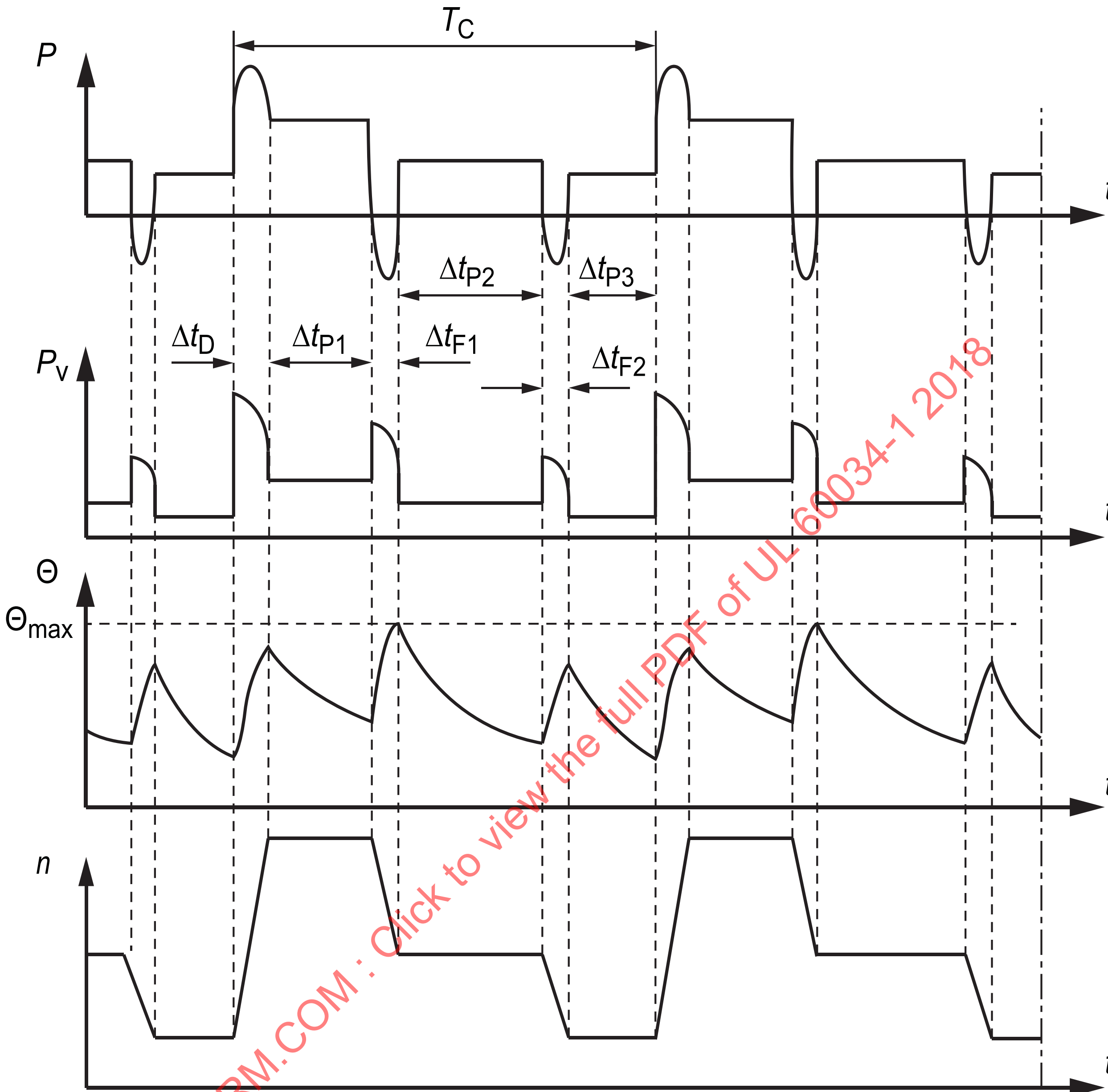
4.2.8 Duty type S8 – Continuous operation periodic duty with related load/speed changes

NOTE Periodic duty implies that thermal equilibrium is not reached during the time on load.

A sequence of identical duty cycles, each cycle consisting of a time of operation at constant load corresponding to a predetermined speed of rotation, followed by one or more times of operation at other constant loads corresponding to different speeds of rotation (carried out, for example, by means of a change in the number of poles in the case of induction motors). There is no time de-energized and at rest (see Figure 8).

The appropriate abbreviation is S8, followed by the moment of inertia of the motor (J_M) and the moment of inertia of the load (J_{ext}), both referred to the motor shaft, together with the load, speed and cyclic duration factor for each speed condition.

Example:	S8	J_M = 0,5 kg × m^2	J_{ext} = 6 kg × m^2	16 kW	740 min^{-1}	30 %
				40 kW	1 460 min^{-1}	30 %
				25 kW	980 min^{-1}	40 %



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Key

P	load	t	time
P_V	electrical losses	T_C	time of one load cycle
Θ	temperature	Δt_D	starting/accelerating time
Θ_{max}	maximum temperature attained	Δt_P	operation time at constant load (P1, P2, P3)
n	speed	Δt_F	time of electric braking (F1, F2)

Cyclic duration factor = $(\Delta t_D + \Delta t_{P1})/T_C$; $(\Delta t_{F1} + \Delta t_{P2})/T_C$; $(\Delta t_{F2} + \Delta t_{P3})/T_C$

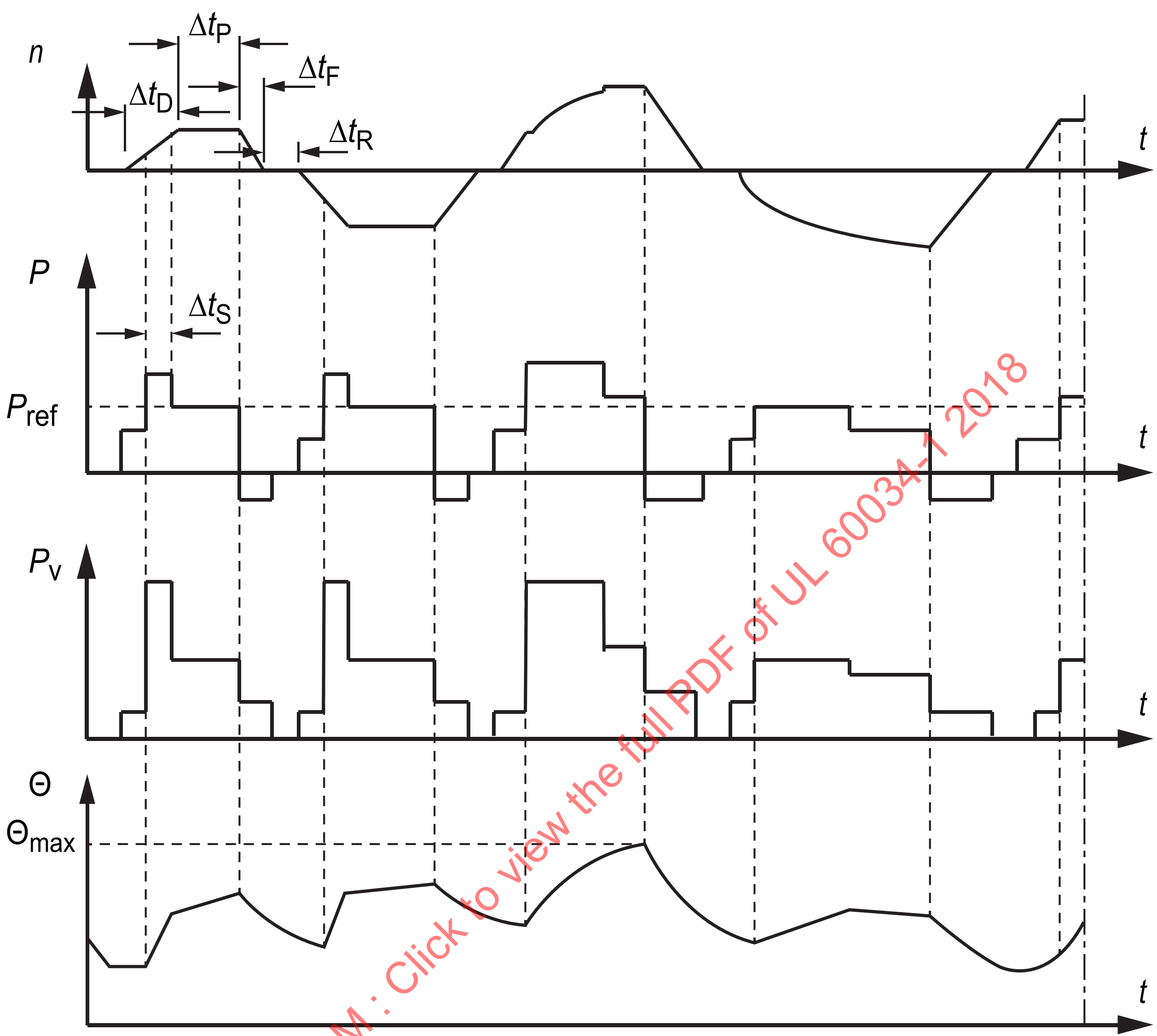
Figure 8 – Continuous operation periodic duty with related load/speed changes – Duty type S8

4.2.9 Duty type S9 – Duty with non-periodic load and speed variations

A duty in which generally load and speed vary non-periodically within the permissible operating range. This duty includes frequently applied overloads that may greatly exceed the reference load (see Figure 9).

The appropriate abbreviation is S9.

For this duty type, a constant load appropriately selected and based on duty type S1 is taken as the reference value ("P_{ref}" in Figure 9) for the overload concept.



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Key

P	load	t	time
P_{ref}	reference load	Δt_D	starting/accelerating time
P_V	electrical losses	Δt_P	operation time at constant load
Θ	temperature	Δt_F	time of electric braking
Θ_{max}	maximum temperature attained	Δt_R	time de-energized and at rest
n	speed	Δt_S	time under overload

Figure 9 – Duty with non-periodic load and speed variations – Duty type S9

4.2.10 Duty type S10 – Duty with discrete constant loads and speeds

A duty consisting of a specific number of discrete values of load (or equivalent loading) and if applicable, speed, each load/speed combination being maintained for sufficient time to allow the machine to reach thermal equilibrium, see Figure 10. The minimum load within a duty cycle may have the value zero (no-load or de-energized and at rest).

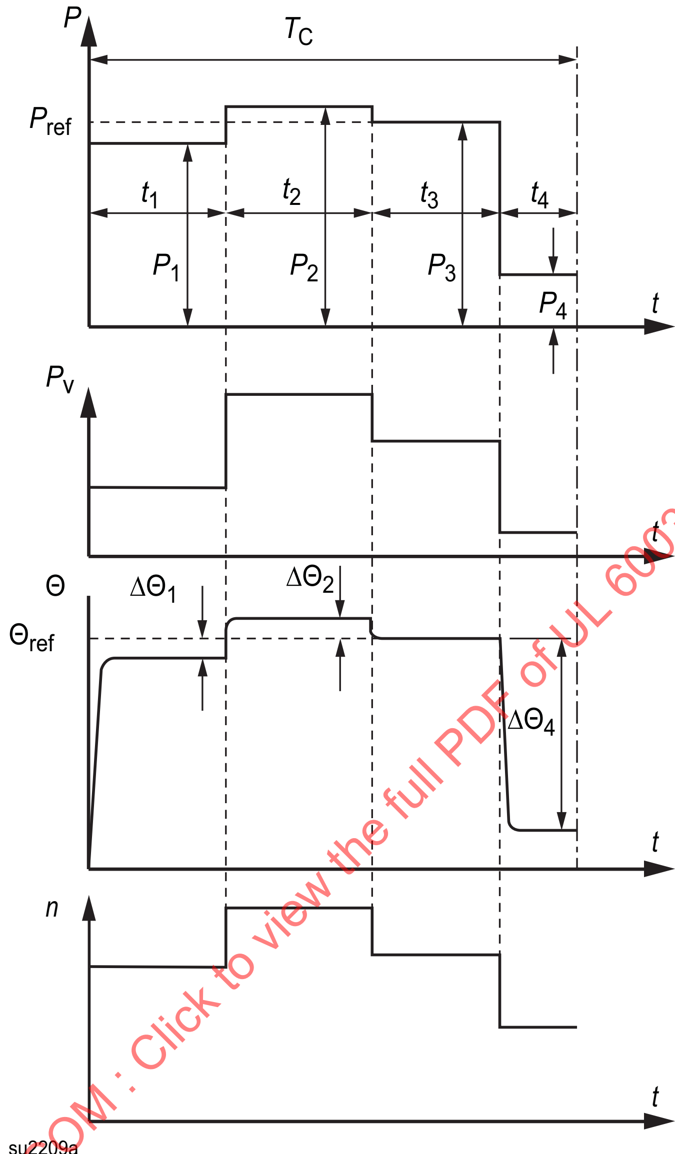
The appropriate abbreviation is S10, followed by the per unit quantities $p/\Delta t$ for the respective load and its duration and the per unit quantity TL for the relative thermal life expectancy of the insulation system. The reference value for the thermal life expectancy is the thermal life expectancy at rating for continuous running duty and permissible limits of temperature rise based on duty type S1. For a time de-energized and at rest, the load shall be indicated by the letter *r*.

Example: S10 $p/\Delta t$ = 1,1/0,4; 1/0,3; 0,9/0,2; *r*/0,1 TL = 0,6

The value of TL should be rounded off to the nearest multiple of 0,05. Advice concerning the significance of this parameter and the derivation of its value is given in Annex A.

For this duty type a constant load appropriately selected and based on duty type S1 shall be taken as the reference value ('P_{ref}' in Figure 10) for the discrete loads.

The discrete values of load will usually be equivalent loading based on integration over a period of time. It is not necessary that each load cycle be exactly the same, only that each load within a cycle be maintained for sufficient time for thermal equilibrium to be reached, and that each load cycle be capable of being integrated to give the same relative thermal life expectancy.



Key

P	load	t	time
P_i	constant load within a load cycle	t_i	time of a constant load within a cycle
P_{ref}	reference load based on duty type S1	T_C	time of one load cycle
P_V	electrical losses	$ΔΘ_i$	difference between the temperature rise of the winding at each of the various loads within one cycle and the temperature rise based on duty cycle S1 with reference load
$Θ$	temperature	n	speed
$Θ_{ref}$	temperature at reference load based on duty type S1		

Figure 10 – Duty with discrete constant loads – Duty type S10

5 Rating

5.1 Assignment of rating

The rating, as defined in 3.2, shall be assigned by the manufacturer. In assigning the rating the manufacturer shall select one of the classes of rating defined in 5.2.1 to 5.2.6. The designation of the class of rating shall be written after the rated output. If no designation is stated, rating for continuous running duty applies.

When accessory components (such as reactors, capacitors, etc.) are connected by the manufacturer as part of the machine, the rated values shall refer to the supply terminals of the whole arrangement.

NOTE This does not apply to power transformers connected between the machine and the supply.

Special considerations are required when assigning ratings to machines fed from or supplying static converters. IEC TS 60034-25 gives guidance on this.

5.2 Classes of rating

5.2.1 Rating for continuous running duty

A rating at which the machine may be operated for an unlimited period, while complying with the requirements of this document.

This class of rating corresponds to duty type S1 and is designated as for the duty type S1.

5.2.2 Rating for short-time duty

A rating at which the machine may be operated for a limited period, starting at ambient temperature, while complying with the requirements of this document.

This class of rating corresponds to duty type S2 and is designated as for the duty type S2.

5.2.3 Rating for periodic duty

A rating at which the machine may be operated on duty cycles, while complying with the requirements of this document.

This class of rating corresponds to one of the periodic duty types S3 to S8 and is designated as for the corresponding duty type.

Unless otherwise specified, the duration of a duty cycle shall be 10 min and the cyclic duration factor shall be one of the following values:

15 %, 25 %, 40 %, 60 %.

5.2.4 Rating for non-periodic duty

A rating at which the machine may be operated non-periodically while complying with the requirements of this document.

This class of rating corresponds to the non-periodic duty type S9 and is designated as for the duty type S9.

5.2.5 Rating for duty with discrete constant loads and speeds

A rating at which the machine may be operated with the associated loads and speeds of duty type S10 for an unlimited period of time while complying with the requirements of this document. The maximum permissible load within one cycle shall take into consideration all parts of the machine, for example, the insulation system regarding the validity of the exponential law for the relative thermal life expectancy, bearings with respect to temperature, other parts with respect to thermal expansion. Unless specified in other relevant IEC standards, the maximum load shall not exceed 1,15 times the value of the load based on duty type S1. The minimum load may have the value zero, the machine operating at no-load or being de-energized and at rest. Considerations for the application of this class of rating are given in Annex A.

This class of rating corresponds to the duty type S10 and is designated as for the duty type S10.

NOTE Other relevant IEC standards may specify the maximum load in terms of limiting winding temperature (or temperature rise) instead of per unit load based on duty type S1.

5.2.6 Rating for equivalent loading

A rating, for test purposes, at which the machine may be operated at constant load until thermal equilibrium is reached and which results in the same stator winding temperature rise as the average temperature rise during one load cycle of the specified duty type.

The determination of an equivalent rating should take account of the varying load, speed and cooling of the duty cycle.

This class of rating, if applied, is designated ’equ’.

5.3 Selection of a class of rating

A machine manufactured for general purpose shall have a rating for continuous running duty and be capable of performing duty type S1.

If the duty has not been specified by the purchaser, duty type S1 applies and the rating assigned shall be a rating for continuous running duty.

When a machine is intended to have a rating for short-time duty, the rating shall be based on duty type S2, see 4.2.2.

When a machine is intended to supply varying loads or loads including a time of no-load or times where the machine will be in a state of de-energized and at rest, the rating shall be a rating for periodic duty based on a duty type selected from duty types S3 to S8, see 4.2.3 to 4.2.8.

When a machine is intended to supply non-periodically variable loads at variable speeds, including overloads, the rating shall be a rating for non-periodic duty based on duty type S9, see 4.2.9.

When a machine is intended to supply discrete constant loads including times of overload or times of no-load (or de-energized and at rest) the rating shall be a rating with discrete constant loads based on duty type S10, see 4.2.10.

5.4 Allocation of outputs to class of rating

In the determination of the rating:

For duty types S1 to S8, the specified value(s) of the constant load(s) shall be the rated output(s), see 4.2.1 to 4.2.8.

For duty types S9 and S10, the reference value of the load based on duty type S1 shall be taken as the rated output, see 4.2.9 and 4.2.10.

5.5 Rated output

5.5.1 DC generators

The rated output is the output at the terminals and shall be expressed in watts (W).

5.5.2 AC generators

The rated output is the apparent power at the terminals and shall be expressed in volt-amperes (VA) together with the power factor.

The rated power factor for synchronous generators shall be 0,8 lagging (over-excited), unless otherwise specified by the purchaser.

NOTE A P-Q capability diagram (power chart) indicating the limits of operation, provides more detailed information on generator's performance.

5.5.3 Motors

The rated output is the mechanical power available at the shaft and shall be expressed in watts (W).

NOTE It is the practice in some countries for the mechanical power available at the shafts of motors to be expressed in horsepower (1 h.p. is equivalent to 745,7 W; 1 ch (cheval or metric horsepower) is equivalent to 736 W).

5.5.4 Synchronous condensers

The rated output is the reactive power at the terminals and shall be expressed in volt-amperes reactive (var) in leading (under-excited) and lagging (over-excited) conditions.

5.6 Rated voltage

5.6.1 DC generators

For d.c. generators intended to operate over a relatively small range of voltage, the rated output and current shall apply at the highest voltage of the range, unless otherwise specified, see also 7.3.

5.6.2 AC generators

For a.c. generators intended to operate over a relatively small range of voltage, the rated output and power factor shall apply at any voltage within the range, unless otherwise specified, see also 7.3.

5.7 Co-ordination of voltages and outputs

It is not practical to build machines of all ratings for all rated voltages. In general, for a.c. machines, based on design and manufacturing considerations, preferred voltage ratings above 1 kV in terms of rated output are as shown in Table 1.

Table 1 – Preferred voltage ratings

Rated voltage kV	Minimum rated output kW (or kVA)
1,0 < U_N ≤ 3,0	100
3,0 < U_N ≤ 6,0	150
6,0 < U_N ≤ 11,0	800
11,0 < U_N ≤ 15,0	2 500

5.8 Machines with more than one rating

For machines with more than one rating, the machine shall comply with this document in all respects at each rating.

For multi-speed machines, a rating shall be assigned for each speed.

When a rated quantity (output, voltage, speed, etc.) may assume several values or vary continuously within two limits, the rating shall be stated at these values or limits. This provision does not apply to voltage and frequency variations during operation as defined in 7.3 or to star-delta connections intended for starting.

6 Site conditions

6.1 General

Unless otherwise specified, machines shall be suitable for the following site conditions outside the casing during operation, for standstill, storage and transportation. The cold coolant inlet temperatures for different types of cooling are specified in Table 5. For site operating conditions deviating from those values, corrections are given in Clause 8.

Machines operating outside the range of the standard site conditions shall require special consideration.

6.2 Altitude

The altitude shall not exceed 1 000 m above sea-level.

6.3 Maximum ambient air temperature

The ambient air temperature shall not exceed 40 °C.

6.4 Minimum ambient air temperature

Unless otherwise agreed between manufacturer and customer, the ambient air temperature shall not be less than –15 °C for all machines except machines with any of the following, for which the ambient temperature shall be not less than 0 °C:

a) rated output greater than 3 300 kW (or kVA) per 1 000 min^{-1};

b) rated output less than 600 W (or VA);

c) a commutator;

d) a sleeve bearing;

e) water as a primary or secondary coolant.

6.5 Water coolant temperature

For the reference water coolant temperature see Table 5. For other water coolant temperatures see Table 10. The water coolant temperature shall not be less than +5 °C.

6.6 Standstill, storage and transport

When temperatures lower than specified in 6.4 are expected during transportation, storage, or after installation at standstill, the purchaser shall inform the manufacturer and specify the expected minimum temperature.

NOTE Special measures may be needed before energizing the machine after longer periods of standstill, storage and transportation. Special measures may also be needed during the un-operational periods. See manufacturer's instructions.

6.7 Purity of hydrogen coolant

Hydrogen cooled machines shall be capable of operating at rated output under rated conditions with a coolant containing not less than 95 % hydrogen by volume.

NOTE For safety reasons, the hydrogen content should at all times be maintained at 90 % or more, it being assumed that the other gas in the mixture is air.

For calculating efficiency in accordance with IEC 60034-2 (all parts), the standard composition of the gaseous mixture shall be 98 % hydrogen and 2 % air by volume, at the specified values of pressure and temperature of the re-cooled gas, unless otherwise agreed. Windage losses shall be calculated at the corresponding density.

7 Electrical operating conditions

7.1 Electrical supply

For three-phase a.c. machines, 50 Hz or 60 Hz, intended to be directly connected to distribution or utilisation systems, the rated voltages shall be derived from the nominal voltages given in IEC 60038.

NOTE For large high-voltage a.c. machines, the voltages may be selected for optimum performance.

For a.c. machines connected to static converters these restrictions on voltage, frequency and waveform do not apply. In this case, the rated voltages shall be selected by agreement.

For electrical machines with Type I insulation systems according to IEC 60034-18-41, which are specifically designed for supply by voltage source converters, the manufacturer can assign an impulse voltage insulation class (IVIC) according to IEC 60034-18-41 for the insulation system. In this case, the insulation system should be suitable for IVIC C for phase-to-phase and IVIC B for phase-to-ground or as otherwise agreed to between the user and the manufacturer. The IVIC level shall be given in the documentation and preferably on the nameplate (see 10.2).

NOTE For more information on special considerations for converter fed machines, see IEC TS 60034-25.

Any bus transfer or fast reclosing of an a.c. machine, as it might occur, for example, due to the voltage ride through requirements of grid codes, can lead to very high peak currents endangering the stator winding overhang and to a very high peak torque of up to 20 times rated torque endangering the mechanical structure including the coupling and the driven or driving equipment. Bus transfer or fast reclosing is therefore only allowed if specified and accepted by the manufacturers of electric machine and driven equipment. For ratings ≤ 10 MW or MVA, slow reclosing exceeding 1,5 times the open circuit time constant is allowed, if specified and accepted by the manufacturers of the electric machine and the driven equipment. For ratings > 10 MW or MVA, the allowed minimum time for slow reclosing should be determined by transient analysis of the complete system by the system integrator and is allowed if accepted by the manufacturers of the electric machine and the driven equipment.

7.2 Form and symmetry of voltages and currents

7.2.1 AC motors

7.2.1.1 AC motors rated for use on a power supply of fixed frequency, supplied from an a.c. generator (whether local or via a supply network) shall be suitable for operation on a supply voltage having a harmonic voltage factor (*HVF*) not exceeding:

– 0,02 for single-phase motors and three-phase motors, including synchronous motors but excluding motors of design N (see IEC 60034-12), unless the manufacturer declares otherwise.

– 0,03 for design N motors.

The *HVF* shall be computed by using the following formula:

$$HVF = \sqrt{\sum_{n=2}^{k} \frac{u_n^2}{n}}$$

where

u_n is the ratio of the harmonic voltage U_n to the rated voltage U_N;

n is the order of harmonic (not divisible by three in the case of three-phase a.c. motors);

k = 13.

Three-phase a.c. motors shall be suitable for operation on a three-phase voltage system having a negative-sequence component not exceeding 1 % of the positive-sequence component over a long period, or 1,5 % for a short period not exceeding a few minutes, and a zero-sequence component not exceeding 1 % of the positive-sequence component.

Should the limiting values of the *HVF* and of the negative-sequence and zero-sequence components occur simultaneously in service at the rated load, this shall not lead to any harmful temperature in the motor and it is recommended that the resulting excess temperature rise related to the limits specified in this document should be not more than approximately 10 K.

NOTE In the vicinity of large single-phase loads (e.g. induction furnaces), and in rural areas particularly on mixed industrial and domestic systems, supplies may be distorted beyond the limits set out above. Special arrangements will then be necessary.

7.2.1.2 AC motors supplied from static converters have to tolerate higher harmonic contents of the supply voltage; see IEC TS 60034-25.

NOTE When the supply voltage is significantly non-sinusoidal, for example from static converters, the r.m.s. value of the total waveform and of the fundamental are both relevant in determining the performance of an a.c. machine.

7.2.2 AC generators

Three-phase a.c. generators shall be suitable for supplying circuits which, when supplied by a system of balanced and sinusoidal voltages:

a) result in currents not exceeding a harmonic current factor (*HCF*) of 0,05, and

b) result in a system of currents where neither the negative-sequence component nor the zero-sequence component exceed 5 % of the positive-sequence component.

The *HCF* shall be computed by using the following formula:

$$HCF = \sqrt{\sum_{n=2}^{k} i_n^2}$$

where

i_n is the ratio of the harmonic current I_n to the rated current I_N;

n is the order of harmonic;

$k = 13$.

Should the limits of deformation and imbalance occur simultaneously in service at the rated load, this shall not lead to any harmful temperature in the generator and it is recommended that the resulting excess temperature rise related to the limits specified in this document should be not more than approximately 10 K.

7.2.3 Synchronous machines

Unless otherwise specified, three-phase synchronous machines shall be capable of operating continuously on an unbalanced system in such a way that, with none of the phase currents exceeding the rated current, the ratio of the negative-sequence component of current (I_2) to the rated current (I_N) does not exceed the values in Table 2 and under fault conditions shall be capable of operation with the product of $(I_2/I_N)^2$ and time (t) not exceeding the values in Table 2.

Table 2 – Unbalanced operating conditions for synchronous machines

Item	Machine type	Maximum I_2/I_N value for continuous operation	Maximum $(I_2/I_N)^2 \times t$ in seconds for operation under fault conditions
	Salient pole machines and PM excited machines		
1	Indirect cooled windings		
	motors	0,1	20
	generators	0,08	20
	synchronous condensers	0,1	20
2	Direct cooled (inner cooled) stator and/or field windings		
	motors	0,08	15
	generators	0,05	15
	synchronous condensers	0,08	15
	Cylindrical rotor synchronous machines		
3	Indirect cooled rotor windings		
	air-cooled	0,1	15
	hydrogen-cooled	0,1	10
4	Direct cooled (inner cooled) rotor windings		
	≤350 MVA	0,08	8
	>350 ≤900 MVA	a	b
	>900 ≤1 250 MVA	a	5
	>1 250 ≤1 600 MVA	0,05	5

[a] For these machines, the value of I_2/I_N is calculated as follows:

$(I_2/I_N) = 0{,}08 - [(S_N - 350)/(3 \times 10^4)]$

[b] For these machines, the value of $(I_2/I_N)^2 \times t$, in seconds, is calculated as follows:

$(I_2/I_N)^2 \times t = 8 - 0{,}005\ 45\ (S_N - 350)$

where in the two footnotes, S_N is the rated apparent power in MVA.

7.2.4 DC motors supplied from static power converters

In the case of a d.c. motor supplied from a static power converter, the pulsating voltage and current affect the performance of the machine. Losses and temperature rise will increase and the commutation is more difficult compared with a d.c. motor supplied from a pure d.c. power source.

It is necessary, therefore, for motors with a rated output exceeding 5 kW, intended for supply from a static power converter, to be designed for operation from a specified supply, and, if considered necessary by the motor manufacturer, for an external inductance to be provided for reducing the undulation.

The static power converter supply shall be characterized by means of an identification code, as follows:

$$[CCC - U_{aN} - f - L]$$

where

CCC is the identification code from Table 3, which is based on IEC 61148;

U_{aN} consists of three or four digits indicating the rated alternating voltage at the input terminals of the converter, in V;

f consists of two digits indicating the rated input frequency, in Hz;

L consists of one, two or three digits indicating the series inductance to be added externally to the motor armature circuit, in mH. If this is zero, it is omitted.

Table 3 – *CCC* symbol designation

Identification code *CCC*	1-pair configuration (Configuration name)	Pair number "m" for arms in IEC 61148	Clause No. and title in IEC 61148
A-Type	Thyristor + Thyristor (Full bridge)	m = 3	5.1.3.2 Bridge connection
B-Type	Thyristor + Diode (Mixed bridge)	m = 3	Same as above
C-Type	Thyristor + Thyristor (Full bridge)	m = 2	Same as above
D-Type	Thyristor + Diode (Mixed bridge)	m = 2	Same as above

Motors with rated output not exceeding 5 kW, instead of being tied to a specific type of static power converter, may be designed for use with any static power converter, with or without external inductance, provided that the rated form factor for which the motor is designed will not be surpassed and that the insulation level of the motor armature circuit is appropriate for the rated alternating voltage at the input terminals of the static power converter.

In all cases, the undulation of the static power converter output current is assumed to be so low as to result in a current ripple factor not higher than 0,1 at rated conditions.

7.3 Voltage and frequency variations during operation

For a.c. machines rated for use on a power supply of fixed frequency supplied from an a.c. generator (whether local or via a supply network), combinations of voltage variation and frequency variation are classified as being either zone A or zone B, in accordance with Figure 11 for generators and synchronous condensers, and Figure 12 for motors.

For d.c. machines, when directly connected to a normally constant d.c. bus, zones A and B apply only to the voltages.

A machine shall be capable of performing its primary function, as specified in Table 4, continuously within zone A, but need not comply fully with its performance at rated voltage and frequency (see rating point in Figures 11 and 12), and may exhibit some deviations. Temperature rises may be higher than at rated voltage and frequency.

A machine shall be capable of performing its primary function within zone B, but may exhibit greater deviations from its performance at rated voltage and frequency than in zone A. Temperature rises may be higher than at rated voltage and frequency and most likely will be higher than those in zone A. Extended operation at the perimeter of zone B is not recommended.

In practical applications and operating conditions, a machine will sometimes be required to operate outside the perimeter of zone A. Such excursions should be limited in value, duration and frequency of occurrence. Corrective measures should be taken, where practical, within a reasonable time, for example, a reduction in output. Such action may avoid a reduction in machine life from temperature effects.

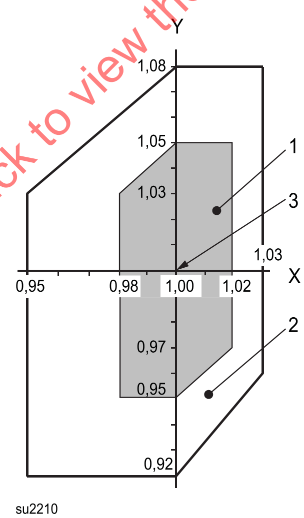
NOTE 1 The temperature-rise limits or temperature limits in accordance with this document apply at the rating point and may be progressively exceeded as the operating point moves away from the rating point. For conditions at the extreme boundaries of zone A, the temperature rises and temperatures typically exceed the limits specified in this document by approximately 10 K.

NOTE 2 An a.c. motor will start at the lower limit of voltage only if its starting torque is adequately matched to the counter-torque of the load, but this is not a requirement of this clause. For starting performance of design N motors, see IEC 60034-12.

NOTE 3 For machines covered by IEC 60034-3, different voltage and frequency limits apply.

Table 4 – Primary functions of machines

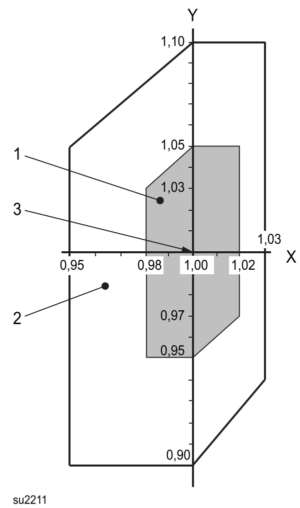
Item	Machine type	Primary function
1	AC generator, excluding item 5	Rated apparent power (kVA), at rated power factor where this is separately controllable
2	AC motor, excluding items 3	Rated torque (Nm)
3	Synchronous motor	Rated torque (Nm), the excitation maintaining either rated field current or rated power factor, where this is separately controllable
4	Synchronous condenser	Rated reactive power (kVAr) within the zone applicable to a generator, see Figure 11, unless otherwise agreed
5	Synchronous generator driven by steam turbines or combustion gas turbines with rated output ≥10 MVA	See IEC 60034-3
6	DC generator	Rated output (kW)
7	DC motor	Rated torque (Nm), the excitation of a shunt motor maintaining rated speed, where this is separately controllable



Key

X axis	frequency p.u.	1	zone A
Y axis	voltage p.u.	2	zone B (outside zone A)
		3	rating point

Figure 11 – Voltage and frequency limits for generators



Key

X axis	frequency p.u.	1	zone A
Y axis	voltage p.u.	2	zone B (outside zone A)
		3	rating point

Figure 12 – Voltage and frequency limits for motors

7.4 Three-phase a.c. machines operating on unearthed systems

Three-phase a.c. machines shall be suitable for continuous operation with the neutral at or near earth potential. They shall also be suitable for operation on unearthed systems with one line at earth potential for infrequent periods of short duration, for example as required for normal fault clearance. If it is intended to run the machine continuously or for prolonged periods in this condition, a machine with a level of insulation suitable for this condition will be required.

If the winding does not have the same insulation at the line and neutral ends, this shall be stated by the manufacturer.

The earthing or interconnection of the machine's neutral points should not be undertaken without consulting the machine manufacturer because of the danger of zero-sequence components of currents of all frequencies under some operating conditions and the risk of mechanical damage to the windings under line-to-neutral fault conditions.

7.5 Voltage (peak and gradient) withstand levels

For a.c. machines, the manufacturer shall declare a limiting value for the peak voltage and for the voltage gradient in continuous operation, if required by the customer.

For machines used in power drive systems (PDS), see also IEC TS 60034-25.

For machines with a specified Impulse Voltage Insulation Class IVIC, see IEC 60034-18-41 in the case of machines designed to operate without partial discharges.

For high-voltage a.c. machines, see also IEC 60034-15.

For creepage and clearance distances of bare live copper, see IEC 60664-1.

8 Thermal performance and tests

8.1 Thermal class

A thermal class in accordance with IEC 60085 shall be assigned to the insulation systems used in machines.

It is the responsibility of the manufacturer of the machine to interpret the results obtained by thermal endurance testing according to the appropriate part of IEC 60034-18.

NOTE 1 The thermal class of a new insulation system should not be assumed to be directly related to the thermal capability of the individual materials used in it.

NOTE 2 The continued use of an existing insulation system is acceptable where it has been proved by satisfactory service experience.

8.2 Reference coolant

The reference coolant for a given method of cooling the machine is specified in Table 5.

Table 5 – Reference coolant (see also Table 11)

Item	Primary coolant	Method of cooling	Secondary coolant	Table number	Table referred to in column 5 specifies limits of:	Reference coolant
1	Air	Indirect	None	7	Temperature rise	Ambient air Reference temperature: 40 °C
2	Air	Indirect	Air	7		
3	Air	Indirect	Water	7		Coolant at inlet to machine or ambient water reference temperature of cooling gas at inlet to machine: 40 °C
4	Hydrogen	Indirect	Water	8		Reference temperature of ambient water: 25 °C (see note)

Table 5 – Reference coolant (see also Table 11) Continued on Next Page

Table 5 – Reference coolant (see also Table 11) Continued

Item	Primary coolant	Method of cooling	Secondary coolant	Table number	Table referred to in column 5 specifies limits of:	Reference coolant
5	Air	Direct	None	12	Temperature	Ambient air
6	Air	Direct	Air	12		Reference temperature: 40 °C
7	Air	Direct	Water	12		Gas at entry to machine or liquid at entry to the windings
8	Hydrogen or liquid	Direct	Water	12		Reference temperature: 40 °C
NOTE A machine with indirect cooled windings and a water cooled heat exchanger may be rated using either the primary or secondary coolant as the reference coolant (see also 10.2 for information to be given on the rating plate). A submersible machine with surface cooling or a machine with water jacket cooling should be rated using the secondary coolant as reference coolant.						

If a third coolant is used, temperature rise shall be measured above the temperature of the primary or secondary coolant as specified in Table 5.

NOTE A machine may be so arranged and cooled that more than one item of Table 5 applies, in which case different reference coolants may apply for different windings.

8.3 Conditions for thermal tests

8.3.1 Electrical supply

During thermal testing of an a.c. machine the HVF of the supply shall not exceed 0,015 and the negative-sequence component of the system of voltages shall be less than 0,5 % of the positive-sequence component, the influence of the zero-sequence component being eliminated.

By agreement, the negative-sequence component of the system of currents may be measured instead of the negative-sequence component of the system of voltages. The negative-sequence component of the system of currents shall not exceed 2,5 % of the positive-sequence component.

8.3.2 Temperature of machine before test

If the temperature of a winding is to be determined from the increase of resistance, the initial winding temperature shall not differ from the coolant by more than 2 K.

When a machine is to be tested on a short-time rating (duty type S2) its temperature at the beginning of the thermal test shall be within 5 K of the temperature of the coolant.

8.3.3 Temperature of coolant

A machine may be tested at any convenient value of coolant temperature. See Table 12 (for indirect cooled windings) or Table 15 (for direct cooled windings).

8.3.4 Measurement of coolant temperature during test

8.3.4.1 General

The value to be adopted for the temperature of a coolant during a test shall be the mean of the readings of the temperature detectors taken at equal intervals of time during the last quarter of the duration of the test. To reduce errors due to the time lag of the change of temperature of large machines following variations in the temperature of the coolant, all reasonable precautions shall be taken to minimize such variations.

8.3.4.2 Closed machines without heat exchangers (cooled by surrounding ambient air or gas)

The temperature of the ambient air or gas shall be measured by means of several detectors placed at different points around and halfway up the machine at 1 m to 2 m from it. Each detector shall be protected from radiant heat and draughts.

8.3.4.3 Open machines and machines cooled by air or gas from a remote source through ventilation ducts and machines with separately mounted heat exchangers

The temperature of the primary coolant shall be measured where it enters the machine.

8.3.4.4 Closed machines with machine-mounted or internal heat exchangers

The temperature of the primary coolant shall be measured where it enters the machine. The temperature of the secondary coolant shall be measured where it enters the heat exchanger.

8.4 Temperature rise of a part of a machine

The temperature rise, $\Delta\theta$, of a part of a machine is the difference between the temperature of that part measured by the appropriate method in accordance with 8.5, and the temperature of the coolant measured in accordance with 8.3.4.

For comparison with the limits of temperature rise (see Table 8 or Table 9) or of temperature (see Table 13), when possible, the temperature shall be measured immediately before the machine is shut down at the end of the thermal test, as described in 8.7.

When this is not possible, for example, when using the direct measurement of resistance method, see 8.6.2.3.

For machines tested on actual periodic duty (duty types S3 to S8) the temperature at the end of the test shall be taken as that at the middle of the rise period causing the greatest heating in the last cycle of operation (but see also 8.7.3).

8.5 Methods of measurement of temperature

8.5.1 General

Three methods of measuring the temperature of windings and other parts are recognized:

– resistance method;

– embedded temperature detector (ETD) method;

– thermometer method.

Different methods shall not be used as a check upon one another.

For indirect testing see IEC 60034-29.

8.5.2 Resistance method

The temperature of the windings is determined from the increase of the resistance of the windings.

8.5.3 Embedded temperature detector (ETD) method

The temperature is determined by means of temperature detectors (e.g. resistance thermometers, thermocouples or semi-conductor negative coefficient detectors) built into the machine during construction, at points which are inaccessible after the machine is completed.

8.5.4 Thermometer method

The temperature is determined by thermometers applied to accessible surfaces of the completed machine. The term 'thermometer' includes not only bulb-thermometers, but also non-embedded thermocouples and resistance thermometers. When bulb-thermometers are used in places where there is a strong varying or moving magnetic field, alcohol thermometers shall be used in preference to mercury thermometers.

8.6 Determination of winding temperature

8.6.1 Choice of method

In general, for measuring the temperature of the windings of a machine, the resistance method in accordance with 8.5.2 shall be applied (but see also 8.6.2.3.3).

For a.c. stator windings of machines having a rated output of 5 000 kW (or kVA) or more the ETD method shall be used.

For a.c. stator windings of machines having a rated output less than 5 000 kW (or kVA) but greater than 200 kW (or kVA) the manufacturer shall choose either the resistance or the ETD method, unless otherwise agreed.

For a.c. stator windings of machines having a rated output less than or equal to 200 kW (or kVA) the manufacturer shall choose the direct measurement version or the superposition version of the resistance method (see 8.6.2.1), unless otherwise agreed (but see also below).

For machines having a rated output less than or equal to 600 W (or VA), when the windings are non-uniform or severe complications are involved in making the necessary connections, the temperature may be determined by means of thermometers. Temperature rise limits in accordance with Table 8, item 1d) for resistance method shall apply.

The thermometer method is recognized in the following cases:

a) when it is not practicable to determine the temperature rise by the resistance method as, for example, with low-resistance commutating coils and compensating windings and, in general, in the case of low-resistance windings, especially when the resistance of joints and connections forms a considerable proportion of the total resistance;

b) single layer windings, rotating or stationary;

c) during routine tests on machines manufactured in large numbers.

For a.c. stator windings having only one coil-side per slot, the ETD method shall not be used for verifying compliance with this document: the resistance method shall be used.

NOTE For checking the temperature of such windings in service, an embedded detector at the bottom of the slot is of little value because it gives mainly the temperature of the iron core. A detector placed between the coil and the wedge will follow the temperature of the winding much more closely and is, therefore, better for checks in service. Because the temperature there may be rather low, the relation between it and the temperature measured by the resistance method should be determined by a thermal test.

For other windings having one coil-side per slot and for end windings, the ETD method shall not be used for verifying compliance with this document.

For windings of armatures having commutators and for field windings, the resistance method is recognized. For stationary field windings of d.c. machines having more than one layer the ETD method may be used.

8.6.2 Determination by resistance method

8.6.2.1 Measurement

One of the following methods shall be used:

– direct measurement at the beginning and the end of the test, using an instrument having a suitable range;

– measurement by d.c. current/voltage in d.c. windings, by measuring the current in and the voltage across the winding, using instruments having suitable ranges;

– measurement by d.c. current/voltage in a.c. windings, by injecting direct current into the winding when de-energized;

– Measurement by d.c. current/voltage in a.c. windings, by superposing small amount of d.c. current into the winding, when energized.

8.6.2.2 Calculation

The temperature rise, $\theta_2 - \theta_a$, may be obtained from the formula:

$$\frac{\theta_2 + k}{\theta_1 + k} = \frac{R_2}{R_1}$$

where

θ_1 is the temperature (°C) of the winding (cold) at the moment of the initial resistance measurement;

θ_2 is the temperature (°C) of the winding at the end of the thermal test;

θ_a is the temperature (°C) of the coolant at the end of the thermal test;

R_1 is the resistance of the winding at temperature θ_1 (cold);

R_2 is the resistance of the winding at the end of the thermal test;

k is the reciprocal of the temperature coefficient of resistance at 0 °C of the conductor material.

For copper $k = 235$

For aluminium $k = 225$ unless specified otherwise.

For practical purposes, the following alternative formula may be found convenient:

$$\theta_2 - \theta_a = \frac{R_2 - R_1}{R_1} \times (k + \theta_1) + \theta_1 - \theta_a$$

8.6.2.3 Correction for stopping time

8.6.2.3.1 General

The measurement of temperatures at the end of the thermal test by the direct measurement resistance method requires a quick shutdown. A carefully planned procedure and an adequate number of people are required.

8.6.2.3.2 Short stopping time

If the initial resistance reading is obtained within the time interval specified in Table 6, that reading shall be accepted for the temperature measurement.

Table 6 – Time interval

Rated output (P_N) **kW or kVA**	**Time interval after switching off power** **s**
$P_N \leq 50$	30
$50 < P_N \leq 200$	90
$200 < P_N \leq 5\ 000$	120
$5\ 000 < P_N$	By agreement

8.6.2.3.3 Extended stopping time

If a resistance reading cannot be made in the time interval specified in Table 6, it shall be made as soon as possible but not after more than twice the interval specified in Table 6, and additional readings shall be taken at intervals of approximately 1 min until these readings have begun a distinct decline from their maximum value. A curve of these readings shall be plotted as a function of time and extrapolated to the appropriate time interval of Table 6 for the rated output of the machine. A semi-logarithmic plot is recommended where temperature or resistance is plotted on the logarithmic scale. The value of temperature thus obtained shall be considered as the temperature at shutdown. If successive measurements show increasing temperatures after shutdown the highest value shall be taken.

If a resistance reading cannot be made until after twice the time interval specified in Table 6, this method of correction shall only be used by agreement.

8.6.2.3.4 Windings with one coil-side per slot

For machines with one coil-side per slot, the resistance method by direct measurement may be used if the machine comes to rest within the time interval specified in Table 6. If the machine takes more than 90 s to come to rest after switching off the power, the superposition method (see 8.6.2.1) may be used if previously agreed.

8.6.3 Determination by ETD method

8.6.3.1 General

The detectors shall be suitably distributed throughout the winding and the number of detectors installed shall be not less than six.

All reasonable efforts, consistent with safety, shall be made to place the detectors at the points where the highest temperatures are likely to occur, in such a manner that they are effectively protected against contact with the primary coolant.

The highest reading from the ETD elements shall be used to determine the temperature of the winding.

ETD elements or their connections may fail and give incorrect readings. Therefore, if one or more readings are shown to be erratic, after investigation they should be eliminated.

8.6.3.2 Two or more coil-sides per slot

The detectors shall be located between the insulated coil-sides within the slot in positions at which the highest temperatures are likely to occur.

8.6.3.3 One coil-side per slot

The detectors shall be located between the wedge and the outside of the winding insulation in positions at which the highest temperatures are likely to occur, but see also 8.6.1.

8.6.3.4 End windings

The temperature detectors shall be located between two adjacent coil-sides within the end windings in positions where the highest temperatures are likely to occur. The sensing point of each detector shall be in close contact with the surface of a coil-side and be adequately protected against the influence of the coolant, but see also 8.6.1.

When placing a temperature detector in the end windings of high voltage machines, care shall be taken that the stress grading of the insulation is not compromised and that the difference of potential along the winding overhang does not cause problems. In addition, the ground of the measuring system is thus directly capacitive coupled to the HV-system. Disconnection of the measurement ground will in this case immediately lead to over voltages on the measuring system. Measures have to be taken to prevent consequential damage up to lethal injuries.

NOTE If the stator winding is a direct liquid cooled bar type, a temperature detector installed in the nozzle area of each bar monitoring water outlet temperature can give an indication of conductor strand cooling passage blocking.

8.6.4 Determination by thermometer method

All reasonable efforts, consistent with safety, shall be made to place thermometers at the point, or points where the highest temperatures are likely to occur (e.g. in the end windings close to the core iron) in such a manner that they are effectively protected against contact with the primary coolant and are in good thermal contact with the winding or other part of the machine.

The highest reading from any thermometer shall be taken to be the temperature of the winding or other part of the machine.

8.7 Duration of thermal tests

8.7.1 Rating for continuous running duty

The test shall be continued until thermal equilibrium has been reached.

8.7.2 Rating for short-time duty

The duration of the test shall be the time given in the rating.

8.7.3 Rating for periodic duty

Normally the rating for equivalent loading assigned by the manufacturer (see 5.2.6) shall be applied until thermal equilibrium has been reached. If a test on the actual duty is agreed, the load cycle specified shall be applied and continued until practically identical temperature cycles are obtained. The criterion for this shall be that a straight line between the corresponding points of successive duty cycles on a temperature plot has a gradient of less than 1 K per half hour. If necessary, measurements shall be taken at reasonable intervals over a period of time (see 3.25).

8.7.4 Ratings for non-periodic duty and for duty with discrete constant loads

The rating for equivalent loading assigned by the manufacturer (see 5.2.6) shall be applied until thermal equilibrium has been reached.

8.8 Determination of the thermal equivalent time constant for machines of duty type S9

The thermal equivalent time constant with ventilation as in normal operating conditions, suitable for approximate determination of the temperature course, can be determined from the cooling curve plotted in the same manner as in 8.6.2.3. The value of the time constant is 1,44 times (that is to say, 1/ln(2) times) the time taken by the machine to cool to one-half of the full load temperature rise, after its disconnection from the supply.

8.9 Measurement of bearing temperature

Either the thermometer method or the ETD method may be used.

The measuring point shall be as near as possible to one of the two locations specified in Table 7.

Table 7 – Measuring points

Type of bearing	Measuring point	Location of measuring point
Ball or roller	A	In the bearing housing preferably in contact with the outer ring of the bearing, but not more than 10 mm[a] from it[b]
	B	Outer surface of the bearing housing as close as possible to the outer ring of the bearing
Sleeve or tilting pad	A	In the pressure zone of the bearing shell[c] and not more than 10 mm[a] from the oil-film gap[b].
	B	Elsewhere in the bearing shell

[a] The distance is measured to the nearest point of the ETD or thermometer bulb.

[b] In the case of an 'inside out' machine, point A will be in the stationary part not more than 10 mm from the inner ring and point B on the outer surface of the stationary part as close as possible to the inner ring.

[c] The bearing shell is the part supporting the bearing material and which is secured in the housing. The pressure zone is the portion of the circumference which supports the combination of rotor weight and radial loads.

The thermal resistance between the temperature detector and the object whose temperature is to be measured shall be minimized; for example, air gaps shall be packed with thermally conducting paste.

NOTE Between the measuring points A and B, as well as between these points and the hottest point of the bearing, there are temperature differences which depend, among other things, on the bearing size. For sleeve bearings with pressed-in bushings and for ball and roller bearings with an inside diameter of up to 150 mm, the temperature difference between points A and B may be assumed to be negligible. In the case of larger bearings, the temperature difference between measuring points A and B is approximately 15 K.

8.10 Limits of temperature and of temperature rise

8.10.1 General

Limits are given for operation under site operating conditions specified in Clause 6 and at rating for continuous running duty (reference conditions), followed by rules for the adjustment of those limits when operating at site under other conditions and on other ratings. Further rules give adjustments to the limits during thermal testing when conditions at the test site differ from those at the operating site.

It is understood that the temperature of the hottest point of each winding under reference conditions, i. e. the rated conditions, generally does not exceed the agreed thermal class temperature of the insulation system.

The limits are stated relative to the reference coolant specified in Table 5.

A rule is given to allow for the purity of hydrogen coolant.

8.10.2 Indirect cooled windings

Temperature rises under reference conditions shall not exceed the limits given in Table 8 (air coolant) or Table 9 (hydrogen coolant) as appropriate for both, ETD and R method if applicable.

NOTE The measured temperature differences between method ETD and method R may be significantly higher or lower than the temperature limits specified in Table 8 or Table 9, depending on the machine design and the cooling system. It is not intended to compare ETD and R method against each other.

For other operating site conditions, for ratings other than continuous running duty, and for rated voltages greater than 12 000 V, the limits shall be adjusted according to Table 10. (See also Table 11 for limit on coolant temperature which is assumed in Table 10.)

In the case of thermometer readings made in accordance with 8.6.1, the limit of temperature rise shall be according to Table 8.

If, for windings indirectly cooled by air, conditions at the test site differ from those at the operating site, the adjusted limits given in Table 12 shall apply at the test site.

If the adjusted limits given in Table 12 lead to permissible temperatures at the test site which the manufacturer considers to be excessive, the testing procedure and the limits shall be agreed.

No adjustments at the test site are given for windings indirectly cooled by hydrogen, because it is very unlikely that they will be tested at rated load anywhere other than at the operating site.

Table 8 – Limits of temperature rise of windings indirectly cooled by air

Thermal class		130 (B)			155 (F)			180 (H)			200 (N)		
Method of measurement	Th = Thermometer, R = Resistance, ETD = Embedded temperature detector	TH K	R K	ETD K	TH K	R K	ETD K	TH K	R K	ETD K	TH K	R K	ETD K
Item	Part of machine												
1a)	AC windings of machines having outputs of 5 000 kW (or kVA) or more	–	80	85 [a]	–	105	110 [a]	–	125	130 [a]	–	145	150 [a]
1b)	AC windings of machines having outputs above 200 kW (or kVA), but less than 5 000 kW (or kVA)	–	80	90 [a]	–	105	115 [a]	–	125	140 [a]	–	145	160 [a]
1c)	AC windings of machines having outputs of 200 kW (or kVA) or less, other than those in items 1d) or 1e) [b]	–	80	–	–	105	–	–	125	–	–	145	–
1d)	AC windings of machines having rated outputs of less than 600 W (or VA) [b]	–	85	–	–	110	–	–	130	–	–	150	–
1e)	AC windings which are self-cooled without a fan (IC 40) and/or with encapsulated windings [b]	–	85	–	–	110	–	–	130	–	–	150	–
2	Windings of armatures having commutators	70	80	–	85	105	–	105	125	–	125	145	–
3	Field windings of a.c. and d.c. machines other than those in item 4	70	80	–	85	105	–	105	125	–	125	145	–
4a)	Field windings of synchronous machines with cylindrical rotors having a d.c. excitation winding embedded in slots, except synchronous induction motors	–	90	–	–	115	–	–	135	–	–	155	–
4b)	Insulated stationary field windings of d.c. machines having more than one layer	70	80	90	85	105	115	105	125	140	125	145	160
4c)	Low-resistance field windings of d.c. machines having more than one layer and compensating windings of d.c. machines	80	80	–	100	105	–	125	125	–	145	145	–
4d)	Single-layer windings of a.c. and d.c. machines with exposed bare or varnished metal surfaces [c]	90	90	–	110	115	–	135	135	–	155	155	–

[a] For adjustment for high-voltage a.c. windings, see item 4 of Table 10.

[b] With the application of the superposition test method to windings of machines rated at 200 kW (or kVA) or less with thermal classes 130 (B) and 155 (F), the limits of temperature rise given for the resistance method may be exceeded by 5 K.

[c] Also includes multiple layer windings, provided that the under layers are each in contact with the circulating primary coolant.

Table 9 – Limits of temperature rise of windings indirectly cooled by hydrogen

Thermal class			130 (B)		155 (F)	
Method of measurement ETD = Embedded temperature detector			Resistance K	ETD K	Resistance K	ETD K
Item						
1	AC windings of machines having outputs of 5 000 kW (or kVA) or more or having a core length of 1 m or more					
	Absolute hydrogen pressure [b)]	≤ 150 kPa (1,5 bar)	–	85 [a]	–	105 [a]
	> 150 kPa	≤ 200 kPa (2,0 bar)	–	80 [a]	–	100 [a]
	> 200 kPa	≤ 300 kPa (3,0 bar)	–	78 [a]	–	98 [a]
	> 300 kPa	≤ 400 kPa (4,0 bar)	–	73 [a]	–	93 [a]
	> 400 kPa		–	70 [a]	–	90 [a]
2a	AC windings of machines having outputs of less than 5 000 kW (or kVA), or having a core length of less than 1 m		80	85 [a]	100	110 [a]
2b	DC field windings of a.c. and d.c. machines other than those in items 3 and 4		80	–	105	–
3	DC field windings of machines having cylindrical rotors		85	–	105	–
4a	Low-resistance field windings of more than one layer and compensating windings		80	–	100	–
4b	Single-layer windings with exposed bare or varnished metal surfaces [c]		90	–	110	–

[a] For adjustment for high-voltage a.c. windings see item 4 of Table 10.

[b] This is the only item where the limit of temperature rise is dependent on hydrogen pressure.

[c] Also includes multi-layer field windings provided that the under layers are each in contact with the circulating primary coolant.

Table 10 – Adjustments to limits of temperature rise at the operating site of indirect cooled windings to take account of non-reference operating conditions and ratings

Item	Operation conditions or rating	Adjustment to limit of temperature rise ($\Delta\theta$) in Table 8 and Table 9	Item
1a	Maximum temperature of ambient air or of the cooling gas at inlet to the machine (θ_c) and for altitudes of up to 1 000 m. If the difference between the thermal class and the observable limit of temperature, consisting of the sum of the reference cold coolant inlet temperature of 40 °C and the limit of temperature rise according to Table 8 and Table 9 is less or equal to 5 K: For a higher altitude replace 40 °C with the value given in Table 11.	0 °C ≤ θ_c ≤ 40 °C	Increased by the amount by which the coolant temperature is less than 40 °C.

Table 10 – Adjustments to limits of temperature rise at the operating site of indirect cooled windings to take account of non-reference operating conditions and ratings Continued on Next Page

Table 10 – Adjustments to limits of temperature rise at the operating site of indirect cooled windings to take account of non-reference operating conditions and ratings Continued

Item	Operation conditions or rating	Adjustment to limit of temperature rise ($\Delta\theta$) in Table 8 and Table 9	Item
1b	Maximum temperature of ambient air or of the cooling gas at the inlet to the machine (θ_c) and for altitudes of up to 1 000 m. If the difference between the thermal class and the observable limit of the temperature, consisting of the sum of the reference cold coolant inlet temperature of 40 °C and the limit of temperature rise according to Table 8 and Table 9 is larger than 5 K: For a higher altitude replace 40 °C with the value given in Table 11.	0 °C $\leq \theta_c \leq$ 40 °C	The limit of temperature rise $\Delta\theta$ for cold gas temperature θ_c shall be $\Delta\theta = \Delta\theta_{ref}\ [(\theta_{ThCl} - \theta_C) / (\theta_{ThCl} - \theta_{C\text{-}ref})]$ with $\Delta\theta_{ref}$ limit of temperature rise according to Table 8 or Table 9 at 40 °C θ_{ThCl} temperature of the thermal class (for example 130 °C or 155 °C) θ_{Cref} reference cold coolant temperature (40 °C)
1c		40 °C < $\theta_c \leq$ 60 °C	Reduced by the amount by which the coolant temperature exceeds 40 °C
1d		θ_c < 0 °C or θ_c > 60 °C	By agreement
2	Maximum temperature of the water at the inlet to water-cooled heat exchangers or maximum temperature of the ambient water for submersible machines with surface cooling or machines with water jacket cooling (θ_w)	5 °C $\leq \theta_w \leq$ 25 °C θ_w > 25 °C	Increased by 15 K and by the difference between 25 °C and θ_w Increased by 15 K and reduced by the difference between θ_w and 25 °C
3a	Altitude (*H*) – general rule	1 000 m < *H* $\leq$ 4 000 m and maximum ambient air temperature not specified H > 4 000 m	No adjustment. It shall be assumed that the reduced cooling resulting from altitude is compensated by a reduction of maximum ambient temperature below 40 °C and that the total temperature will therefore not exceed 40 °C plus the Table 8 and Table 9 temperature rises [a] By agreement
3b	Altitude (*H*) – power plant generator specific	according specification of the purchaser	The capability of power plant generators should be adjusted and is a function of the altitude (air pressure). No adjustment of the capability is needed for power plant generators if the absolute coolant pressure is maintained constant regardless of the altitude.
4	Rated stator winding voltage (U_N)	12 kV < $U_N \leq$ 24 kV U_N > 24 kV	$\Delta\theta$ for embedded temperature detectors (ETD) shall be reduced by 1 K for each 1 kV (or part thereof) from 12 kV up to and including 24 kV By agreement
5 [b]	Rating for short-time duty (S2), with rated output less than 5 000 kW (kVA)		Increased by 10 K
6 [b]	Rating for non-periodic duty (S9)		$\Delta\theta$ may be exceeded for short periods during the operation of the machine
7 [b]	Rating for duty with discrete loads (S10)		$\Delta\theta$ may be exceeded for discrete periods during the operation of the machine

[a] Assuming the decrease in ambient temperature is 1 % of the limiting rises for every 100 m of altitude above 1 000 m, the maximum ambient air temperature at the operating site can be as shown in Table 11.

[b] For air-cooled windings only.

Table 11 – Assumed maximum ambient temperature

Altitude m	Thermal class			
	130 (B)	155 (F)	180 (H)	200 (N)
	Temperature °C			
1 000	40	40	40	40
2 000	32	30	28	26
3 000	24	19	15	12
4 000	16	9	3	0

8.10.3 Direct cooled windings

Temperatures under reference conditions shall not exceed the limits given in Table 13.

For other operating site conditions the limits shall be adjusted according to Table 14.

If conditions at the test site differ from those at the operating site, the adjusted limits given in Table 15 shall apply at the test site.

If the adjusted limits given in Table 15 lead to temperatures at the test site which the manufacturer considers to be excessive, the testing procedure and the limits shall be agreed.

8.10.4 Adjustments to take account of hydrogen purity on test

For windings directly or indirectly cooled by hydrogen, no adjustment shall be made to limits of temperature rise or of total temperature if the proportion of hydrogen in the coolant is between 95 % and 100 %.

8.10.5 Permanently short-circuited windings, magnetic cores and all structural components (other than bearings) whether or not in contact with insulation

The temperature rise or the temperature shall not be detrimental to the insulation of that part or to any other part adjacent to it.

8.10.6 Commutators and sliprings, open or enclosed and their brushes and brushgear

The temperature rise or temperature of any commutator, slipring, brush or brushgear shall not be detrimental to the insulation of that part or any adjacent part.

The temperature rise or temperature of a commutator or slipring shall not exceed that at which the combination of brush grade and commutator or slipring material can handle the current over the full operating range.

Table 12 – Adjusted limits of temperature rise at the test site ($\Delta\theta_T$) for windings indirectly cooled by air to take account of test site operating conditions

Item	Test condition		Adjusted limit at test site $\Delta\theta_T$
1	Temperature difference of reference coolant at test site (θ_{cT}) and operating site (θ_c)	Absolute value of $(\theta_c - \theta_{cT}) \leq 30$ K	$\Delta\theta_T = \Delta\theta$
		Absolute value of $(\theta_c - \theta_{cT}) > 30$ K	By agreement
2	Difference of altitudes of test site (H_T) and operating site (H)	1 000 m < $H \leq$ 4 000 m $H_T \leq$ 1 000 m	$\Delta\theta_T = \Delta\theta$ {1 – [(H – 1000 m) / 10 000 m]}
		$H \leq$ 1 000 m 1 000 m < $H_T \leq$ 4 000 m	$\Delta\theta_T = \Delta\theta$ {1 + [(H_T – 1000 m) / 10 000 m]}
		1 000 m < $H \leq$ 4 000 m 1 000 m < $H_T \leq$ 4 000 m	$\Delta\theta_T = \Delta\theta$ {1 + [(H_T – H) / 10 000 m]}
		H > 4 000 m or H_T > 4 000 m	By agreement

NOTE 1 $\Delta\theta$ is given in Table 8 and adjusted if necessary in accordance with Table 10.

NOTE 2 If temperature rise is to be measured above the temperature of the water where it enters the cooler, the effect of altitude on the temperature difference between air and water should strictly be allowed for. However, for most cooler designs, the effect will be small, the difference increasing with increasing altitude at the rate of roughly 2 K per 1 000 m. If an adjustment is necessary, it should be by agreement.

Table 13 – Limits of temperature of directly cooled windings and their coolants

Thermal class		130 (B)			155 (F)		
Method of measurement		Thermometer °C	Resistance °C	ETD °C	Thermometer °C	Resistance °C	ETD °C
Item	Part of the machine						
1	Coolant at the outlet of direct-cooled a.c. windings. These temperatures are preferred to the values given in item 2 as the basis of rating.						
1a)	Gas (air, hydrogen, helium, etc.)	110	–	–	130	–	–
1b)	Water	90	–	–	90	–	–
2	AC windings						
2a)	Gas cooled	–	–	120 [a]	–	–	145 [a]
2b)	Liquid cooled						
3	Field windings of turbine type machines						
3a)	Cooled by gas leaving the rotor through the following number of outlet regions [b]						
	1 and 2	–	100	–	–	115	–
	3 and 4	–	105	–	–	120	–
	5 and 6	–	110	–	–	125	–

Table 13 – Limits of temperature of directly cooled windings and their coolants Continued on Next Page

Table 13 – Limits of temperature of directly cooled windings and their coolants Continued

Thermal class		130 (B)			155 (F)		
Method of measurement		Thermometer °C	Resistance °C	ETD °C	Thermometer °C	Resistance °C	ETD °C
Item	Part of the machine						
	7 to 14	–	115	–	–	130	–
	above 14	–	120	–	–	135	–
3b)	Liquid cooled	Observance of the maximum coolant temperature given in item 1b) will ensure that the hotspot temperature of the winding is not excessive					
4	Field windings of a.c. and d.c. machines having d.c. excitation other than in item 3.						
4a)	Gas cooled	–	130	–	–	150	–
4b)	Liquid cooled	Observance of the maximum coolant temperature given in item 1b) will ensure that the hotspot temperature of the winding is not excessive					

[a] No adjustment in the case of high-voltage a.c. windings is applicable to these items, see Table 14, item 2.

[b] The rotor ventilation is classified by the number of radial outlet regions on the total length of the rotor. Special outlet regions for the coolant of the end windings are included as one outlet for each end. The common outlet region of two axially opposed flows is to be counted as two regions.

Table 14 – Adjustments to limits of temperature at the operating site for windings directly cooled by air or hydrogen to take account of non-reference operating conditions and ratings

Item	Operating condition or rating		Adjustment to limit of temperature in Table 13
1	Temperature θ_c of reference coolant	0 °C ≤ θ_c ≤ 40 °C	Reduction by the amount of the difference between 40 °C and θ_c. However, by agreement, a smaller reduction may be applied, provided that for θ_c < 10 °C the reduction is made at least equal to the difference between 10 °C and θ_c.
		40 °C < θ_c ≤ 60 °C	No adjustment
		θ_c < 0 °C or θ_c > 60 °C	By agreement
2	Rated stator winding voltage (U_N)	U_N > 11 kV	No adjustment The heat flow is mainly towards the coolant inside the conductors and not through the main insulation of the winding.

Table 15 – Adjusted limits of temperature at the test site θ_T for windings directly cooled by air to take account of test site operating conditions

Item	Test condition		Adjusted limit of temperature at test site θ_T
1	Difference of reference coolant temperatures of test site (θ_{cT}) and operating site (θ_c)	Absolute value of ($\theta_c - \theta_{cT}$) $\leq$ 30 K	$\theta_T = \theta$
		Absolute value of ($\theta_c - \theta_{cT}$) > 30 K	By agreement
2	Difference of altitudes of test site (H_T) and operating site (H)	1 000 m < $H \leq$ 4 000 m $H_T \leq$ 1 000 m	$\theta_T = (\theta - \theta_c)\ \{1 - [(H - 1000\text{ m}) / 10\ 000\text{ m}]\} + \theta_{cT}$
		$H \leq$ 1 000 m 1 000 m < $H_T \leq$ 4 000 m	$\theta_T = (\theta - \theta_c)\ \{1 + [(H_T - 1000\text{ m}) / 10\ 000\text{ m}]\} + \theta_{cT}$
		1 000 m < $H \leq$ 4 000 m 1 000 m < $H_T \leq$ 4 000 m	$\theta_T = (\theta - \theta_c)\ \{1 + [(H_T - H) / 10\ 000\text{ m}]\} + \theta_{cT}$
		H > 4 000 m or H_T > 4 000 m	By agreement
NOTE θ is given in Table 13 and adjusted if necessary in accordance with Table 14.			

9 Other performance and tests

9.1 Routine tests

Routine tests are always factory tests. They shall be performed on all machines which are assembled at the factory of the manufacturer. The machine needs not be completely assembled. It can lack components which are not significant for the testing. Routine tests do not need the machine to be coupled except for the open-circuit test on synchronous machines.

The minimum test schedule is listed in Table 16 and is applicable for machines with rated output $\leq$ 20 MW (MVA) that are assembled and tested in the factory. Additional routine tests may be performed especially on machines with ratings above 200 kW (kVA). The term synchronous machines includes brushless permanent magnet machines.

For d.c. machines, depending on size and design, a commutation test under load may be performed as a routine test.

Table 16 – Minimum routine tests for machines assembled and tested in the factory of the manufacturer

Number	Test	Induction machines (including synchronous induction motors) [a]	Synchronous machines		DC machines with separate or shunt excitation
			Motors	Generators	
1	Resistance of windings (cold)	Yes	Yes		Yes
2	No-load losses and current [e]	Yes	–		–
3a	No-load losses at unity power factor [b]	–	Yes [d]		–
3b	No-load excitation current at rated voltage by open-circuit test [b]	–	Yes [d]		–
4	Excitation current at rated speed and rated armature voltage	–	–		Yes
5	Open circuit secondary induced voltage at standstill (wound rotor)[c]	Yes	–		–

Table 16 – Minimum routine tests for machines assembled and tested in the factory of the manufacturer
Continued on Next Page

Table 16 – Minimum routine tests for machines assembled and tested in the factory of the manufacturer Continued

Number	Test	Induction machines (including synchronous induction motors) [a]	Synchronous machines		DC machines with separate or shunt excitation
			Motors	Generators	
6a	Direction of rotation	Yes	Yes	–	Yes
6b	Phase sequence	–	–	Yes	–
7	Withstand voltage test according to 9.2	Yes	Yes		Yes

[a] IEC 60050-411:1996, 411-33-04.
[b] Permanent magnet machines excluded.
[c] For safety considerations this test may be performed at reduced voltage.
[d] Only one of the tests 3a or 3b is required.
[e] No stabilization of temperature required for measurement of no-load losses.

9.2 Withstand voltage test

A test voltage, as specified below, shall be applied between the windings under test and the frame of the machine, with the core and the windings not under test connected to the frame. It shall be applied only to a new and completed machine with all its parts in place under conditions equivalent to normal working conditions and shall be carried out at the manufacturer's factory or after erection on site. A withstand voltage test shall be carried out after the completion of the full test sequence.

NOTE 1 For high voltage machines, additional methods as described in the parts of IEC 60034-27 can be used to proof the suitability of the machine winding insulation system.

Except as stated below, the frequency of the test voltage shall be the power frequency at the factory of the manufacturer, and the voltage waveform shall be as near as possible to a sine wave form. The final value of the voltage shall be in accordance with Table 17. However, for machines with a rated voltage 6 kV or greater, when power frequency equipment is not available, then by agreement a d.c. test may be carried out at a voltage 1,7 times the r.m.s. value given in Table 17.

NOTE 2 It is recognized that, during a d.c. test, the surface potential distribution along the end winding insulation and the ageing mechanisms are different from those occurring during an a.c. test.

In the case of polyphase machines with rated voltage above 1 kV having both ends of each phase individually accessible, the test voltage shall be applied between each phase and the frame, with the core and the other phases and windings not under test connected to the frame. The test shall be commenced at a voltage not exceeding half of the full test voltage. The voltage shall then be increased to the full value, steadily or in steps of not more than 5 % of the full value, the time allowed for the voltage increase from half to full value being not less than 10 s. The full test voltage shall then be maintained for 1 min in accordance with the value as specified in Table 17. There shall be no failure (see IEC 60060-1) during this period.

During the routine testing of quantity produced machines up to 200 kW (or kVA) and rated for $U_N \leq 1$ kV, the 1 min test may be replaced by a test of 1 s at 120 % of the test voltage specified in Table 17.

The withstand voltage test at full voltage made on the windings on acceptance shall not be repeated. If, however, a second test is made at the request of the purchaser, after further drying if considered necessary, the test voltage shall be 80 % of the voltage specified in Table 17.

To determine the test voltage from Table 17 for d.c. motors supplied by static power converters, the direct voltage of the motor or the r.m.s. phase-to-phase value of the rated alternating voltage at the input terminals of the static power converter shall be used, whichever is the greater.

Voltage variation according to 7.3 should not be considered when determining the test voltage.

Completely rewound windings shall be tested at the full test voltage for new machines.

When a user and a repair contractor have agreed to carry out withstand voltage tests in cases where windings have been partially rewound or in the case of an overhauled machine, the following procedure is recommended:

a) partially rewound windings are tested at 75 % of the test voltage for a new machine. Before the test, the old part of the winding shall be carefully cleaned and dried;

b) overhauled machines, after cleaning and drying, are subjected to a test at a voltage equal to 1,5 times the rated voltage, with a minimum of 1 000 V if the rated voltage is equal to or greater than 100 V and a minimum of 500 V if the rated voltage is less than 100 V.

Table 17 – Withstand voltage tests

Item	Machine or part	Test voltage (r.m.s.)
1	Insulated windings of rotating machines of rated output less than 1 kW (or kVA) and of rated voltage less than 100 V with the exception of those in items 4 to 8	500 V + twice the rated voltage
2	Insulated windings of rotating machines of rated output less than 10 000 kW (or kVA) with the exception of those in item 1 and items 4 to 8 [b]	1 000 V + twice the rated voltage with a minimum of 1 500 V [a]
3	Insulated windings of rotating machines of rated output 10 000 kW (or kVA) or more with the exception of those in items 4 to 8 [b] Rated voltage [a]: – up to and including 24 000 V – above 24 000 V	 1 000 V + twice the rated voltage Subject to agreement
4	Separately excited field windings of d.c. machines	1 000 V + twice the maximum rated circuit voltage with a minimum of 1 500 V
5	Field windings of synchronous generators, synchronous motors and synchronous condensers.	
5a)	Rated field voltage: – up to, and including 500 V, – above 500 V.	 Ten times the rated field voltage with a minimum of 1 500 V 4 000 V + twice the rated field voltage
5b)	When a machine is intended to be started with the field winding short-circuited or connected across a resistance of value less than ten times the resistance of the winding	Ten times the rated field voltage with a minimum of 1 500 V and a maximum of 3 500 V.
5c)	When the machine is intended to be started either with the field winding connected across a resistance of value equal to, or more than, ten times the resistance of the winding, or with the field windings on open circuit with or without a field-dividing switch	1 000 V + twice the maximum value of the r.m.s. voltage, which can occur under the specified starting conditions, between the terminals of the field winding, or in the case of a sectionalized field winding between the terminals of any section, with a minimum of 1 500 V [c]
6	Secondary (usually rotor) windings of induction machines or synchronous induction motors if not permanently short-circuited (e.g. if intended for rheostatic starting)	

Table 17 – Withstand voltage tests Continued on Next Page

Table 17 – Withstand voltage tests Continued

Item	Machine or part	Test voltage (r.m.s.)
6a)	For non-reversing motors or motors reversible from standstill only	1 000 V + twice the open-circuit standstill voltage as measured between slip-rings or secondary terminals with rated voltage applied to the primary windings
6b)	For motors to be reversed or braked by reversing the primary supply while the motor is running	1 000 V + four times the open-circuit standstill secondary voltage as defined in item 6a)
7	Exciters (except as below)	As for the windings to which they are connected
	Exception 1: exciters of synchronous motors (including synchronous induction motors) if connected to earth or disconnected from the field windings during starting	1 000 V + twice the rated exciter voltage, with a minimum of 1 500 V
	Exception 2: separately excited field windings of exciters (see item 4)	
8	Electrically interconnected machines and apparatus	A repetition of the tests in items 1 to 7 above should be avoided if possible, but if a test is performed on a group of machines and apparatus, each having previously passed its withstand voltage test, the test voltage to be applied to such an electrically connected arrangement shall be 80 % of the lowest test voltage appropriate for any individual piece of the arrangement [d]
9	Devices that are in physical contact with windings, for example, temperature detectors, shall be tested to the machine frame. During the withstand test on the machine, all devices in physical contact with the winding shall be connected to the machine frame.	1 500 V

[a] For two-phase windings having one terminal in common, the voltage in the formula shall be the highest r.m.s. voltage arising between any two terminals during operation.

[b] Withstand tests on machines having graded insulation should be the subject of agreement.

[c] The voltage occurring between the terminals of the field windings, or sections thereof, under the specified starting conditions, may be measured at any convenient reduced supply voltage, and the voltage so measured shall be increased in the ratio of the specified starting supply voltage to the test supply voltage.

[d] For windings of one or more machines connected together electrically, the voltage to be considered is the maximum voltage that occurs in relation to earth.

[e] The leakage current drawn by the machine during withstand voltage test will vary according to the size of the machine.

9.3 Occasional excess current

9.3.1 General

The excess current capability of rotating machines is given for the purpose of co-ordinating these machines with control and protective devices. Tests to demonstrate these capabilities are not a requirement of this document. The heating effect in the machine windings varies approximately as the product of the time and the square of the current. A current in excess of the rated current will result in increased temperature. Unless otherwise agreed, it can be assumed that the machine will not be operated at the excess currents specified for more than a few short periods during the lifetime of the machine. When an a.c. machine is to be used as both a generator and a motor, the excess current capability should be the subject of agreement.

NOTE For the capability of synchronous machines concerning the occasional negative-sequence component of current under fault conditions, see 7.2.3.

9.3.2 Generators

AC generators having rated outputs not exceeding 1 200 MVA shall be capable of withstanding a current equal to 1,5 times the rated current for not less than 30 s.

AC generators having rated outputs above 1 200 MVA shall be capable of withstanding a current equal to 1,5 times the rated current for a period which shall be agreed, but this period shall be not less than 15 s.

9.3.3 Motors (except commutator motors and permanent magnet motors)

Polyphase motors having rated outputs not exceeding 315 kW and rated voltages not exceeding 1 kV shall be capable of withstanding:

– a current equal to 1,5 times the rated current for not less than 2 min.

NOTE For polyphase motors having rated outputs above 315 kW and all single-phase motors, no occasional excess current is specified.

9.3.4 Commutator machines

A commutator machine shall be capable of withstanding, for 60 s, 1,5 times rated current under the appropriate combination of conditions as follows:

a) speed:

1) d.c. motor: highest full-field speed;

2) d.c. generator: rated speed;

3) a.c. commutator motor: highest full-field speed;

b) armature voltage: that corresponding to the specified speed.

NOTE Attention should be given to the limits of commutation capability.