
British Standard

General requirements for rotating electrical machines

Part 101. Specification for rating and performance

Règles générales pour les machines électriques tournantes

Partie 101. Caractéristiques assignées et caractéristiques de fonctionnement — Spécifications

Allgemeine Anforderungen an umlaufende elektrische Maschinen

Teil 101. Auslegung und Leistung

Contents

	Page		Page
Foreword	1	Section twelve. Co-ordination of voltages and outputs	
Committees responsible	Back cover	29. Co-ordination of voltages and outputs	43
Specification		Section thirteen. Constructional requirements	
Section one. Scope		30. Earth terminals	43
1. Scope	2	31. Shaft extension key	44
Section two. Definitions		Appendices	
2. General	2	I. Classification of insulating materials	56
Section three. Duty and rating		A. Measurement of final temperatures of machines: guidance on method of extrapolation	59
3. Rules for declaration of duty and for selection of a class of rating	5	B. Information to be given by purchaser with enquiry and order	60
4. Duty types	6	C. New arrangement of BS 4999	62
5. Classes of rating	7		
6. Designation	8	Tables	
7. Assignment of ratings	9	I. Limits of temperature rise of machines indirectly cooled by air	22
8. Rated output	10	II. Limits of temperature rise of machines indirectly cooled by hydrogen	23
9. Rated voltage	10	III. Limits of temperature of directly cooled machines and their coolants	24
10. Machines with more than one rating	10	IV. Assumed maximum ambient temperatures	26
Section four. Operating conditions		V. Dielectric tests	28
11. Altitude, temperature and coolant	11	VI. Overspeeds	32
12. Electrical conditions	12	VII. Unbalanced operating conditions for synchronous machines	34
Section five. Temperature rise		VIII. Schedule of tolerances	38
13. (Reserved for future use)		IX. Weighting factors	42
14. Conditions during temperature-rise test	14	X. Cross-sectional areas of earth conductors	44
15. Determination of temperature rise	15	XI. (Untitled)	56
16. Limits of temperatures and temperature rises	21	XII. Classification of insulating materials	58
Section six. Dielectric tests		Figures	
17. Dielectric tests	27	1. Continuous running duty. Duty type S1	45
Section seven. Miscellaneous characteristics		2. Short time duty. Duty type S2	46
18. Occasional excess current for rotating machines	30	3. Intermittent periodic duty. Duty type S3	47
19. Momentary excess torque for motors	30	4. Intermittent periodic duty with starting. Duty type S4	48
20. Pull-up torque	31	5. Intermittent periodic duty with electric braking. Duty type S5	49
21. Overspeed	32	6. Continuous operation periodic type. Duty type S6	50
22. Unbalanced currents of synchronous machines	34	7. Continuous operation periodic duty with electric braking. Duty type S7	51
23. Short-circuit current	34	8. Continuous operation periodic duty with related load/speed changes. Duty type S.8	52
24. Short-circuit withstand and excitation of synchronous machines	35	9. Duty with non-periodic load and speed variations. Duty type S9	53
Section eight. Commutation test		10. Weighting curve	54
25. Commutation test for direct or alternating current commutator machines	37	11. Adjustments for maximum ambient or primary coolant temperature (see Sub-clauses 16.3.3 and 16.3.4)	55
Section nine. Tolerances		A.1 Measurement of final temperature of machine: method of extrapolation	59
26. Schedule of tolerances on quantities involved in the rating of electrical machines	37		
Section ten. Rating plates			
27. Rating plates	39		
Section eleven. Irregularities of waveform			
28. Requirements and tests	40		

Foreword

This Part of BS 4999 has been prepared under the direction of the Power Electrical Engineering Standards Committee. It supersedes the 1972 editions of BS 4999 : Parts 1, 4, 30, 31, 32 and 69, which are withdrawn.

This standard implements CENELEC* Harmonization Document HD 53.1.S2 (1984) and is technically equivalent to Publication 34-1 : 1983 of the International Electrotechnical Commission. For convenience, the IEC text has been reproduced in this standard with some changes to take account of the CENELEC common modifications. As a result, some terminology and certain conventions are not identical with those used in British Standards. The clauses in which the IEC text has been changed to take account of the CENELEC modifications are **1, 2.23, 2.28, 11.3, 12.2.1, 15.3, 15.3.3, 17, 24.2, 27** and **31** and these are indicated by a vertical line in the margin. Any references in these clauses to CENELEC Harmonization Documents have been changed to references to the British Standards that implement the Harmonization Documents. Also throughout the text, references to IEC publications and ISO standards have been changed to the technically equivalent British Standards, except in the case of the reference to IEC Publication 38 in **12.1** and the reference to IEC Publication 279 in **15.2.4** for which there are no technically equivalent British Standards. The Technical Committee has reviewed the provisions of these two IEC publications and has decided that they are acceptable for use in conjunction with this standard. In IEC Publication 38 reference is made in Table 1 to a nominal system voltage of 230/400 V but in the UK the corresponding nominal system voltage is 240/415 V.

Three national appendices have been included in this standard: national appendix A 'Measurement of the final temperatures of machines: guidance on method of extrapolation' was included in BS 4999 : Part 32 : 1972, which is now withdrawn. A note has been added to **15.4.2** to make reference to this national appendix.

National appendix B 'Information to be given by the purchaser with enquiry and order' was included in BS 4999 : Part 31 : 1972, which is now withdrawn.

National appendix C 'New arrangement of BS 4999' gives the arrangement that is being adopted to bring the Part numbers into line with those of IEC Publication 34. In the new arrangement, Parts 101, 102, 105 to 109, 111 and 112 are related to Parts 1, 2, 5 to 9, 11 and 12 respectively of IEC Publication 34, the 100 series of numbers having been adopted to avoid confusion with superseded Parts of BS 4999. A gap has been left between numbers 112 and 140 to allow for the future addition of Parts related to the future Parts of IEC Publication 34. Parts 140 to 145 are not closely related to the Parts of the IEC Publication 34.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

* European Committee for Electrotechnical Standardization.

British Standard

General requirements for rotating electrical machines

Part 101. Specification for rating and performance

SECTION ONE — SCOPE

1. Scope

This Part of BS 4999 is applicable to all rotating machines except those covered by other British Standards, as far as they exist, e.g. BS 173 covering the performance of rotating electrical machines for rail and road vehicles. Machines within the scope of this standard may also be subject to superseding, modifying or additional requirements in other British Standards, for example BS 5501 : Parts 1 to 7 covering electrical apparatus for potentially explosive atmospheres.

Note 1. — If particular clauses of this standard are modified to meet special applications, for example machines subject to radioactivity or machines for aerospace all other clauses apply in so far as they are compatible.

2. — The titles of the publications referred to in this standard are listed on the inside back cover.

SECTION TWO — DEFINITIONS

2. General

For the definitions of general terms used in this standard, reference should be made to BS 4727 : Part 2 : Group 03.

For the purposes of this Part of BS 4999, the following definitions apply:

2.1 Rating

The whole of the numerical values of the electrical and mechanical quantities with their durations and sequence assigned to the machine by the manufacturer and stated on the rating plate, the machine complying with the specified conditions.

2.2 Rated value

The numerical value of a quantity included in the rating.

2.3 Rated output

The numerical value of the output included in the rating.

2.4 Load

All the numerical values of the electrical and mechanical quantities that signify the demand to be made on a rotating machine by an electrical circuit or a mechanism at a given instant.

2.5 No-load (operation)

The state of a machine rotating with zero output power (but under otherwise normal operating conditions).

2.6 Full load

The highest value of load specified for a machine operating at rated output.

2.7 Full load power

The highest value of power specified for a machine operating at rated output.

Note. — This concept also applies to torque, current, speed, etc.

2.8 Rest and de-energized

The complete absence of all movement and of all electrical supply or mechanical drive.

2.9 Duty

The 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.

2.10 Duty type

A 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.

2.11 Thermal equilibrium

The state reached when the temperature rises of the several parts of the machine do not vary by more than 2 K over a period of 1 h.

2.12 Cyclic duration factor

The ratio between the period of loading, including starting and electric braking, and the duration of the duty cycle, expressed as a percentage.

2.13 Locked rotor torque

The minimum measured torque which the motor develops with the rotor locked and rated voltage applied at rated frequency.

2.14 Locked rotor current

The measured steady-state root-mean-square current taken from the line with the rotor locked with rated voltage and frequency applied.

2.15 Pull-up torque (of an a.c. motor)

The smallest 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.

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

Note. — This value applies to the usual mean torque characteristic which excludes transient effects.

2.16 Breakdown torque (of an a.c. motor)

The maximum torque which the motor develops with rated voltage and frequency applied at operating temperature without an abrupt drop in speed.

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

Note. — This value applies to the usual mean torque characteristic which excludes transient effects.

2.17 Pull-out torque (of a synchronous motor)

The maximum torque which the synchronous motor develops at operating temperature and at synchronous speed with rated voltage, frequency and field current.

2.18 Cooling

A procedure by means of which heat resulting from losses occurring in a machine is given up first to a primary coolant, by increasing its temperature. The heated primary coolant may be replaced by a new coolant at a lower temperature or may be cooled by a secondary coolant in some form of heat exchanger.

2.19 Coolant

A medium (liquid or gas) by means of which heat is transferred.

2.20 Primary coolant

A medium (liquid or gas) which, by being at a lower temperature than a part of a machine and in contact with it, removes heat from that part.

2.21 Secondary coolant

A 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.

2.22 Direct cooled (inner cooled) winding

A winding in which the coolant flows through hollow conductors, tubes or channels which form an integral part of the winding inside the main insulation.

2.23 Indirect cooled winding

A winding cooled by any other method than that of Sub-clause 2.22.

Notes 1. — In all cases when “indirect” or “direct” is not stated, an indirect cooled winding is implied.

2. — For other definitions, other than those in Sub-clauses 2.18 to 2.23, concerning cooling and coolants, reference should be made to BS 4999 : Part 106.

2.24 *Supplementary insulation*

An independent insulation applied in addition to the basic insulation in order to ensure protection against electric shock in the event of failure of the basic insulation.

2.25 *Moment of inertia*

The (dynamic) moment of inertia of a body about an axis is the sum (integral) of the products of its mass elements and the squares of their distances (radii) from the axis.

Note. — This quantity is designated by the letter symbol J and is expressed in kg/m^2 .

2.26 *Thermal equivalent time constant*

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

2.27 *Encapsulated winding*

A winding which is completely enclosed or sealed by moulded insulation.

2.28 *Direction of rotation and terminal markings*

For this definition reference shall be made to BS 4999 : Part 108.

SECTION THREE — DUTY AND RATING

3. Rules for declaration of duty and for selection of a class of rating**3.1 *Duty***

The duty, as defined in Sub-clause 2.9, may be described by one of the duty types defined in Clause 4, or by the specification of another duty by the purchaser.

3.2 *Declaration of duty*

It is the responsibility of the purchaser to declare the duty as accurately as possible.

In certain cases, where the load does not vary or where it varies in a known manner, the duty may be declared numerically or with the aid of a time sequence graph of the variable quantities.

If the time sequence is indeterminate, a fictitious time sequence (duty types S2 to S8) not less onerous than the true one, shall be selected, or the duty type S9 shall be applied.

If the duty is not stated, duty type S1 (continuous running duty) applies.

3.3 *Rating*

The rating, as defined in Sub-clause 2.1, is assigned by the manufacturer by selection of one of the classes of rating defined in Clause 5. The class of rating selected shall normally be maximum continuous rating based on duty type S1 (continuous running duty) or short-time rating based on duty type S2 (short-time duty).

If this is not possible, a periodic duty type rating based on one of the duty types S3 to S8 (periodic duty) or the non-periodic duty type rating based on the duty type S9 (non-periodic duty) shall be selected.

3.4 *Selection of a class of rating*

Where a machine is manufactured for general purposes, it shall have maximum continuous rating and be capable of performing duty type S1.

If the duty has not been specified by the purchaser, duty type S1 applies and the class of rating assigned shall be maximum continuous rating.

When a machine is intended to have a short-time rating, the rating shall be based on duty type S2 as defined in Sub-clause 4.2 and as designated in Clause 6.

When a machine is intended to supply varying loads or loads including a period of no-load or periods where the machine will be in a state of rest and de-energized, the class of rating shall be a periodic duty type rating based on a duty type selected from duty types S3 to S8 as defined in Sub-clauses 4.3 to 4.8 and as designated in Clause 6.

When a machine is intended non-periodically to supply variable loads at variable speeds, including overloads, the non-periodic duty type rating shall be based on duty type S9 as defined in Sub-clause 4.9 and as designated in Clause 6.

A class of rating having been assigned to a machine on the basis of a duty type selected from duty types S3 to S9, where a test is specified it is normally sufficient to test the machine at an equivalent continuous rating as defined in Sub-clause 5.3.

In some cases, a test at the actual or estimated duty may be arranged by agreement between manufacturer and purchaser but such a procedure is not generally practical.

In the determination of the rating:

- For duty types S1 to S8, the specified value(s) of the constant load(s) is taken to be the rated output and is expressed in watts for motors and volt-amperes for generators. See Sub-clauses 4.1 to 4.8 and period(s) “N” in Figures 1 to 8.
- For duty type S9, a suitable full load value(s) is taken as the rated output. See Sub-clause 4.9 and “C_p” in Figure 9.

4. **Duty types***

The duty types are as follows:

4.1 *Continuous running duty — Duty type S1*

Operation at constant load of sufficient duration for thermal equilibrium to be reached (see Figure 1.).

4.2 *Short-time duty — Duty type S2*

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

* Whilst the nine duty types are intended to apply primarily to motors, certain of them may also be used to define generator duties (e.g. the duty types S1, S2).

4.3 *Intermittent periodic duty — Duty type S3**

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

4.4 *Intermittent periodic duty with starting — Duty type S4**

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

4.5 *Intermittent periodic duty with electric braking — Duty type S5**

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

4.6 *Continuous-operation periodic duty — Duty type S6**

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

4.7 *Continuous-operation periodic duty with electric braking — Duty type S7**

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

4.8 *Continuous-operation periodic duty with related load/speed changes — Duty type S8**

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

4.9 *Duty with non-periodic load and speed variations — Duty type S9*

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

Note. — For this duty type suitable full load values should be taken as the basis of the overload concept.

5. **Classes of rating**

In assigning the rating, the manufacturer shall select one of the classes of rating defined in Sub-clauses 5.1 to 5.5.

* The duration of a cycle is generally too short for thermal equilibrium to be reached (see Sub-clause 5.4).

5.1 *Maximum continuous rating*

The statement of the load and conditions, assigned to the machine by the manufacturer, at which the machine may be operated for an unlimited period while complying with the requirements of this standard.

5.2 *Short-time rating*

The statement of the load, time and conditions, assigned to the machine by the manufacturer, at which the machine may be operated for a limited period, starting at the ambient temperature, while complying with the requirements of this standard.

5.3 *Equivalent continuous rating*

The statement of the load and conditions, assigned to the machine for test purposes by the manufacturer, at which the machine may be operated until thermal equilibrium is reached, and which is considered to be equivalent to one of the periodic duty types defined in Sub-clauses 4.3 to 4.8 or to the duty type S9, as defined in Sub-clause 4.9, while complying with the requirements of this standard.

5.4 *Periodic duty type rating*

The statement of the loads and conditions, assigned to the machine by the manufacturer, at which the machine may be operated on duty cycles while complying with the requirements of this standard.

This class of rating if applied shall correspond to one of the periodic duty types defined in Sub-clauses 4.3 to 4.8.

The time for a duty cycle shall be 10 min and the cyclic duration factor shall be one of the following values:

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

5.5 *Non-periodic duty type rating*

The statement of the varying loads over varying speed and conditions, including overloads, assigned to the machine by the manufacturer, at which the machine may be operated non-periodically while complying with the requirements of this standard.

This class of rating if applied shall correspond to the non-periodic duty with non-periodic load and speed variations, as defined in Sub-clause 4.9.

6. **Designation**

6.1 *Duty types*

A duty type may be designated by an abbreviation of the terms given in Clause 4, for example duty types S1 and S9 by S1 and S9.

For the duty type S2, the abbreviation S2 is followed by an indication of the duration of the duty. For duty types S3 and S6, the abbreviations S3 and S6 are followed by the cyclic duration factor.

Examples: S2 60 min
S3 25%
S6 40%

For the duty types S4 and S5, the abbreviations S4 and S5 are followed by the indication of the cyclic duration factor and 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% $J_M = 0.15 \text{ kg m}^2$ $J_{ext} = 0.7 \text{ kg m}^2$

For the duty type S7, the abbreviation S7 is 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 $J_M = 0.4 \text{ kg m}^2$ $J_{ext} = 7.5 \text{ kg m}^2$

For the duty type S8, the abbreviation S8 is 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 $J_M = 0.5 \text{ kg m}^2$ $J_{ext} = 6 \text{ kg m}^2$ 16 kW 740 r/min 30%
 40 kW 1460 r/min 30%
 25 kW 980 r/min 40%

6.2 Classes of rating

The designations of the classes of rating are as follows:

- maximum continuous rating — “cont” or “S1”.
- short time rating — duration of the operating period, e.g. “60 min” or “S2 60 min”.
- equivalent continuous rating — “equ”.
- periodic and non-periodic duty type ratings — as for the duty types. See above, for example “S3 25%”.

The designations specified in Sub-clauses 6.1 and 6.2 follow the value of the rated output. If no designation follows the rated output, maximum continuous rating applies.

7. Assignment of ratings

The ratings shall be assigned in accordance with the requirements of this section and be marked on the rating plate in accordance with Section Ten.

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

Where reactors are connected between machine terminals and the supply and are regarded as an integral part of the machine, the rated values shall refer to the terminals of the reactor on the supply side.

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

For all machines the preferred rated output values expressed in watts, shall be taken from the R40 series of preferred numbers, rounded-off in accordance with BS 2045.

When a specific British Standard publication exists for machines of a particular type, the rated output values shall be in accordance with any series specified in that publication.

8. Rated output

8.1 *D.C. generators*

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

8.2 *A.C. generators*

The rated output is the apparent electric 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.

8.3 *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 many countries for the mechanical power available at the shafts of motors to be expressed also in horsepower (1 h.p. is equivalent to 745.7 W, 1 ch (cheval or metric horsepower) is equivalent to 736 W).

8.4 *Synchronous condensers*

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

9. Rated voltage

9.1 *Rated voltage at the terminals*

The rated voltage is the voltage between lines at the terminals of the machine at rated output.

9.2 *Generators intended for operation over a relatively small range of voltages*

D.C. generators.

For d.c. generators intended to operate over a relatively small range of voltage, the rated output and current shall relate to the highest voltage of the range, unless otherwise specified (see Sub-clause 12.3).

A.C. generators.

For a.c. generators intended to operate over a relatively small range of voltage, the rated output and power factor shall relate to any voltage within the range, unless otherwise specified (see Sub-clause 12.3).

10. Machines with more than one rating

10.1 *Ratings for multi-speed motors*

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

10.2 *Ratings for machines with varying quantities*

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 variations of $\pm 5\%$ or to star-delta connections intended for starting.

SECTION FOUR — OPERATING CONDITIONS

11. **Altitude, temperature and coolant**

Machines shall be designed for the following operating site conditions, unless other conditions are specified by the purchaser.

11.1 *Altitude*

Height above sea level not exceeding 1 000 m.

For machines intended for operation on a site where the altitude is in excess of 1 000 m, see Sub-clause 16.3.

For machines intended for operation on a site where the coolant temperature is low, by reason of high altitude, see Sub-clause 16.3.

11.2 *Ambient temperature and temperature of the coolant*

11.2.1 *Maximum ambient and coolant temperatures*

The temperature of the air at the operating site (which may be the primary or the secondary coolant, depending on the ventilation system of the machine) is subject to seasonal variation, but does not exceed 40 °C.

Machines intended for operation with a maximum ambient temperature other than 40 °C are covered by Sub-clause 16.3.

For machines having water-cooled heat exchangers, the temperature of the water at the intake to the heat exchangers shall not exceed 25 °C (see also Sub-clause 16.1.4).

11.2.2 *Minimum ambient and coolant temperatures*

The minimum temperature of the air at the operating site (which may be the primary or the secondary coolant, depending on the ventilation system of the machine) is -15 °C , the machine being installed and in operation or at rest and de-energized.

This applies to all machines except the following:

- a) a.c. machines with rated outputs exceeding 3 300 kW (or kVA) per 1 000 r/min, machines with rated outputs less than 600 W (or VA) and all machines having a commutator or sleeve bearings. For these machines the minimum ambient temperature is $+5\text{ °C}$;
- b) machines having water as a primary or secondary final coolant. The minimum temperature of the water and the ambient air is $+5\text{ °C}$.

Note. — If temperatures below those given are to be expected, the manufacturer should be informed of the minimum ambient temperature and it should be specified whether this applies only during transport and storage or also after installation. Temperatures below those given should be the subject of an agreement between manufacturer and purchaser.

11.3 *Characteristics of the gas used as a coolant in hydrogen-cooled machines*

Hydrogen-cooled machines shall be capable of operating at a 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 BS 4999 : Part 102, the standard composition of the gaseous mixture shall be 98 % hydrogen and 2 % air by volume, at the specified values of pressure and re-cooled temperature, unless otherwise agreed between manufacturer and purchaser. Windage losses shall be calculated at the corresponding density.

12. **Electrical conditions**

12.1 *Electrical supply*

A.C. machines within the scope of this standard shall be suitable for three-phase, 50 Hz or 60 Hz, with voltages derived from the nominal voltages given in IEC Publication 38: IEC Standard Voltages.

In deriving rated voltages for machines, it is necessary to take into consideration the differences between distribution and utilization system voltages.

Note. — For large high-voltage a.c. generators, the voltages may be selected for optimum performance.

12.2 *Form and symmetry of voltages and currents*

Machines shall be so designed as to be capable of operating under the conditions detailed in Sub-clauses 12.2.1, 12.2.2 (see also Clause 22) or 12.2.3 as appropriate.

12.2.1 In the case of an a.c. motor, the supply voltage is assumed to be virtually sinusoidal as defined in Item *a)* below. In the case of a polyphase motor, the supply voltages are also assumed to form a virtually balanced system as defined in Item *b)* below.

Should the limits in Items *a)* and *b)* occur simultaneously in service at the rated load, this shall not lead to any deleterious temperature in the motor and it is recommended that the excess resulting temperature rise or temperature related to the limits specified in Tables I, II and III should be not more than approximately 10 K.

a) The voltage is considered to be virtually sinusoidal, if, when supplying an a.c. motor at rated load, the waveform is such that the difference between the instantaneous value and the instantaneous value of the fundamental component does not exceed 5% of the amplitude of the latter.

In temperature-rise testing, as specified in Section Five, such amplitude difference shall not exceed 2.5%.

- b) A polyphase voltage system is deemed to form a virtually balanced system of voltages if the negative sequence component does not exceed 1% of the positive-sequence component of the system of voltages over a long period, or 1.5% for a short period not exceeding a few minutes, and if the voltage of the zero-sequence component does not exceed 1% of the positive-sequence component.

Note 1. — Motors shall be able to operate with a negative sequence component of voltage of 2 %; but this may involve very severe conditions which could affect the life of motors.

In temperature-rise testing as specified in Section Five, the negative sequence component shall be less than 0.5% of the positive-sequence component of the system of voltages, the influence of the zero-sequence system being eliminated. By agreement between manufacturer and purchaser, the negative-sequence component of the system of currents may be measured instead of the negative-sequence component of the voltages, and this shall not exceed 2.5% of the positive-sequence component of the system of currents.

Note 2. — 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 between manufacturer and purchaser.

- 12.2.2 In the case of an a.c. generator, the circuit which it supplies is assumed to be virtually non-deforming and virtually balanced as defined in Items *a)* and *b)* below.

Should the limits defined in Items *a)* and *b)* occur simultaneously in service at the rated load, this shall not lead to any deleterious temperature in the generator and it is recommended that the excess resulting temperature rise or temperature related to the limits specified in Tables I, II and III should be not more than approximately 10 K.

- a) A circuit is considered to be virtually non-deforming if, when supplied by a sinusoidal voltage, the current is virtually sinusoidal, that is to say, none of the instantaneous values differ from the instantaneous value of the same phase of the fundamental wave by more than 5% of the amplitude of the latter.
- b) A polyphase circuit is considered to be virtually balanced if, when supplied by a balanced system of voltages, the system of currents is virtually balanced, that is to say, neither the negative-sequence component nor the zero-sequence component exceeds 5% of the positive-sequence component.

- 12.2.3 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.

Thus it is necessary for motors intended for static power converter supply to be designed to operate under these conditions and it is often necessary to provide a d.c. motor with an external inductance for reducing the pulsation.

In order to obtain a proper combination of d.c. motor and static power converter, the motor manufacturer should be consulted.

12.3 *Voltage variations during operation*

Generators complying with these requirements shall be capable of supplying their rated output at rated speed (and at rated power factor where separately controllable) at a voltage that may vary between 95% and 105% of their rated voltage.

Motors complying with these requirements shall be capable of providing their rated output when they are supplied (in the case of a.c. machines at their rated frequency) by a voltage that may vary between 95% and 105% of their rated voltage.

In the case of continuous operation at the extreme voltage limits specified above, the temperature-rise limits stated in Tables I and II may be exceeded by:

- 10 K for machines of outputs up to and including 1 000 kW (or kVA);
- 5 K for machines of outputs exceeding 1 000 kW (or kVA).

Note. — Machines should not be operated in service at loads in excess of their rated load or under conditions differing from the rated conditions unless it is known that they are suitable for such use.

12.4 *Machine neutral earthing*

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 and the condition shall be defined in operating instructions.

If the windings do not have the same insulation at the line and the neutral ends, this shall be defined in operating instructions.

Note. — The earthing of interconnection of machine 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 possible mechanical damage to the winding under line-to-neutral fault conditions.

SECTION FIVE — TEMPERATURE RISE

13. (Reserved for future use)

14. **Conditions during temperature-rise test**

14.1 *Temperature of coolant*

A machine may be tested at any convenient value of coolant temperature. If the temperature of the coolant at the end of the temperature-rise tests differs by more than 30 K from that specified (or assumed from Sub-clause 16.3.5) for operation on site, the corrections given in Sub-clause 16.4 shall be made.

14.2 *Measurement of coolant temperature during tests*

The value to be adopted for the temperature of the 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.

In order to avoid errors due to the time-lag between the temperature of large machines and the variations in the temperature of the coolant, all reasonable precautions shall be taken to reduce these variations.

14.2.1 *Open machines or closed machines without heat exchangers (cooled by surrounding ambient air or gas)*

The ambient air or gas temperature shall be measured by means of several temperature detectors placed at different points around and half-way up the machine at a distance of from 1 m to 2 m from it and protected from all heat radiation and draughts.

14.2.2 *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.

14.2.3 *Closed machines with machine-mounted or internal-heat exchangers*

The temperature of the primary coolant shall be measured where it enters the machine. For machines having water-cooled or air-cooled heat exchangers, the temperature of the secondary coolant shall be measured where it enters the heat exchanger.

15. Determination of temperature rise

15.1 *Temperature rise of a part of a machine*

The temperature rise of a part of a machine is the difference in temperature between that part of the machine measured by the appropriate method in accordance with Sub-clause 15.3, and the coolant measured in accordance with Sub-clauses 14.1 and 14.2.

15.2 *Methods of measurement of temperature or temperature rise*

Four methods of determining the temperature of windings and other parts are recognized:

- a) resistance method;
- b) embedded temperature detector (ETD) method;
- c) thermometer method;
- d) superposition method.

The different methods shall not be used as a check against each other.

15.2.1 *Resistance method*

In this method, the temperature rise of the windings is determined from the increase of the resistance of the windings.

15.2.2 *Embedded temperature detector (ETD) method*

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

15.2.3 *Thermometer method*

In this method, the temperature is determined by thermometers applied to the accessible surfaces of the completed machine. The term “thermometer” also includes non-embedded thermocouples and resistance thermometers provided they are applied to the points accessible

to the usual bulb-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.

15.2.4 *Superposition method*

In this method the resistance measurements used for determination of temperature rises of a.c. windings in accordance with Sub-clause 15.3.1, are made without interruption of the a.c. load current by applying a small d.c. measuring current superposed upon the load current.

Note. — Details of this method are given in IEC Publication 279: Measurement of the Winding Resistance of an A.C. Machine during Operation at Alternating Voltage.

15.3 *Choice of method of measuring temperatures of windings*

In general, for measuring the temperature of the windings of a machine, the resistance method in accordance with Sub-clause 15.2.1 shall be applied.

The embedded temperature detector (ETD) method shall be used for a.c. stator windings of machines having a rated output: of 5 000 kW (or kVA) or more, unless otherwise agreed.

For a.c. machines having a rated output below 5 000 kW (or kVA) and above 200 kW (or kVA) the resistance method shall be used, unless the ETD method is agreed.

For a.c. machines having a rated output of 200 kW (or kVA) or less the resistance method shall be used, unless the superposition method is agreed.

For machines rated 600 W (or VA) or less, when the windings are non-uniform or severe complications are involved in making the necessary connections, the temperature rise may be determined by means of thermometers (or non-embedded thermocouples). Temperature-rise limits in accordance with Table I shall apply.

For a.c. stator windings having only one coil-side per slot, the embedded detector method is not recognized and the resistance method shall be used (see also Sub-clause 15.3.2.2).

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 check tests, although the temperature there may be rather low. The relation between the temperature measured at that place and the temperature measured by the resistance method should be determined by a temperature-rise test.

For windings of armatures having commutators and for field windings, except for field windings in cylindrical rotors of synchronous machines, the resistance method and the thermometer method are recognized (see also Sub-clause 15.3.3). The resistance method is preferred.

For stationary field windings of d.c. machines having more than one layer the ETD method may also be used.

15.3.1 *Determination of temperature rise of windings by the resistance method*

15.3.1.1 *Copper windings*

The temperature-rise $t_2 - t_a$ may be obtained from the ratio of the resistance by the formula:

$$\frac{t_2 + 235}{t_1 + 235} = \frac{R_2}{R_1}$$

where:

t_2 = temperature (°C) of the winding at the end of the test

t_1 = temperature (°C) of the winding (cold) at the moment of the initial resistance measurement

t_a = temperature (°C) of coolant at the end of the test

R_2 = resistance of the winding at the end of the test

R_1 = resistance of the winding at temperature t_1 (cold)

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

$$t_2 - t_a = \frac{R_2 - R_1}{R_1} (235 + t_1) + t_1 - t_a$$

When the temperature of a winding is determined by resistance, the temperature of the winding before the test, measured by thermometer, shall be practically that of the coolant.

15.3.1.2 *Non-copper windings*

For materials other than copper, replace the number 235 in the above formula with the reciprocal of the temperature coefficient of resistance at 0 °C of the material. For aluminium, unless otherwise specified, the number 225 shall be used.

15.3.2 *Determination of temperature rise by the embedded temperature detector (ETD) method*

When the ETD method is used, the detectors shall be suitably distributed throughout the machine windings and the number of embedded detectors installed shall be not less than six.

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

For Table I, the highest reading of ETD elements (excluding unreliable readings) shall be used to determine compliance with requirements for temperature rise or temperature limits.

Note. — For Tables II and III the average of the readings may be used.

If there are two or more coil-sides per slot the detectors shall be installed in accordance with Sub-clause 15.3.2.1. If there is only one coil-side per slot, or if it is desired to measure the end winding temperature, the recommended methods of installation are given in Sub-clauses 15.3.2.2 and 15.3.2.3, but in these cases the ETD method of temperature measurement is not a recognized method for determining temperature rise or temperature limits in order to verify the compliance of the rating with this standard.

15.3.2.1 *Two coil-sides per slot or more than two coil-sides per slot*

When the winding has two coil-sides per slot or more than two sides per slot, the temperature detectors shall be located between the insulated coil-sides within the slot in positions at which the highest temperatures are likely to occur.

15.3.2.2 *One coil-side per slot*

When the winding has one coil-side per slot, detectors that are embedded in the slots should be located between the wedge and the outside of the winding insulation in positions at which the highest temperatures are likely to occur.

15.3.2.3 *End windings*

The temperature detectors should be located between two adjacent coil-sides within the external range of the end windings in positions at which the highest temperatures are likely to occur. The temperature sensing point of the temperature detector should be in close contact with the surface of the coil-side and be adequately insulated against the coolant influence.

15.3.3 *Determination of temperature rise by the thermometer method*

The thermometer method is recognized in the cases in which neither the ETD method nor the resistance method is applicable.

Use of the thermometer method is also 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) The measurement of temperature rise during routine tests on machines manufactured in large quantities.

If the purchaser wishes to have a thermometer reading in addition to the values determined by the resistance method or by the ETD method, the temperature rise determined by thermometer, when placed at the hottest accessible spot, shall be the subject of agreement between manufacturer and purchaser, but shall not exceed:

65 K for Class A insulation of windings
 80 K for Class E insulation of windings
 90 K for Class B insulation of windings
 115 K for Class F insulation of windings
 140 K for Class H insulation of windings

Note. — For the classification of the insulations, see appendix I.

15.4 *Correction of measurements taken after the machine has come to rest and is de-energized*

15.4.1 The measurement of temperatures after shutdown by the resistance method requires a quick shutdown of the machine at the end of the temperature test. A carefully planned procedure and an adequate number of people are required to obtain readings quickly enough to give reliable data.

If the initial resistance reading is obtained within the time interval indicated below, this reading shall be accepted as the temperature measurement, and extrapolation of observed temperatures to the instant of switching off the power is unnecessary.

Rated output (<i>P</i>) (kW [kVA])	Time delay after switching off power (s)
$P \leq 50$	30
$50 < P \leq 200$	90
$200 < P \leq 5\,000$	120
$5\,000 < P$	By agreement