IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above

C50.13™

IEEE Power Engineering Society

Sponsored by the
Electric Machinery Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

15 February 2006

IEEE Std C50.13™-2005
(Revision of ANSI C50.13-1989)

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ANSI C50.13-1989)

IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above

Sponsor

Electric Machinery Committee
of the
IEEE Power Engineering Society

Approved 22 September 2005

IEEE-SA Standards Board

Approved 29 December 2005

American National Standards Institute

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Abstract: The requirements in this standard are applied to 50 Hz and 60 Hz, two-pole and four-pole, cylindrical-rotor synchronous generators driven by steam turbines and/or by combustion gas turbines. The drive may be direct or through a gearbox or other device that permits different speeds for the turbine and the generator. The generators covered by this standard are to have rated outputs of 10 MVA and above.
Keywords: ac generator, combustion gas turbine generator, cylindrical-rotor generator, steam turbine generator, synchronous generator, turbine generator

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Introduction

This introduction is not part of IEEE Std C50.13-2005, IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above.

This introduction provides some background on the rationale used to develop this standard. This information is meant to aid in the understanding and usage of this standard.

From the early 1990s until the date of issue of this standard, two different working groups of the Electrical Machinery Committee (EMC) of the IEEE Power Engineering Society have carefully pursued the modernization of the ANSI C50 standards for large steam turbine- and combustion turbine-generators. Throughout the mid-1990s the first working group (IEEE PES EMC Task Force on Standards Harmonization) compared American National Standards Institute (ANSI) standards for several different types of electrical machines with corresponding International Electrotechnical Commission (IEC) standards. In the late 1990s members of the EMC Task Force published several summaries of their work [B2], [B16], [B19], [B20].[a]

In association with the general initiative by the Electric Machinery Committee to compare different standards for electric machines, the Synchronous Machinery Subcommittee (SMSC) of the EMC commissioned a second working group in 1998 to focus on clarifying and modernizing the ANSI C50 series of standards for synchronous generators. The SMSC Working Group (WG) No. 4 (Revision of C50.1X series) included the following ANSI C50.1X standards in their scope:

a) ANSI C50.10-1990, Rotating Electrical Machinery—Synchronous Machines.[b]

b) ANSI C50.12-1982 (Reaff 1989), Requirements for Salient-Pole Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications.

c) ANSI C50.13-1989, Requirements for Cylindrical-Rotor Synchronous Generators.

d) ANSI C50.14-1977, Requirements for Combustion Gas Turbine Driven Cylindrical Rotor Synchronous Generators.

e) ANSI C50.15-1989, Hydrogen-Cooled, Combustion-Gas-Turbine-Driven, Cylindrical-Rotor Synchronous Generators—Requirements.

This SMSC WG No. 4 has periodically reported their progress [B4], [B5], [B6], [B17]. As has been communicated in these papers, where it has been possible for this group to agree to the appropriateness of requirements recorded in the IEC 60034 standards [B7], [B8], those requirements have been incorporated into the revised IEEE C50.1X series of standards.

As the most workable approach to clarify and modernize the IEEE standards for cylindrical-rotor synchronous generators the SMSC WG No. 4 chose to consolidate the previously separate ANSI C50.10, ANSI C50.13, ANSI C50.14, and ANSI C50.15 standards into one consolidated IEEE Std C50.13 standard. This modernized IEEE Std C50.13 has been written to consolidate the previously separate ANSI C50.13, ANSI C50.14, and ANSI C50.15 standards in their entire scope and to incorporate applicable parts of ANSI C50.10. Similarly, WG No. 4 chose to modify ANSI C50.12 to become a consolidated standard for large salient-pole generators and generator/motors for hydraulic turbine applications. All applicable parts of ANSI C50.10 have been incorporated into the modernized IEEE Std C50.12™. Also, wherever possible, the modernized IEEE Std C50.12 and IEEE Std C50.13 have been harmonized with each other.

[a] The numbers in brackets correspond to those of the bibliography in Annex A.

[b] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

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The logic to consolidate ANSI C50.13, ANSI C50.14, and ANSI C50.15 into one standard was primarily that ANSI C50.14 and ANSI C50.15 contained a significant amount of content that had been duplicated from ANSI C50.13 solely to cover different applications of the same basic configuration of generators covered by ANSI C50.13. Additionally, because some newer applications to which no C50 standards directly pertained had occurred since the creation of the separate ANSI C50.14 and ANSI C50.15, the working group had to choose between creating additional highly duplicated standards or finding a way to consolidate them. The decision to drop the general standard, ANSI C50.10, and to incorporate appropriate parts of its content into IEEE Std C50.12 and IEEE Std C50.13 was made after an initial attempt to retain and update ANSI C50.10. During that effort it was recognized that the content directly applicable to IEEE Std C50.12 and IEEE Std C50.13, respectively, was not that great. It was also recognized that most ultimate users of the generator standards would significantly benefit from having a single standard for each of these two major types of machines. This approach would provide a better focus and alignment of the standards to purchasers and manufacturers knowledgeable in each product affected by the standard. That better focus and alignment would minimize the risk of conflict or ambiguity between the general and type-specific standards, reduce the risk of missed requirements or ineffectively communicated requirements, and also ease future maintenance of the standards.

A significant improvement to this standard is the addition of Annex B. The specification of a large generator covered by IEEE Std C50.13 is a complex task. Unfortunately, it is not as simple as specifying a single point power rating and also specifying IEEE Std C50.13. Annex B is included to assist purchasers of generators covered by IEEE Std C50.13 to provide the necessary requirements and data to the generator manufacturer that will ensure that a generator designed to meet the specified requirements will meet the long term needs of the purchaser without over specifying and adding unnecessary cost. The core guidelines in Annex B are contained in Table B.1 through Table B.4. These tables may be used as a checklist to show which party in the process typically originates each requirement. These tables also provide some explanation as to the basis of many requirements that must be provided by the purchaser and their potential impacts on the generator design.

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IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above

1. Scope

The requirements in this standard apply to all 50 Hz and 60 Hz, two-pole and four-pole, cylindrical-rotor synchronous generators driven by steam turbines and/or by combustion gas turbines. The drive may be direct or through a gearbox or other device that permits different speeds for the turbine and the generator.

The generators covered by this standard are to have rated outputs of 10 MVA and above. Cylindrical-rotor, two-pole and four-pole generators below this rating are generally covered by NEMA MG 1-2003 [B18].[1]

2. Normative references

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

IEEE Std 1™, IEEE Recommended Practice—General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation.[2, 3]

IEEE Std 4™, IEEE Standard Techniques for High-Voltage Testing.

IEEE Std 43™, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

IEEE Std 67™, IEEE Guide for Operation and Maintenance of Turbine Generators.

IEEE Std 95™, IEEE Recommended Practice for Insulation Testing of AC Electric Machinery (2300 V and above) with High Direct Voltage.

IEEE Std 115™, IEEE Guide: Test Procedures for Synchronous Machines, Part 1—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

[1]The numbers in brackets correspond to those of the Bibliography in Annex A.
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IEEE Std 275™, IEEE Recommended Practice for Thermal Evaluation of Insulation Systems for Alternating-Current Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900 V and below.

IEEE Std 421.1™, IEEE Standard Definitions for Excitation Systems for Synchronous Machines.

IEEE Std 433™, IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency.

IEEE Std 434™, IEEE Guide for Functional Evaluation of Insulation Systems for Large High-Voltage Machines.

IEEE Std 522™, IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electrical Machines.

IEEE Std C37.102™, IEEE Guide for AC Generator Protection.

ISO 3746, Acoustics—Determination of Sound Power Levels of Noise Sources Using Sound Pressure-Survey Method Using an Enveloping Measurement Surface over a Reflecting Plane.[4]

ISO 7919-2, Mechanical Vibration of Non-Reciprocating Machines—Measurements on Rotating Shafts and Evaluation Criteria—Part 2: Large Land-Based Steam Turbine Generator Sets.

ISO 7919-4, Mechanical Vibration of Non-Reciprocating Machines—Measurements on Rotating Shafts and Evaluation Criteria—Part 4: Gas Turbine Sets.

3. Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standard Terms* [B10] should be referenced for terms not defined in this clause.

Cooling classification

3.1 directly cooled windings: A direct cooled stator or rotor winding is one in which the primary coolant (air, hydrogen, or liquid) flows in direct contact with the conductors so that the heat generated within the principal portion of the winding reaches the primary coolant without flowing through the major ground insulation.

3.2 indirectly cooled windings: An indirect cooled stator or rotor winding is one in which the heat generated within the principal portion of the winding must flow through the major ground insulation before reaching the primary coolant (air or hydrogen).

Coolant types

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

3.4 secondary coolant: A medium, liquid or gas, that, being at a lower temperature than the primary coolant, removes heat given up by the primary coolant by means of a heat exchanger or through the external surface of the machine.

[4]ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iso.ch/). ISO publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

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Generator capability

3.5 ambient-following machine: A generator expected to operate where turbine output capability is affected by ambient temperatures, usually with lower output at higher temperatures, and whose capability must be coordinated with turbine output capability for various ambient conditions.

3.6 base capability: The output capability, specified by the manufacturer, that will keep the temperatures of its various windings within limits allowed for their insulation class.

3.7 peak capability: The output capability, when specified by the manufacturer, that some generators may safely have to operate above the base capability, but with increased aging of the insulation than would occur at base capability.

Operational duty

3.8 base load unit: A generator whose expected operational duty will be to operate at relatively constant loads for much of the time with some load follow, and with complete start/stop cycles limited to 3000 over the life of the unit.

3.9 peaking unit: A generator whose expected operational duty will include being started up during peak system loads and shut down during off-peak system loads with over 3000 start/stop cycles and less than 10 000 complete start/stop cycles over the life of the unit.

Turbine type

Different types of steam turbines and combustion gas turbines that are used to drive two-pole and four-pole cylindrical-rotor synchronous generators are recorded in the following definitions. For descriptions of operational requirements imposed on these generators by these turbines, refer to 4.1.1.

3.10 combined cycle combustion and steam turbines: A combined cycle combustion and steam turbine arrangement utilizes the waste heat from the combustion turbine to make steam to drive a steam turbine. This heat is vented into the atmosphere in a simple cycle combustion turbine, and so the combined cycle arrangement is inherently more efficient than the simple cycle arrangement.

NOTE—Described in the following definitions of multi- and single-shaft combined cycle turbines are two basic arrangements of combined cycle combustion and steam turbine plants. In both arrangements, since the combustion turbine output is dependent on the ambient temperature, all the generators must be capable of matching the turbine output over the designated ambient-temperature range.[5]

3.11 multi-shaft combined cycle turbines: In a multi-shaft arrangement, the waste heat from one or more separate combustion turbines is taken to a heat recovery steam generator, where steam is generated and fed into a separate steam turbine. In this arrangement, there is a separate generator for each combustion turbine and each steam turbine.

3.12 simple cycle combustion gas turbine: A simple cycle combustion turbine burns either liquid or gaseous fossil fuels at very high temperatures, converting the thermal energy into rotational energy in the power turbine. A compressor, mounted on the same shaft as the power turbine, provides high-pressure inlet air to the combustion process. The output of such a combustion turbine depends on a number of factors, and it varies with ambient temperature. The generator has to be capable of matching the combustion turbine output over the designated range of ambient temperatures.

[5] Notes in text, tables, and figures of a standard are given for information only, and do not contain requirements needed to implement the standard.

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3.13 simple cycle steam turbine: A steam turbine of this type works in a closed cycle loop with steam provided by a fossil-fuel-fired boiler or by a nuclear steam supply system. Steam turbines of this type usually carry one power rating corresponding to prescribed steam conditions. Generators for these turbines are generally designated for base capability.

3.14 single-shaft combined cycle turbines: In a single-shaft combined cycle arrangement, the steam generated from the heat recovery steam generator is fed into a steam turbine that is on the same shaft as the gas turbine. In this arrangement, the generator is rated for the combined output of the combustion turbine and the steam turbine.

General

3.15 rated voltage, V_n: Rated voltage is line-to-line rms voltage as stated on the nameplate.

4. Operational requirements

4.1 Service conditions and steady-state duty

4.1.1 Matching the generator to the turbine power output

Because of the wide range of possible cycles, especially when combustion turbines are used, it is important to examine the match between the generator output and the turbine output very carefully, to ensure that the generator is capable of accepting the maximum output that the turbines are capable of producing. Generators are typically rated at a single point in the output range, defined by the cold gas temperature in the machine (see 5.1). Particular care must be taken if the generator primary coolant is supplied from heat exchangers, as is commonly the case if a water source is used as a secondary coolant.

4.1.1.1 Simple cycle steam turbines

The power output of a steam turbine operating in a simple cycle configuration is relatively independent of the ambient conditions of temperature (humidity, etc.). The generator for this type of steam turbine is given a base rating that is usually dependent on the output of the steam turbine with the steam valves wide open and with the boiler at overpressure. It is usually sufficient to ensure that the generator capability (at rated power factor and maximum expected secondary coolant temperature) is sufficient at this operating condition.

4.1.1.2 Simple cycle combustion turbines

Combustion gas turbines for simple cycle power plants usually carry two power ratings, base capability and peak capability, that correspond to different combustion temperatures. Generators for these turbines are generally designed for both base capability and peak capability.

Power output from a combustion turbine that operates without any form of power augmentation is a strong function of the inlet air-mass flow rate, and thus is a strong function of the inlet air temperature and atmospheric pressure. If the inlet air is the ambient air at the site, then the combustion turbine output is strongly dependent on the ambient air temperature, falling off as the ambient temperature rises. The generator must match the turbine output over the designated ambient-temperature range.

Power augmentation of a combustion turbine is achieved by modifying the inlet air conditions to increase the inlet air-mass flow rate by increasing the density of the inlet airflow. One way is to reduce the inlet air

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temperature with chillers or evaporative coolers. Another way to increase inlet airflow density is to inject steam or water into the inlet air stream. These techniques increase the combustion turbine power output. The percentage increase is greater in the warmer end of the ambient-temperature range where the output power would otherwise fall off with increasing ambient temperature. The increased output power may be sufficiently close to the mechanical limit of the turbine that the output power may vary only slightly over the ambient-temperature range. Because the generator still must match the turbine output over the entire ambient-temperature range, the generator may have to be larger in order to match the higher turbine outputs on hot days.

4.1.1.3 Combined cycle combustion and steam turbines

In combined cycle arrangements, exhaust gas from one or more combustion gas turbines is ducted into a heat-recovery steam generator (HRSG) to heat steam for a steam turbine. A single combustion turbine produces sufficient exhaust heat to power a steam turbine of approximately half the output power of the combustion turbine.

In multi-shaft combined cycle arrangements, the combustion turbine-generator sets and the steam turbine-generators are on separate shafts. In a multi-shaft arrangement where there is one combustion turbine and one steam turbine, the generator rating of the steam turbine-generator is approximately half that of the generator rating of the gas turbine-generator. In a multi-shaft arrangement where two combustion turbines operate in combination with one steam turbine, the rating of the steam turbine-generator can be equal to the rating of the gas turbine-generator, and the steam turbine-generator can be identical to the combustion turbine-generators. In multi-shaft arrangements with more than two combustion turbines for each steam turbine, the steam turbine output is approximately equal to half the output of one combustion turbine times the number of combustion turbines involved.

In single-shaft combined cycle arrangements, both a combustion turbine and a steam turbine drive one generator. Generator output in a single-shaft arrangement is the combined output of the combustion turbine and the steam turbine. This output is about 50% greater than the output of the combustion turbine alone.

Because the outputs of the turbines vary with ambient conditions, as for simple cycle combustion turbines, the generators must match the turbine outputs over the designated ambient-temperature range. All power augmentation techniques described in 4.1.1.2 are possible. These augmentation techniques affect the output power from all involved turbines and thus affect capability requirements for the generators.

In combined cycle operation, it is also possible to augment the steam turbine output by raising the temperature of the gas entering the HRSG. Burning fuel in the HRSG inlet gas stream does this. The increase in steam turbine output obtained in this manner can be quite significant, and must be accounted for when determining the steam turbine-generator rating in a multi-shaft arrangement, or the combined generator rating in a single-shaft arrangement.

4.1.2 Coolant temperatures

Refer to Clause 3 for definitions of primary and secondary coolants.

An open ventilated (OV) air-cooled generator draws cooling air from the surrounding ambient, usually through a system of filters. This air is circulated over the active parts of the generator to remove heat, and is then exhausted back into the surrounding ambient, usually through exhaust silencers. For OV air-cooled generators, the primary cold coolant temperature is the temperature of the air entering the machine. This will normally be the ambient air temperature. The range of this temperature shall be specified by the purchaser. It will normally be from –20 °C to +50 °C.

An enclosed generator continuously recirculates the primary coolant through the active parts of the machine. For a hydrogen-cooled generator the primary coolant is hydrogen. For a totally enclosed water-to-air-cooled (TEWAC) generator, the primary coolant is the air enclosed within the generator. The heat is removed from the primary coolant by passing the primary coolant through a heat exchanger, where the heat

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is transferred to a secondary coolant, usually water. The secondary coolant may be drawn from and discharged into an ambient source such as a lake or river, or may itself be in a closed loop with a further heat exchanger to discharge the heat to the ambient. The range of the primary coolant temperature shall be determined by the manufacturer, to obtain optimum design of machine and coolers, based on the range of secondary coolant temperature (ambient air or water) specified by the purchaser. The typical range of secondary coolant temperature is from –20 °C to +50 °C if the coolant is air. If the secondary coolant is water, a temperature range of 5 °C to +35 °C is typical.

4.1.3 Ambient air temperature

The generator shall be designed to operate with surrounding ambient temperatures in the range from –20 °C to +50 °C. Note that capability may vary with ambient temperature (see Clause 5 and Clause 7).

4.1.4 Altitude

The altitude should be specified by the purchaser. The usual range of altitudes is from 0 m to 1000 m.

The power output of a combustion turbine decreases with increasing altitudes. The decrease in capability of an air-cooled generator is normally less than the decrease in turbine rating with increased altitudes. The capability of a hydrogen-cooled generator will not decrease with increasing altitudes if the secondary coolant temperature and the absolute hydrogen pressure are maintained constant regardless of altitude.

4.1.5 Starting

4.1.5.1 Number of starts

The unit shall be designed for a minimum number of starts over the operating life of the machine. The minimum number of starts from zero speed or turning gear speed to operating speed up to rated load shall be as follows:

— 3 000 starts for base load units

— 10 000 starts for peaking units or other frequently cycled units

4.1.5.2 Use of generator as a starting motor

The generator can be used as the starting motor for driving a combustion turbine using a variable frequency static starting system. To assure that the generator windings do not overheat during starting, give consideration to the static power electronics characteristics, the drive-train losses, the inertia characteristics, the starting speed versus time, and restart interval requirements.

4.1.6 Application of load

The rate of increase of generator loading should be limited only by the ability of the turbine to increase load.

4.1.7 Variation from rated voltage and frequency

Generators shall be thermally capable of continuous operation within the confines of their reactive capability curves over the ranges of ±5% in voltage and ±2% in frequency, as defined by the shaded area of Figure 1, but not necessarily in accordance with the standards of performance established for operation at rated voltage and rated frequency. The same variation in voltage and frequency applies to reduced gas pressure operation of hydrogen-cooled generators and also to base and peak capability curves for ambient-following generators.

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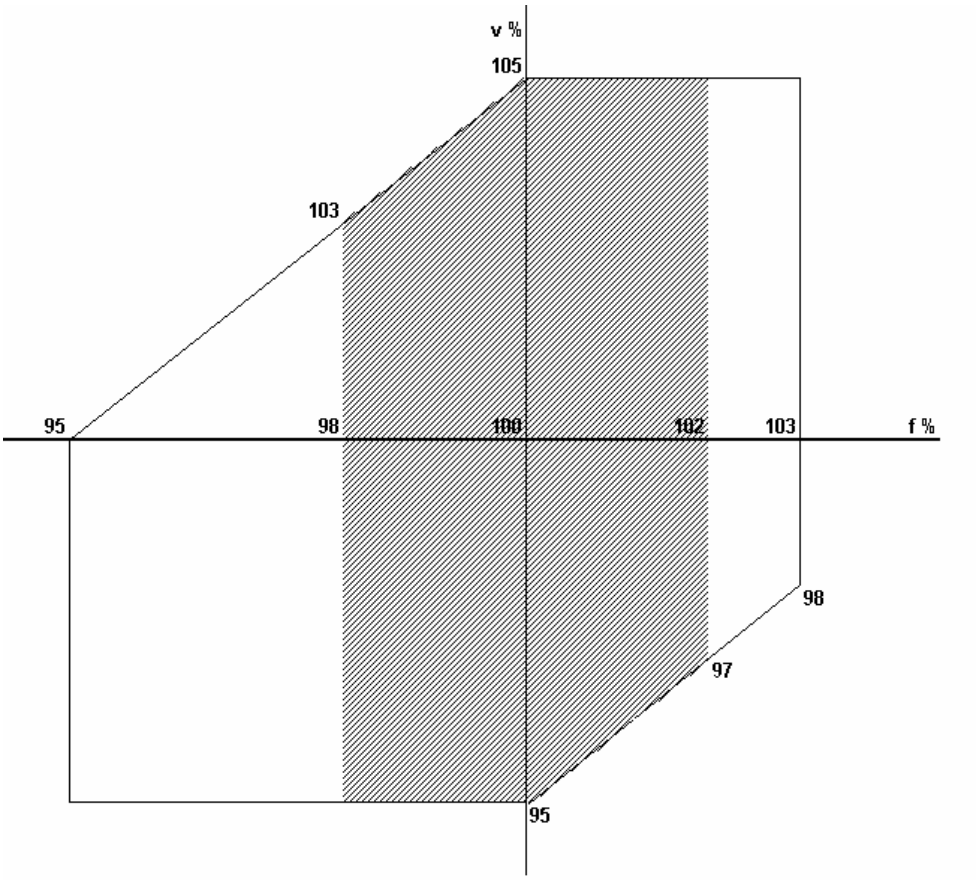

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Figure 1—Operation over ranges of voltage and frequency

Reasons for the limits summarized in Figure 1 are described in the following list:

a) As the operating point moves away from rated values of voltage and frequency, the temperature rise or total temperatures of components may progressively increase. Continuous operation near certain parts of the boundary of the shaded area in Figure 1 at outputs near the limits of the generator's reactive capability curve may cause insulation to age thermally at approximately two times to six times its normal rate.

b) Generators will also be capable of operation within the confines of their reactive capability curves within the ranges of ±5% in voltage and +3%/–5% in frequency as defined by the outer boundary of Figure 1 with further reduction of insulation life. However, operation at "peak" capability on ambient-following machines is restricted to the shaded area of Figure 1.

c) To minimize the reduction of the generator's lifetime because of the effects of temperature and temperature differentials, operation outside the shaded area should be limited in extent, duration, and frequency of occurrence. The output should be reduced or other corrective measures taken as soon as practicable.

d) The boundaries of Figure 1 result in the magnetic circuits of the generator to be overfluxed or underfluxed by no more than 5%. The sloped boundaries in Figure 1 correspond to constant volts per hertz.

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e) The machine may be unstable or margins of stability may be reduced under some of the operating conditions shown in Figure 1. Excitation margins may also be reduced under some of the operating conditions shown in Figure 1.

f) As the operating frequency moves away from the rated frequency, effects outside the generator may become important and need to be considered. As examples, the turbine manufacturer will specify ranges of frequency and corresponding periods during which the turbine can operate, and the ability of the auxiliary equipment to operate over a range of voltage and frequency should be considered.

g) Operation over a still wider range of voltage and frequency, if required, should be subject to agreement between the purchaser and the manufacturer.

h) Operation at voltages below –5% may be acceptable for the generator provided that there is a similar reduction in the MVA operating range. In such cases, consideration should be given to limitations of other equipment connected electrically to the generator.

4.1.8 Rotor surface heating

4.1.8.1 Continuous phase current unbalance capability (I_2)

A generator shall be capable of withstanding, without injury, the effects of a continuous phase current unbalance corresponding to a negative-sequence current of the values in Table 1, provided that the maximum current does not exceed 105% of rated current in any phase. In Table 1, negative-sequence current I_2 is expressed in percent of rated stator current. Ambient-following machines operating above nameplate rating shall have permissible I_2 levels corresponding to the 40 °C primary coolant nameplate rating.

Table 1—Continuous negative-sequence current capability

Type of generator	Permissible I_2 (%)
Indirectly cooled (rotor)	10
Directly cooled (rotor)	—
to 350 MVA	8
351 MVA to 1250 MVA	8–(MVA–350)/300
1251 MVA to 1600 MVA	5

These values also express the negative-sequence current capability when the generator kilovolt-ampere capability is reduced either as a result of higher than rated cold gas temperatures, or as a result of operation at lower than rated hydrogen pressure, as a percentage of the stator current corresponding to the reduced capability.

4.1.8.2 Harmonic current capability

If there are significant levels of harmonics of the fundamental frequency present in the generator phase current, there are several areas of concern, including harmonic content in the air-gap torque, additional heating of the stator winding, and induced harmonic effects on the rotor surface.

The presence of harmonic currents in the stator phase current results in induced currents on the rotor surface and in components such as wedges, retaining rings, and amortisseurs. The temperature rise resulting from these currents reduces the capability of the rotor to carry the induced negative-sequence currents that result from a fundamental frequency stator phase current unbalance.

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The extent of this impact can be determined using Equation (1) to calculate the net effect of a given harmonic content and negative-sequence content in the stator current.

$$I_{2\,eq} = \sqrt{I_2^2 + \sum_n \sqrt{\frac{n+i}{2}}\, I_n^2} \qquad (1)$$

where

i = +1 when n = 5, 11, 17, etc.,
i = –1 when n = 7, 13, 19, etc.,
and n = harmonic order.

The values of $I_{2\,eq}$ should be compared with the acceptable levels of negative-sequence currents defined in Table 1.

If "$I_{2\,eq}$" is expected to be greater than 25% of the acceptable levels of negative-sequence current, the manufacturer should be made aware of the anticipated harmonic current levels and frequencies so that the manufacturer can determine if this is acceptable and/or assure that due attention is paid to these effects during the design of the machine.

It is the intent of this standard that the values of combined negative phase sequence current and harmonic currents ($I_{2\,eq}$) should not exceed the values given in the Table 1 unless other values are agreed upon by the manufacturer and purchaser.

4.1.9 Direction of rotation

The direction of the rotation of the generator shall suit the prime mover requirements.

4.1.10 Rotor assembly critical speeds and shaft set vibration

A rotor dynamics analysis of the entire shaft system should be performed. This analysis should include the prime mover, generator, and any other rotating components. This analysis should include lateral and torsional shaft system responses to the various excitations that are possible within the operational duties allowed by this standard. When the turbine-generator is purchased as a set, it would be typical that the manufacturer would perform this analysis. When shaft train components are purchased from different manufacturers, the purchaser should arrange for performance of this analysis. Critical speeds of the generator rotor assembly shall not cause unsatisfactory operation within the speed range corresponding to the frequency range agreed upon in accordance with 4.1.7. The generator rotor assembly shall also operate satisfactorily for a reasonable period of time at speeds between standstill and rated speed as agreed upon by the prime mover and generator designers. To allow for satisfactory long-term operation, the turbine-generator set shaft vibration, at operating speed, should be within limits specified by ISO 7919-2[6] for steam turbine applications and ISO 7919-4 for combustion turbine applications

4.1.11 Phase sequence

Phase sequence defines the order in which the phase voltages reach their positive maximum at the terminals of the machine, and shall be agreed upon between the manufacturer and purchaser. Typically this is given as a three-letter sequence, R, C, L (right, center, left) or L, C, R (left, center, right), as defined by an observer looking at the terminals from outside the machine. In the case of terminals on the top or bottom of the machine, the sequence is defined looking from the end of the machine nearest the terminals toward the centerline of the machine.

[6]For information on references, see Clause 2.

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Care must be exercised to ensure that the defined phase sequence of the machine is consistent with that of the connected equipment, particularly in situations where the plant layout requires otherwise identical machines to have different phase sequences.

4.1.12 Variation from rated hydrogen pressure

Capabilities at hydrogen pressures lower than rated pressure shall be available from the manufacturer, and shall be determined such that the hottest-spot temperatures of the machine meet the requirements specified in 7.1.

4.1.13 Hydrogen purity variation

A hydrogen-cooled generator with a hydrogen purity of 98% or higher should be capable of meeting all output and efficiency requirements within the limits specified in this standard.

Operation with hydrogen gas purity lower than 98% may result in temperatures that exceed those discussed in 7.1 and will result in reduced efficiencies.

Hydrogen-cooled machines shall be capable of operating at rated output under rated conditions with a coolant containing 95% or greater hydrogen by volume, but not necessarily in accordance with the temperature requirements given in 7.1.

CAUTION

For safety reasons, at all times, the hydrogen purity should be maintained at 90% or more, based on the assumption that the other gas in the mixture is air.

4.1.14 Sound emissions

Near field A-weighted sound pressure levels, spatially averaged on a rectangular perimeter 1.5 m above the floor or operating platform level and along the measurement surface enveloping the generator at a distance of 1 m from the nearest generator surface on each side, may be specified. A typical value would be in the range of 85 dB (A) to 95 dB (A) where increasing levels of acoustic treatment would likely be necessary to achieve decreasing sound pressure levels. If no value is specified, the generator shall achieve less than or equal to a sound pressure level of 95 dB (A) as defined above. Test procedures for verification testing, if required, shall be based upon ISO 3746.

4.2 Transient event and emergency duty requirements

Transient events and emergency duty include transient and emergency duty imposed on a generator because of power system faults. A generator conforming to this standard shall be suitable for withstanding exposure to these operating conditions as described in this clause.

4.2.1 Stator winding short-time thermal requirements

The generator stator shall be capable of operating at 150% of rated stator current for at least 30 s starting from stabilized temperatures at rated conditions. The permissible stator currents, in the range of 10 s up to 120 s, based on the same increment of heat storage, is represented by Equation (2) as follows:

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$$I = 100\sqrt{\frac{37.5}{t} + 1} \quad (2)$$

where

I is the stator current (percent)
t is the time (seconds)

Four points in the range are listed as follows:

Time (seconds)	10	30	60	120
Stator current (percent)	218	150	127	115

It is recognized that stator winding temperatures will exceed rated load values under these conditions. Therefore, the machine construction is based on the assumption that the number of such operations at stator currents to the limits specified will occur not more than two times per year.

During certain types of unbalanced faults, the short-time negative-sequence thermal capability of the rotor, as defined in 4.2.3, may be exceeded before the stator winding short-time thermal capability, as defined in this clause, is reached. In these circumstances the most limiting restrictions shall apply.

4.2.2 Rotor winding short-time thermal requirements

The generator rotor winding shall be capable of operating at a rotor current of 125% of rated load rotor current for at least 1 min starting from stabilized temperatures at rated conditions.

The permissible rotor currents, in the range of 10 s to 120 s, based on the same increment of heat storage, is represented by Equation (3) as follows:

$$I = 100\sqrt{\frac{33.75}{t} + 1} \quad (3)$$

where

I is the stator current (percent)
t is the time (seconds)

Four points in the range are listed as follows:

Time (seconds)	10	30	60	120
Rotor current (percent)	209	146	125	113

It is recognized that rotor winding temperatures under these conditions will exceed rated load values. Therefore, the machine construction is based on the assumption that the number of such operations at rotor currents to the limits specified will occur not more than two times per year.

4.2.3 Rotor short-time thermal requirements for unbalanced faults (I_2^2t)

The generator rotor shall be capable of withstanding, without injury, unbalanced short circuits or other unbalanced conditions on the system or at the stator terminals resulting in values of I_2^2t as given in Table 2.

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Table 2—Short-time negative-sequence current capability

Type of generator rotor cooling	Minimum generator short-time capability expressed in terms of I_2^2t
Indirectly cooled	30
Directly cooled up to 800 MVA	10
800 MVA to 1600 MVA	10–(0.00625)(MVA–800)

In Table 2, I_2^2t is the integrated product of the square of the generator negative-sequence current (I_2), expressed in per unit stator current at rated kilovolt amperes and duration of the fault in seconds (t).

These values also express the negative-sequence current capability when the generator kilovolt-ampere capability is reduced either as a result of higher than rated cold gas temperatures, or as a result of operation at lower than rated hydrogen pressure, in per unit stator current corresponding to the reduced capability.

The generator unbalanced fault capability expressed in terms of I_2^2t applies for times less than or equal to 120 s, based on a constant increment of heat storage and negligible heat dissipation.

These limits recognize the thermal effect of unbalanced faults at the machine terminals, including the decaying effects of the following:

a) Rotor current, where protection is provided which would cause rotor current reduction, such as with an exciter rotor breaker or equivalent

b) DC component of the stator current

CAUTION

Protective relaying should be applied and set by the purchaser to prevent I_2^2t from reaching damaging levels. In the event of relaying failure, or other equipment failure, values significantly in excess of the preceding values may occur. Generators subjected to faults between the preceding values of I_2^2t and 200% of these values may suffer varying degrees of damage; for faults in excess of 200% of these limits, serious damage may be expected.

4.2.4 Mechanical requirements for short circuits, faulty synchronizations, and rapid reclosures

4.2.4.1 Sudden short circuits at the generator terminals

A generator shall be designed so that it can be fit for service after experiencing a sudden short circuit of any kind at its terminals while operating at rated load and 1.05 per unit rated voltage, provided that the fault is limited by the following conditions:

— The maximum phase current does not exceed the phase current obtained from a three-phase sudden short circuit.

— The stator winding short-time thermal requirements are not exceeded.

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A generator shall be judged fit for service after the incident if it requires no more than the following minor repairs:

a) For the stator winding the term "minor repairs" implies that some attention to the end turn bracing system and to surface coatings of coil ground insulation may be necessary to ensure that the winding will withstand a maintenance high-potential test after the repairs. The term "minor repairs" does not imply replacement of stator coils or ground insulation repair.

b) For the rotor shaft "minor repairs" are those repairs that can be made without removing the rotor, such as some attention to coupling bolts, couplings, and rotor shaft balancing, to ensure that shaft dynamic motion and bearing vibration will be within acceptable limits after the repairs.

4.2.4.2 Synchronizing

Generators shall be designed to be fit for service without inspection or repair after synchronizing that is within the limits listed in Table 3.

Table 3—Synchronizing limits

Breaker closing angle	±10º
Generator side voltage relative to system	0% to +5%
Frequency difference	±0.067 Hz

Additional information on synchronizing practices can be found in IEEE Std C37.102 and in IEEE Std 67.

CAUTION

Faulty synchronizing is that which is outside these limits. Under some power system conditions, faulty synchronizing can cause intense, short-duration currents and torques that exceed those experienced during sudden short circuits. These intense currents and torques may cause some damage to the generator.

Generators shall be designed so that they are capable of coasting down from synchronous speed to a stop or to turning gear speed after being immediately tripped off-line following a faulty synchronization. Any generator that has been subject to a faulty synchronization may have severe damage and may need to be inspected for damage and repaired as necessary before being judged fit for service after the incident. Any loosening of stator winding bracing and blocking and any deformation of coupling bolts, couplings, and rotor shafts should be corrected before returning the generator to service. Even if repairs are made after a severe out-of-phase synchronization, it should also be expected that repetition of less severe faulty synchronizations might lead to further deterioration of the components.

It should be expected that the most severe faulty synchronizations, such as 180° or 120° out-of-phase synchronizing to a system with low system reactance to the infinite bus, might require partial or total rewind of the stator, or extensive repair or replacement of the rotor, or both.

4.2.4.3 Transmission-line switching from steady-state conditions

Switching operations involving the opening or closing of transmission-line circuit breakers in a power system can result in the creation of transients in power and current that can result in various amplitudes of torsional oscillations and stresses in turbine-generator components [B15]. One quantity that can be used to assess the severity of a line switching operation is ΔP, which is defined as the sudden change in average power at the instant of switching, expressed in per unit (p.u.) on the generator rated MVA base. Screening studies have shown that line switching from an initially steady-state condition that results in a ΔP of 0.5 per unit or less will result in zero or negligible loss-of-life per incident. Where the switching ΔP in a specific

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turbine-generator is expected to exceed the value of 0.5 per unit, it is recommended that the manufacturer be consulted and a possible unit-specific study be performed.

4.2.4.4 Rapid reclosure following system faults

Transmission-line faults in close proximity to large turbine-generators and the subsequent line opening in an attempt to clear the fault can set up large shaft torsional oscillations and resulting high stresses in rotation components [B15]. Since it typically takes many seconds for these torsional oscillations to decay in amplitude, reclosing the line while the rotor is still "ringing" with torsional oscillations, whether the fault has cleared or not, could result in torsional oscillations and associated stresses that are significantly higher than that caused by the original fault and fault clearing event. Rapid reclosure of power system circuit breakers on transmission lines in close electrical proximity to a large turbine-generator within the attenuation times of shaft torsional oscillations can cause high local torques in the turbine-generator shaft train even if the reclosures are otherwise within normal limits. The additional torques resulting from rapid reclosures can act to reinforce or amplify the relatively slowly decaying shaft torsional oscillations that are induced by the initial transmission-line fault and the line opening operation. While unsuccessful rapid reclosure events (reclosing into a permanently faulted line) are more severe than successful rapid reclosure events, both successful and unsuccessful rapid reclosure events are of potential concern. Because of the statistical nature of the system torques and local shaft torques and the cumulative effect of the resulting fatigue damage to shafts, generalized requirements are not possible. Where it is expected that a turbine-generator is to be subject to power system rapid reclosures, it is recommended that the manufacturer be consulted and a possible unit-specific study be performed.

Switching operations involving three-phase faults and phase-to-phase faults are more serious than switching operations involving line-to-ground faults.

4.2.5 Subsynchronous resonance

When a generator is connected to a transmission system that has series capacitor compensation, it is possible to develop subsynchronous frequency oscillations and shaft torques that can be damaging to the generators. Therefore, when a generator will be operating on such a series compensated system, the purchaser should work closely with the generator manufacturer in order to ascertain the severity of the problem and to define the requirements for equipment to protect the generator on a particular system. Successful mitigation of the oscillations may be accomplished by equipment selection, control, and protection techniques.

4.2.6 Asynchronous operation

All machines designed in accordance with this standard are intended to operate in synchronism with the system to which they are connected. However, circumstances may arise where, usually due to equipment failure, the generator is operated out of synchronism with the system. If this should occur, a careful evaluation of the event is required, as operation outside the bounds of the equivalent negative-sequence duty described in 4.1.8 and 4.2.3 could easily happen. Inspection of the generator rotor may be required to establish the ability to continue to operate the machine safely.

This type of abnormal operation will usually fall into one of two broad categories.

4.2.6.1 Operation close to synchronous speed

In this case, the generator either drives the prime mover or is driven by the prime mover at a small slip relative to the system frequency. Resulting low slip frequency currents in the rotor may cause heating and potential damage to the rotor. Usually some time is required for temperatures to reach damaging levels, and operators may have a short period available in which they can react to the situation, if relaying fails to protect the machine.

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4.2.6.2 Operation at or near standstill

This type of inadvertent operation usually results from some sequence of events that closes the breaker between the generator and the power system while the generator is at or near standstill on turning gear.

CAUTION

The machine will attempt to accelerate to synchronous speed, and, unless there is rapid intervention, very severe damage up to and including total destruction of the turbine-generator set can occur. Operation of the protective relaying is essential under these circumstances, as there is little or no opportunity for operator intervention before damage occurs.

4.2.7 Short-time volts/hertz variations

At the purchaser's request, the manufacturer shall provide a curve of safe short-time volts/hertz capability. The intent of the curve is to identify the level of overfluxing above which the machine should never be operated, to avoid possible machine failure. Unless otherwise specified, the curve shall apply for time intervals of less than 10 min.

The voltage/frequency excursions of concern result in abnormally high levels of magnetic flux in the machine. The typical sources of such variation are load rejection, and sustained off-line operation. Under normal circumstances, a unit connected to the power system and performing energy conversion will not see substantial overfluxing. Overfluxing of the core well beyond the steady-state levels defined in 4.1.7 can result in not only substantial bulk core overheating, but also possible electromagnetic core failure due to local overheating. The overflux capability of any transformers associated with the generator bus must be considered separately.

4.2.8 Hydrogen explosion containment

4.2.8.1 Machine housing and cover plates

For hydrogen-cooled generators, the complete machine housing, and any pressure-containing cover plates (e.g., over coolers) for use with hydrogen as a coolant, shall be designed to withstand an internal explosion, with the explosive mixture initially at atmospheric pressure, without danger to personnel. If required by the purchaser at the time of the order, a static pressure test shall be made to check the strength of the housing and cover plates. A suitable test would be the application of a gauge pressure of 800 kPA for 15 min.

4.2.8.2 Stator winding high-voltage terminal bushings

The stator winding high-voltage terminal bushings for hydrogen-cooled machines shall be designed to withstand a gas pressure of at least 800 kPA gauge.

4.2.9 Overspeed

Cylindrical-rotor generators shall be constructed so that they will withstand, without mechanical injury, transient operation up to 120% of rated speed.

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4.3 Service environment

4.3.1 Important environmental parameters

Generators will be applied to a variety of sites each with unique environmental conditions. The purchaser should acquaint the generator manufacturer with the site conditions that may impact the generator and request recommendations for any measures necessary either by the generator manufacturer or plant designer to mitigate any potential problems that could occur as a result of these conditions. Conditions should include (but not necessarily be limited to) the following:

a) Air contamination
   1) Abrasive or conducting dust (such as fly ash and coal dust)
   2) Chemical fumes (such as hydrogen sulfide)
   3) Combustible or explosive dust
   4) Salt air
   5) Steam
   6) Lint
   7) Flammable gases
   8) Oil vapor
   9) Nuclear radiation

b) Cooling water contamination
   1) Mineral content
   2) Chemical content (oxygen included)
   3) Biological content

c) Weather conditions (outdoor units only)
   1) Maximum wind speeds
   2) Maximum snow loading
   3) Rainfall amounts
   4) Humidity ranges
   5) Temperature ranges

d) Exposure to abnormal shock or vibration
   1) Earthquake zone
   2) Nearby blasting

e) OV machines in restricted areas

f) Exposure to mechanical loads involving thrust or overhang

g) Subject to operation in an inclined position (including barge mounted or shipboard units)

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4.3.2 Enclosure types and environmental control

For protection from contamination in the surrounding air, the generator enclosure type is important. The two basic types are those used for hydrogen-cooled generators and those used for air-cooled generators. Basic requirements and attributes for each are listed below.

4.3.2.1 Hydrogen-cooled generator housing

Hydrogen-cooled generators allow very little transfer of contamination from the outside environment to the inside when the housing is pressurized with hydrogen.

To keep dangerous air/hydrogen mixtures out of the generator, the hydrogen enclosure should be pressurized to at least 3.4 kPa (0.034 bar) higher than the surrounding ambient air. The hydrogen containment should be well sealed, and it should include shaft seals to prevent significant leakage. Acceptable leakage rates should be established by agreement with the manufacturer. Typical leakage rates range from 5 m^3 to 15 m^3 per day.

Any enclosures around the main hydrogen enclosure should be adequately ventilated to avoid accumulation of hydrogen gas [B9].

4.3.2.2 Air-cooled generator housing

For TEWAC generators, the enclosure should be arranged so as to prevent the free exchange of air between the inside and outside of the case but not sufficiently enclosed to be termed airtight. The enclosure should be arranged that dust should not enter in sufficient quantity to interfere with satisfactory operation of the machine. These enclosures may provide filtered makeup air in a low-pressure zone of the enclosure to compensate for air leaking out from zones that are somewhat over atmospheric pressure.

For OV air-cooled generators, the housing should be enclosed so as to prevent the free exchange of air anywhere but at the inlet and outlet openings, but not sufficiently enclosed to be termed airtight. The enclosure should be arranged so that dust should not enter in sufficient quantity through the enclosure, not including inlet and outlet openings, to interfere with satisfactory operation of the machine. Arrangements should be made between the purchaser and manufacturer to arrange for adequate filtration of the ventilation airflow, either supplied with the generator housing or separately, in order to meet the manufacturer's air quality requirements.

In general, particular attention should be given to air-cooled generators with regard to airborne contaminates of the type discussed in 4.3.1 and discussed with the manufacturer to assure that appropriate mitigating measures are included in procurement requirements.

5. Rating and performance characteristics

5.1 Output rating

The output rating of a generator is the MVA (apparent power) available continuously at the terminals at rated frequency, voltage, power factor, and primary coolant temperature (and hydrogen pressure and purity if hydrogen-cooled). If the generator excitation system power is supplied from the generator terminals, the net power delivered to the system will be lower than the generator rated output by the amount of excitation power being supplied.

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The rated primary coolant temperature shall be established at 40 ºC for all types of generators and shall appear on the nameplate. If an additional rating point matching the rated output of the prime mover is desired, then this capability point shall also appear on the nameplate. This may be of particular importance when the capability point matching a rated or guaranteed turbine output point is at other than 40 ºC primary coolant temperature.

5.2 Capabilities

A generator capability is the highest acceptable continuous loading in MVA (apparent power) under specified conditions of operation. For a generator operated at rated conditions of operation, the capability is equal to the output rating. For a generator operated over a range of conditions of operation, the capability is a range of outputs that includes the output rating.

When the turbine has both a base load capability and a peaking capability, it is appropriate to specify both base and peak capabilities for the generator. The manufacturer shall supply curves of generator capabilities under site conditions over the specified range of generator primary coolant temperature (see Figure 2). For a machine with OV air cooling, this primary coolant temperature will normally be the same as that of the ambient air surrounding the generator.

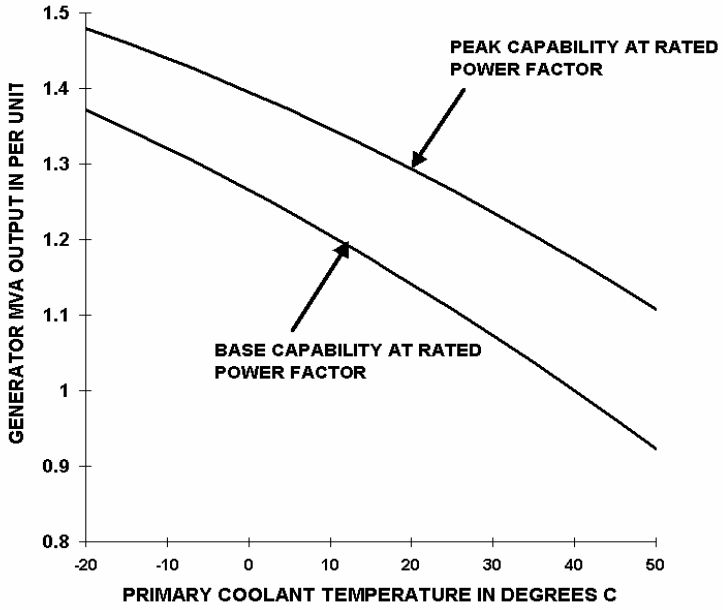

Figure 2—Typical output power capability curves for ambient-following generator

5.2.1 Base capability

The generator base capability is the range of continuous output expressed in MVA available at the machine terminals at the operating site at rated frequency, and voltage (and hydrogen pressure and purity where applicable, and stator winding cooling water flow rates where applicable), corresponding to the range of generator primary coolant temperatures and power factors specified for the operating site, with generator component hottest-spot temperatures not exceeding the values specified in 7.1.1 for base load operation.

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5.2.2 Peak capability

Where peak capability is specified as a requirement, it is the range of continuous outputs expressed in MVA available at the machine terminals at the operating site at rated frequency, and voltage (and hydrogen pressure and purity where applicable, and stator winding cooling water flow rates where applicable), corresponding to the range of generator primary coolant temperatures and power factors specified for the operating site, with generator component temperatures not exceeding the values specified in 7.1.2 for peak load operation. The peak capability must be established by agreement.

5.2.3 Matching turbine and generator capabilities.

For combustion gas turbines and combined cycle steam turbines having output capabilities that depend on ambient air temperature at the site, the generator should normally be specified by the purchaser so as not to limit the specified turbine output over the ambient range within base generator capability and at rated power factor. As an alternative and by agreement, a generator may be selected so that in specified part(s) of the range it is not necessary for the base capabilities of the generator to equal or exceed the base capabilities of the turbine. It may then be possible to utilize a slightly smaller generator. Adjustments in power factor from rated or the utilization of peak capability (with accelerated life usage as given in 7.1.2) may often allow full turbine output in the specified part(s) of the range.

5.3 Voltage and current ratings

5.3.1 Stator

Stator voltage ratings along with the winding configuration (wye or delta) for all generators shall be fixed by agreement (see 4.1.7).

Rated stator current is defined by the rated voltage and rated MVA of the generator.

5.3.2 Rotor

Rated generator rotor voltage is specified by the manufacturer, based on the rotor winding resistance and the excitation current required for full load operation at rated voltage and power factor, including suitable margin. Ceiling voltage shall be agreed upon by the manufacturer and purchaser. See IEEE Std 421.1 for definitions of ceiling voltage, and typical values.

5.4 Power factor and reactive power capability

Power factor at output rating shall be fixed by agreement. The real and reactive power capabilities across the ranges of base and peak capability, primary coolant temperature, and hydrogen pressure (if applicable) shall be provided by the manufacturer. Figure 3 illustrates a typical reactive power capability diagram. Operation when the generator supplies megavars to the power system is overexcited operation; operation when the generator absorbs megavars from the power system is underexcited operation.

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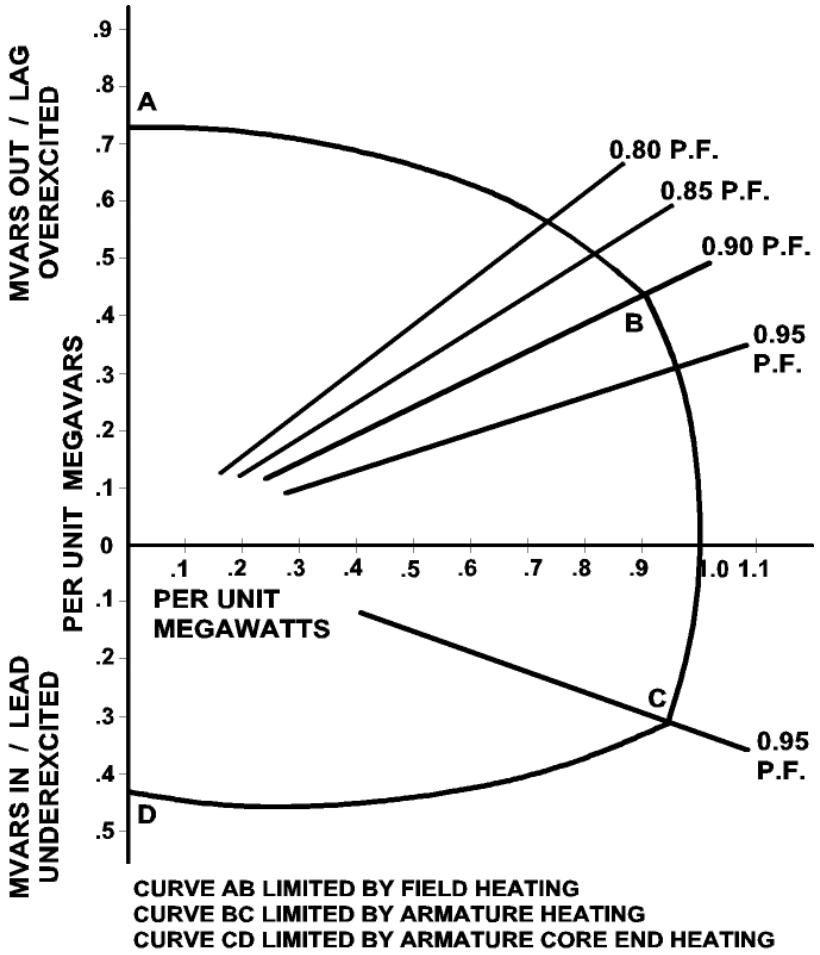

Figure 3—Typical reactive power capability curve at rated cold gas temperature

Rated power factor is the power factor specified for operation at rated megawatt load and rated megavars overexcited. Specifying a lower power factor results in an increased capability to supply megavars to the system but requires a generator with a larger MVA rating. For an air-cooled generator, the power factor at output rating is typically set at 0.90, 0.85, or 0.80 overexcited. For a hydrogen-cooled generator, the power factor at output rating is typically set at 0.90 or 0.85 overexcited. If not specified by the purchaser, the minimum rated power factor shall be 0.90.

For both air-cooled and hydrogen-cooled generators, the minimum underexcited power factor (PF) at rated megawatt output power shall be set at 0.95 or higher.

For generators used with generator step-up transformers and unit auxiliary transformers, the useful megavar operating range (high voltage to low voltage) should be considered when specifying the generator power factor rating. For example, the entire megavar operating range may not be available in low power factor rated machines because of voltage range limitations.

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5.5 Short-circuit ratio

Short-circuit ratio (SCR) at output rating shall be fixed by agreement. A higher minimum SCR specification will improve steady-state stability characteristics but may require a larger generator. A minimum SCR should be fixed after consideration of steady-state stability in the power system where the generator is to be installed [B3].

The steady-state stability limits with fixed manual voltage control usually affect how far the unit can operate into the leading power factor or underexcited region of the generator capability curve. Underexcitation limiters are often set based upon this. With modern automatic voltage regulators this limit can be significantly extended, particularly if sophisticated features such as "power system stabilizers" are included to avoid any system dynamic stability issues as a result of fast regulator action. Redundant regulators can be considered to assure automatic control availability.

Typical values specified are usually in the range of 0.35 to 0.58. If not specified by the purchaser, the minimum SCR shall be 0.35.

5.6 Transient and subtransient reactances

Requirements for transient and subtransient reactances are not established by this standard and are not normally specified.

Direct-axis transient reactance (x'_d) and subtransient reactance (x''_d) may be specified or agreed upon, with regard to the operating conditions at output rating and across the ranges of base and peak capability. It may be appropriate to specify or agree on a minimum value of the direct-axis subtransient reactances at the saturation level of rated voltage. It may also be desirable to specify or agree on a maximum value of the direct-axis transient reactance at the unsaturated conditions of rated current. Since the two reactances depend to a great extent on common fluxes, care must be taken to assure that the values specified or agreed upon are compatible, i.e., that the lower limit of the subtransient reactance is not set too close to the upper limit of the transient reactance. It is common practice for the manufacturer to provide estimated values of these reactances and many other parameters that are useful in the design of power systems.

For definitions of saturated and unsaturated transient and subtransient reactances, see *The Authoritative Dictionary of IEEE Standards Terms* [B10].

If it is agreed that values are to be determined by test, the test shall be in accordance with IEEE Std 115.

When the limit values of transient or subtransient reactance have been specified or agreed upon, these limits shall be subject to the tolerances recommended in Table 4.

Table 4—Tolerances on reactance values

	Transient reactance (%)	Subtransient reactance (%)
Upper limit	+0	+30
Lower limit	–30	–0
NOTE—This table applies when limits are specified or agreed upon.		

If no values have been specified or agreed upon, the manufacturer shall provide estimated values subject to a tolerance of ±15%.

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5.7 Voltage wave shape

5.7.1 Maximum allowable deviation factor

The maximum allowable deviation factor (refer to *The Authoritative Dictionary of IEEE Standards Terms* [B10] for the definition of deviation factor) of the open-circuit terminal voltage wave of synchronous machines shall not exceed 0.1.

5.7.2 Telephone influence factor

5.7.2.1 Balanced telephone influence factor

The balanced telephone influence factor (TIF) of synchronous generators [B1], based on the single-frequency weighting factors given in Annex C shall not exceed the values given in Table 5.

Table 5—Balanced TIF limits

MVA rating of machine	Balanced TIF
$10 \leq$ MVA < 20	100
$20 \leq$ MVA < 100	70
$100 \leq$ MVA	40

5.7.2.2 Residual component

The residual component of TIF, based on the weighting factors given in Annex C, shall not exceed the values given in Table 6.

Table 6—Residual TIF limits

MVA rating of machine	Residual TIF
$10 \leq$ MVA < 20	75
$20 \leq$ MVA < 100	50
$100 \leq$ MVA	30

5.7.2.3 Weighting factors

The single-frequency telephone influence weighting factors (TIF_f) according to the 1960 single-frequency weighting are shown in Table C.1 for 60 Hz systems. A comparable set of weighting factors for 50 Hz systems are shown in Table C.2.

Methods of measurement for TIF shall be in accordance with IEEE Std 115.

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6. Insulation systems

6.1 Insulation systems defined

An electrical insulation system is an assembly of insulating materials. For definition purposes, the electrical insulation systems of synchronous machine windings (either rotor or stator) are divided into three components. These components are the coil insulation with its accessories, the connection and winding support insulation, and the associated structural parts.

All of the components described in 6.1.1, 6.1.2, and 6.1.3 associated with the stator winding constitute one insulation system, and all of the components associated with the rotor winding constitute another insulation system.

6.1.1 Coil insulation with its accessories

The coil insulation comprises all of the insulating materials that envelop the current-carrying conductors and their component turns and strands, and forms the insulation between them and the machine structure. This insulation includes the armor tape, the stator ground wall insulation, slot fillers, rotor slot liners, turn insulation, creepage blocks, and rotor retaining ring insulation.

6.1.2 Connection and winding support insulation

The connection and winding support insulation include all of the insulation materials that envelop the connections, which carry current from coil to coil or from bar to bar, and from rotor and stator coil terminals to the points of external circuit and attachment. The connection and winding support insulation also include the insulation of metallic supports for the winding.

6.1.3 Associated structural parts

The associated structural parts of the insulation system include the rotor winding blocking, the slot wedges, the support rings and any conforming materials, the nonmetallic support for the winding, the blocking used to separate the coil ends and connections, terminal boards, stand-off insulators, bushings, and any other nonmetallic components used to provide mechanical support for a current-carrying conductor.

6.1.4 Impregnated insulation

Insulation is considered to be impregnated when a suitable substance provides a bond between components of the structure and also a suitable degree of filling and surface coverage sufficient to give adequate performance under the extremes of temperature, surface contamination (moisture, dirt, etc.), and electrical and mechanical stress expected in service. The impregnant shall not flow or deteriorate enough at operating temperature so as to seriously affect performance in service.

6.1.5 Impaired insulation

The word “impaired” is used here in the sense of causing any change that could disqualify the insulating material from continuously performing its intended function, whether creepage spacing, mechanical support, or dielectric barrier action. The electrical and mechanical properties of the insulation shall not be impaired by the prolonged application of the hottest-spot or limiting observable temperature permitted for the specific insulation class.

6.1.6 Insulation characteristics

It is important to recognize that there are several mechanisms that can lead to impairment of an insulation system. Important mechanisms include (but are not limited to) electrical impairment due to discharges

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within the groundwall, mechanical deterioration due to vibration or fault forces, thermal degradation due to exposure to temperatures beyond the capability of the materials in the system, and the effects of electrical discharge, such as slot vibration sparking, slot discharge sparking, and corona discharge in end turns of stator windings. Some of these effects may act in unison to produce accelerated aging. For example, mechanical vibration of the winding may lead to component wear, which in turn leads to slot discharge sparking. Excessive corona in the end windings may lead to deterioration of the insulation system, or may result in deposition of corona products on the surface of the end winding, which in turn can lead to loss of cooling effectiveness and overheating of the end turns. A number of guides and standards that are helpful in insulation system evaluation are listed in Clause 2 and Annex A.

6.1.7 Insulation life

A well-designed and well-manufactured winding will have a long life if appropriately maintained and operated. It should be recognized that any machine that is frequently load cycled, or that operates in an environment that includes one or more of the service conditions described in 4.3, would require careful maintenance in order to obtain optimum life from the windings.

6.2 Classes of insulation systems

The insulation systems usually employed in synchronous machines covered by this standard are defined in this clause. These definitions, in general, correspond with the principles set forth in IEEE Std 1, which is also the accepted basis for interpretation.

6.2.1 Definitions of classes

Insulation system classes are those by which service experience or accepted comparative tests with service-proven systems can be shown to be capable of continuous operation with the limiting observable temperature rise or hottest-spot total temperature as specified in Table 7 and Table 8 of this standard. Insulation systems of synchronous machines shall be classified as Class 130 (B), Class 155 (F), or Class 180 (H).

6.2.2 Experience or accepted test

In accordance with IEEE Std 1, experience as used in this standard means successful operation for a long time under actual operating conditions of machines designed with temperatures at or near the temperature limits.

Accepted test, as used in this standard, means a test on a system or model system that simulates the electrical, thermal, and mechanical stresses occurring in service.

6.2.3 Test procedures

Where appropriate to the construction, tests should be made in accordance with IEEE Std 275 and IEEE Std 434.

6.3 The use of different classes of insulation systems

6.3.1 Coils, connections, and winding supports

If in any machine the class of the insulation systems used for the connection and winding support insulation is different from the class for the coil insulation, the two distinct classes of insulation that are employed shall be separately listed by the manufacturer. In any such machine having different classes for the coil and

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for the connection insulation systems, the different temperature limits shall apply in accordance with the limits established for the respective classes.

6.3.2 Associated structural parts

If in any machine the class of the insulation systems used for the associated structural parts is lower than the class used for the coil insulation, the insulating materials used for the associated structural parts shall be equivalent, at the operating temperatures of those parts, to the material used for the coil insulation at its limiting temperature with respect to fire resistance, shrinkage, material deterioration, partial discharge, and corona endurance under conditions of mechanical stress and ionization exposure to which they are subjected under the service conditions described in 4.1.

7. Temperatures and temperature limits

7.1 Temperature limits

The temperatures allowed for parts in contact with electrical insulation outlined in this clause are based on the traditional insulation temperature classification of 130 (B), 155 (F), or 180 (H).

In this standard both temperature and temperature rise are specified in degrees Celsius (°C).

7.1.1 Base capability

The hottest-spot temperature of any part of the machine in contact with an electrical insulation system or other nonmetallic component shall not exceed the maximum value of the temperature classification of that insulation or nonmetallic component, when the machine is operating within the base capability as described in 5.2.1, and at rated hydrogen pressure and purity, if applicable.

It is intended that the hottest-spot temperatures of 130 °C for Class 130 (B) insulation system, 155 °C for Class 155 (F) insulation systems, and 180 °C for Class 180 (H) insulation systems should not be exceeded at base capability, defined in 5.2.1. This shall be demonstrable by direct measurement or recognized methods of calculation correlated to special tests on a basically similar machine.

The manufacturer shall demonstrate by design, qualification, or experience that the applied insulation system is qualified to perform reliably and for generally accepted life at the specified temperature limits for the specified insulation class. The qualification of the applied insulation system to one of these classifications establishes the temperature limits of the generator as set forth by this standard. As the hot-spot basis of each of these classifications is 25 °C apart from adjacent classes, there is the possibility of qualified systems for a hot-spot basis in between these classes. When this is the case, temperature limits in between these classes may be established by agreement.

Observable temperatures are to be subject to the limits specified in Table 7 for air-cooled generators and Table 8 for hydrogen-cooled generators. Observable temperatures shall be subject to the limits in Table 7 or Table 8 when the generator is operated under the following conditions:

a) 40 °C primary cold coolant(s)

b) Rated load and power factor

c) Rated voltage and speed

d) Rated hydrogen pressure and purity (if applicable)

e) Site altitude

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Observable temperature limits for indirectly cooled stator windings in Table 7 and Table 8 are for rated stator winding voltages V_n (line-to-line) at or below 12 kV. For machines with rated stator winding voltage V_n above 12 kV these limits are to be reduced according to the following relationships:

$12 < V_n \leq 24$ kV	–1 °C for each kilovolt or part thereof
$V_n > 24$ kV	By agreement

Temperature limits other than those given in Table 7 or Table 8 may be used by agreement when the manufacturer can show that hottest-spot temperature limits are not exceeded. When operating within the capability of the generator, the core and mechanical parts, whether or not in contact with electrical insulation, shall not attain temperatures that are detrimental to the insulation of that part or any adjacent part. Miscellaneous parts such as brush holders and brushes shall not attain temperatures that would injure the machine in any respect.

Table 7—Limiting observable temperature rises of air-cooled, cylindrical-rotor generators

Item	Machine part	Method of temperature determination	Temperature rise (°C) at 40 °C cold coolant		
			Class 130 (B)	Class 155 (F)	Class 180 (H)
1	Indirectly cooled stator windings	Embedded detector[a]	85[b, c]	110[b, c]	130[b, c]
2	Directly cooled stator windings	Air discharge from bar	80	100	NA[e]
		Water discharge from bar	50	50	50
3	Indirectly cooled rotor windings	Resistance	85	105	125
4	Directly air-cooled rotor windings (for 1 to 14 air flow outlet regions)[d]	Resistance			
		1, 2 outlets	60	75	NA[e]
		3, 4 outlets	65	80	NA[e]
		6 outlets	70	85	NA[e]
		8 to 14 outlets	75	90	NA[e]
		>14 outlets	80	95	NA[e]
5	Cores and mechanical parts, whether or not in contact with insulation	Detector or thermometer	Not detrimental to the insulation of that part or any adjacent part		
6	Collector rings	Thermometer	85	85	85
7	Miscellaneous parts (such as brush holders and brushes, etc.) may attain temperatures that will not injure the machine in any respect.				

[a]Embedded detectors are located within the slot of the machine and can be either resistance elements or thermocouples. Embedded detector temperatures shall be used to demonstrate conformity with the standard for generators so equipped.

[b]These values are for insulation systems with thermosetting materials. For insulation systems with thermoplastic materials, Class 155 (F) and Class 180 (H) shall not apply, and the equivalent temperature rises shall be 60 °C for Class 130 (B).

[c]For machines with rated stator winding voltage V_n (line-to-line) above 12 kV the temperature rise of the embedded temperature detector shall be reduced according to the following relationships:

$12 < V_n \leq 24$ kV	–1 °C for each kilovolt or part thereof
$V_n > 24$ kV	By agreement

[d]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.

[e]These values shall be reached by agreement.

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Table 8—Limiting observable temperature rises of hydrogen-cooled, cylindrical-rotor generators

Item	Machine part	Method of temperature determination	Temperature rise (°C) at 40 °C cold coolant		
			Class 130 (B)	Class 155 (F)	Class 180 (H)
1	Indirectly cooled stator windings				
	1) H_2 pressure ≤ 150 kPA abs	Embedded detector[a]	85[b, c]	105[b, c]	NA[d]
	2) H_2 pressure ≤ 200 kPA abs	Embedded detector[a]	80[b, c]	100[b, c]	NA[d]
	3) H_2 pressure ≤ 300 kPA abs	Embedded detector[a]	78[b, c]	98[b, c]	NA[d]
	4) H_2 pressure ≤ 400 kPA abs	Embedded detector[a]	73[b, c]	93[b, c]	NA[d]
	5) H2 pressure > 400 kPA abs	Embedded detector[a]	70[b, c]	90[b, c]	NA[d]
2	Directly cooled stator windings				
	1) Gas-cooled	Gas discharge from bar	70	90	NA[d]
	2) Liquid-cooled	Liquid discharge from bar	50[e]	50[e]	50[e]
3	Indirectly cooled rotor windings	Resistance	85	105	NA[d]
4	Gas directly cooled rotor windings (for 1 to 14 air flow outlet regions)[f]	Resistance			
		1, 2 outlets	60	75	NA[d]
		3, 4 outlets	65	80	NA[d]
		6 outlets	70	85	NA[d]
		8 to 14 outlets	75	90	NA[d]
		>14 outlets	80	95	NA[d]
5	Liquid directly cooled rotor windings	Liquid discharge	50[e]	50[e]	50[e]
6	Cores and mechanical parts, whether or not in contact with insulation	Detector or thermometer	Not detrimental to the insulation of that part or any adjacent part		
7	Collector rings	Thermometer	85	85	85
8	Miscellaneous parts (such as brush holders and brushes, etc.) may attain temperatures that will not injure the machine in any respect.				

[a]Embedded detectors are located within the slot of the machine and can be either resistance elements or thermocouples. Embedded detector temperatures shall be used to demonstrate conformity with the standard for generators so equipped.

[b]These values are for insulation systems with thermosetting materials. For insulation systems with thermoplastic materials, Class 155 (F) and Class 180 (H) shall not apply, and the equivalent temperature rises shall be 60 °C for Class 130 (B).

[c]For machines with rated stator winding voltage V_n above 12 kV the temperature rise of the embedded temperature detector shall be reduced according to the following relationships:

$12 < V_n \leq 24$ kV	–1 °C for each kilovolt or part thereof
$V_n > 24$ kV	By agreement

[d]These values shall be reached by agreement.

[e]The intention of the temperature rise value is that the liquid discharge temperature is to be limited to 90 °C.

[f]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.

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7.1.2 Peak capability

At peak capability, defined in 5.2.2, it is intended that the hottest-spot temperatures of 145 °C for Class 130 (B) insulation systems, 170 °C for Class 155 (F) insulation systems, and 195 °C for Class 180 (H) insulation systems should not be exceeded. This design concept shall be demonstrable by direct measurement or recognized methods of calculation correlated to special tests on a basically similar machine.

Operation at the peak temperature values causes the generator insulation to age thermally at approximately three times the rate that occurs at the base capability temperature values. Under peak conditions, increased vibration and thermal expansion can also be expected to reduce further the life of the windings.

7.2 Methods of temperature determination

It is recognized as acceptable practice for the manufacturer to predict the hottest-spot temperature of a component part, in lieu of direct measurement of it, by providing a correction factor to measurements from other methods such as embedded detector or hot coolant. This correction factor should be based on tests performed on the same or a similar machine.

For detailed methodology of temperature testing, refer to IEEE Std 115.

7.2.1 Thermometer method

This method consists of the determination of the temperature by resistance thermometers, or thermocouples, with these instruments being applied to the hottest part of the machine accessible without permanent installation of the detector.

7.2.2 Resistance method

This method consists of the determination of the temperature by comparison of the resistance of a winding at the temperature to be determined with the resistance at a known temperature. This method is preferred for determining observable temperatures of rotor windings.

7.2.3 Embedded detector method

This method consists of the determination of the temperature by thermocouples or resistance temperature detectors built into the machine, located outside the major insulation, as specified in 7.3.

7.2.4 Coolant method

This method consists of determination of the temperature, by thermocouples, resistance temperature detectors, or other equivalent means, of the coolant at a specific location. This is applicable to those cases in which the coolant path is defined to be in intimate thermal contact with the part of interest

7.2.5 Other methods

Other methods of temperature determination include infrared temperature detectors, optical temperature detectors, and temperature sensitive paints. These methods require special engineering judgment and skill for their successful use and generally would be used only by a manufacturer during type testing for engineering information and calculation method calibration.

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7.3 Locations of embedded temperature detectors

For machines having indirectly cooled stator windings, the resistance temperature detector is recommended. Although the resistance temperature detector is given preference, the use of thermocouple detectors is also recognized as acceptable practice.

At least four detectors per phase shall be built into the machine, symmetrically distributed around the circumference, located between coil sides, and in positions along the length of the slots normally having the highest temperature. Each detector shall be assembled with strips of suitable insulating materials, so that the assembled unit shall be as wide as the slots and shall be somewhat longer than the detector. The detector shall be located in the center of the slot (with respect to the slot width) and in intimate contact with the insulation of both the upper and lower coil sides whenever possible; otherwise, it shall be in intimate contact with the insulation of the upper coil side (i.e., the coil side nearest the air gap). Each detector shall be installed and its leads brought out in such a manner that the detector is effectually protected from contact with cooling medium. If the detector strip is not the full length of the core, suitable packing shall be inserted between the coils to the full length of the core to provide uniform slot fill and prevent the cooling medium from affecting the detector.

7.4 Location of coolant temperature detectors

For machines with indirectly cooled stator windings, measurement of the temperature of the cold primary coolant (exit coolant from the heat exchanger, if furnished) shall be made by suitable devices whose temperature-sensing elements are located so as to allow determination of the average temperature of the coolant.

For machines with directly gas-cooled stator windings, measurement of the temperature of the coolant shall be made in the coolant exit streams of at least one coil in each phase group. For machines with liquid-cooled stator windings, measurement of the temperature of the coolant shall be made in the coolant exit streams in each coolant circuit.

8. Efficiency

8.1 Methods

Methods for determining efficiency and losses shall be as described in IEEE Std 115. The efficiencies of contained sets, such as steam-turbine-generator sets, are specified as set efficiencies and not as efficiencies of the individual machines. The separate efficiency of the generator may be reported by agreement.

8.2 Reference conditions

The efficiency shall be determined at the rated output, voltage, speed, frequency, power factor, and altitude, and under balanced load conditions. For hydrogen-cooled machines, the losses affected by pressure shall be included at the hydrogen pressure and purity associated with the rating.

In determining I^2R losses, the resistance of windings shall be corrected to the reference temperature in Table 9. This reference temperature shall be used for determining I^2R losses at all loads.

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Table 9—Reference temperatures for use in determining I^2R losses

Class of insulation system	Reference temperature (°C)
130 (B)	95
155 (F)	115
180 (H)	130

If the rated temperature rise is specified as that of a lower temperature class of insulation system, the temperature for resistance correction shall conform to the lower temperature class, that is, Class 130 (B) rise with Class 155 (F) insulation.

No temperature correction shall be applied to losses other than I^2R. When input–output tests are used for determining efficiency, they shall be made, as nearly as possible, at the final temperature attained at operation at rating, and under the conditions of this clause.

Friction and windage loss will be determined with the machine operating at rated speed and at rated hydrogen pressure and purity, if applicable, and with the generator unexcited at rated cold gas temperature. Friction and windage loss tests at lower pressure may be performed when agreed upon by the purchaser and the manufacturer.

8.3 Types of losses

The following losses shall be included in determining efficiency:

a) I^2R losses of stator winding
b) I^2R losses of rotor winding
c) Core loss
d) Stray load loss
e) Excitation system loss
f) Friction and windage loss
g) Ventilation and cooling loss, if applicable

8.3.1 Stator winding I^2R loss

The stator winding I^2R loss is the sum of the I^2R losses in all of the stator winding current paths. The I^2R loss in each current path shall be the product of the square of its current in amperes and its resistance in ohms as measured with direct current corrected in accordance with reference temperatures in Table 9.

8.3.2 Rotor winding I^2R loss

The rotor winding I^2R loss shall be the product of the square of rotor winding current in amperes and the measured resistance in ohms of the rotor winding corrected in accordance with reference temperatures in 8.2. The value of rotor winding current used shall be such that the conditions of 8.2 are fulfilled for the load at which the loss is computed. The rotor winding current may be calculated from test data as described in IEEE Std 115.

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8.3.3 Core loss

The core loss shall be taken as the difference in power required to drive the machine at normal speed when separately excited to produce a voltage at the terminals corresponding to the rated voltage at open circuit, and the power required to drive the unexcited machine at the same speed.-

8.3.4 Stray load loss

The stray load loss is determined by subtracting the stator winding I^2R loss at a specific value of stator current from the short-circuit loss at the same value of stator current. The steady-state short-circuit loss shall be taken as the difference in power required to drive the machine at normal speed, when separately excited to circulate current in the stator winding with its terminals shorted, and the power required to drive the unexcited machine at the same speed. The stator winding I^2R loss shall be calculated for the temperature of the winding during the short-circuit test.

8.3.5 Excitation system losses

These losses are the total of electrical and mechanical losses in the equipment supplying excitation. They shall include the exciter, voltage regulator, and associated devices comprising the excitation system for a particular synchronous machine. Include motor loss if unit motor-generator exciter set is used; if a unit rectifier is used, include the loss of the rectifier and rectifier transformer. Include collector electrical brush contact voltage drop loss if applicable.

8.3.6 Friction and windage loss

The friction and windage loss, including brush mechanical friction, is the power required to drive the unexcited machine at rated speed with the brushes in contact, deducting certain portions of the loss that result from the driving of direct-connected flywheels or other direct-connected apparatus. For hydrogen-cooled generators, the hydrogen purity should be at 98% or losses should be corrected to a purity of 98%. However, when requested by the purchaser, these additional losses will be furnished as a separate item.

8.3.7 Ventilating and cooling loss

This loss includes any power required to circulate the cooling medium through the machine and cooler (if used) by fans or pumps that are driven by external means (such as a separate motor), so that their power requirements are not included in the friction and windage loss.

8.4 Test tolerance on losses

The tolerance on generator-declared losses shall be +10% when comparing to acceptance test values. The generator losses determined by acceptance tests shall not exceed the generator-declared losses by more than 10%.

9. Tests

9.1 Categories and scope of tests

There are the following three primary categories of generator tests:

a) Required manufacturing proof tests

b) Recommended site tests

c) Special performance tests

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These tests are specified in Table 10 and Table 11, and shall be conducted in accordance with IEEE Std 115.

9.1.1 Required manufacturing proof tests

Required manufacturing proof tests are a measure of assurance that the generator has been acceptably manufactured. These tests, which do not involve running the assembled generator, are listed in Table 10. Manufacturers may supplement these required tests with their own set of recommended tests, and other testing may be added by agreement.

9.1.2 Recommended site tests

Recommended site tests ensure acceptability for initial startup. The recommended tests are listed in Table 10. Manufacturers may supplement these recommended tests with other tests, and tests may be added to or eliminated from Table 10 by agreement. The responsibility to perform these site tests shall be defined by agreement.

Table 10—Required manufacturing proof tests and recommended site tests on cylindrical-rotor synchronous generators

Description	Required manufacturing proof tests[a]	Recommended site tests[a]
Resistance of stator and rotor windings	X	X
Dielectric tests of stator and rotor windings	X	X
Voltage balance	—	X
Phase sequence	X[b]	X
Mechanical balance[c]	X	X
Overspeed to 120% of rated speed	X	—
Measurement of insulation resistance of stator and rotor windings	X	X
Measurement of bearing insulation resistance[d]	X	X
Rotor winding shorted turn test at rated speed	X	—

[a]An X indicates that test shall be made on each unit.
[b]A visual check of the stator winding connections or alternative method of checking phase rotation may be made when a factory running test is not required.
[c]A field check of mechanical balance of all generators is recommended after installation.
[d]On all generators furnished with one or more insulated bearings, a factory measurement of the bearing insulation resistance is recommended if the bearings are assembled for shipment or testing.

9.1.3 Special performance tests

Special performance tests provide performance parameters of a generator and supplement the testing of Table 10. These running tests, which are conducted with the generator fully assembled, are listed in Table 11. These tests should be conducted when running tests are specified or when a design that is significantly different from a previously tested design is offered by the manufacturer. Manufacturers may also supplement these special performance tests with other running tests, and tests may be added to or eliminated from Table 11 by agreement.

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Table 11—Special performance tests on cylindrical-rotor synchronous generators

Current balance
No load/open-circuit saturation curve
Synchronous impedance curve[a] (short-circuit saturation)
Harmonic analysis and measurement of TIF
Heat runs
Short-circuit tests at reduced voltage to determine reactance and time constants
Measurement of segregated losses
Shaft voltage

[a]On generators run with brushless exciters, readings of exciter rotor current instead of generator rotor current may be obtained.

9.2 Test procedural requirements

9.2.1 Noise tests

When validation tests of sound pressure level are required, tests will be performed according to ISO 3746-1995.

9.2.2 Dielectric tests

9.2.2.1 Standard test voltages

9.2.2.1.1 Stator windings

Stator windings shall be tested with an ac voltage whose effective value is 1000 V plus twice the rated voltage of the machine. Alternatively, for windings rated 6000 V and above, and when agreed upon by the manufacturer and the purchaser, the test voltage may be a dc voltage of 1.7 times the ac rms test voltage. An alternative of very low frequency (VLF) testing, as given in IEEE Std 433 of 1.63 times the rms of the ac standard test level may also be used when agreed upon by the manufacturer and the purchaser. (For further information regarding insulation testing of large ac rotating machinery with high direct voltage, see IEEE Std 95.)

9.2.2.1.2 Rotor windings

The test voltage for rotor windings rated up to and including 500 V dc shall be an ac voltage whose effective value is ten times the rated excitation voltage but in no case less than 1500 V ac. The test voltage for rotor windings rated greater than 500 V dc shall be an ac voltage whose effective value is 4000 V ac plus twice the rated excitation voltage.

9.2.2.2 Duration of application of the test voltage

The test voltage shall be applied continuously for a period of 1 min. Repeated applications of the test voltage are not recommended.

9.2.2.3 Test voltage requirements

Frequency, wave shape, and crest value of test ac voltage shall be as follows:

a) The frequency of the test ac voltage shall be 50 Hz or 60 Hz.

b) The wave shape of the test ac voltage shall be of acceptable commercial standards, that is, it shall come within the deviation specified as allowable in 5.7.

c) The crest value of the test ac voltage shall be equal to 1.414 times the rms test voltage specified.

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For a description of the methods of measuring the voltage for dielectric tests, see IEEE Std 4.

9.2.2.4 Measurement of ac test voltage

The transformer-voltmeter method shall be used.

9.2.2.5 Points of application of test voltage

The test voltage shall be successively applied between each electric circuit and the frame, with the windings not under test and the core and other metal parts connected to the frame. Interconnected polyphase windings may be considered as one circuit.

9.2.2.6 Location of tests

When the windings are completely assembled at the plant of the manufacturer, and unless otherwise agreed upon, dielectric tests shall be made at the plant of the manufacturer after the completion of the manufacturer's other shop tests. They shall be made either with the machine completely assembled, or on the stator with windings and connections completely assembled, and on the rotor completely assembled, unless otherwise agreed upon. When the windings are completely or partly assembled at destination, the tests in accordance with this clause, shall be made as soon as possible after completing the assembly of the winding. Depending on the agreements covering such cases, the tests may be conducted by the manufacturer, the purchaser, or a subcontractor.

9.2.2.7 Condition of machine to be tested

The machine shall be in good condition, and the dielectric tests, unless otherwise agreed upon, shall be applied before the machine is put into commercial service, and shall not be applied when the insulation resistance is low because of dirt or moisture (refer to IEEE Std 43 for information on insulation resistance testing). Dielectric tests to determine whether or not specifications are fulfilled are permissible on new machines only. Where both short-circuit and dielectric tests are made on a machine, the dielectric test shall follow the short-circuit test.

9.2.2.8 Temperature for dielectric tests

Unless otherwise agreed upon, dielectric tests may be made at room temperature, or at any higher temperature attained in the process of commercial testing up to rated-load operating temperature of the machine.

9.2.2.9 Additional tests after installation

When a test is performed after installation on a new machine that has previously passed its dielectric test at the factory, and whose windings have not since been disturbed, the test voltage, unless otherwise agreed upon, shall be 85% of the value specified for tests in the manufacturing plant.

9.2.2.10 Stator winding turn insulation test

When agreed upon by the manufacturer and purchaser, the stator winding turn-to-turn insulation of multiturn coils may be tested. Test details are described in IEEE Std 522.

9.2.2.11 Other insulation tests

Other insulation tests techniques are available for testing and developing trend data for electrical insulation systems. These test techniques include but are not limited to corona tests, frequency spectrum tests measured at coupling capacitors or wideband current transformers (CTs), partial discharge tests, and power factor tip-up tests.

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9.3 Heat exchanger testing

Water-cooled heat exchangers used for cooling the ventilating air, gas, or liquid shall be designed for the specified inlet water temperature and working pressure. These heat exchangers shall be designed so as not to trap air, and to withstand a test pressure of 150% of the rated working pressure.

9.4 Testing high-voltage terminal bushings

High-voltage terminal bushings (when used) shall be tested independently of the machine windings, and they shall withstand for 60 s a 50 Hz or 60 Hz dry dielectric test in air of not less than 1.5 times the 1 min ac test voltage of the machine winding. When the high-voltage terminal bushings are liquid-cooled, the coolant connections need not be made for the high-voltage test.

9.5 Overspeed testing

Generator rotors shall be overspeed tested at 120% of rated speed. The rotor should be kept at 120% speed for a brief length of time that is sufficient to validate the ability of the rotor to withstand momentary exposure to this speed when in service. This length of time should be 2 min unless the rotor cannot be safely kept at this speed because of rotor dynamics modes that occur when the generator rotor is not coupled to the prime mover.

10. Marking

10.1 Nameplate

A nameplate having the following minimum information shall be provided: manufacturer's name and model, manufacturer's serial number, or other suitable identification and applicable standards

The following information at output rating shall be supplied on the nameplate:

a) Output MVA
b) Voltage
c) Number of phases
d) Power factor
e) Revolutions per minute
f) Stator current
g) Frequency
h) Altitude
i) Temperature(s) of primary cold coolant(s)
j) Temperature of secondary coolant
k) Temperature rise of stator winding
l) Temperature rise of rotor winding
m) Stator winding insulation class
n) Rotor winding insulation class
o) Winding connection (wye or delta)

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p) Generator rotor voltage

q) Generator rotor current

r) Rated hydrogen pressure (if hydrogen-cooled)

10.2 Information about other output capabilities

When specified by the purchaser, additional information shall be provided to define other capability points of significance at other than the rated primary coolant temperature. This information shall typically include the following:

a) Output MVA

b) Power factor

c) Primary coolant temperature

d) Secondary cold coolant temperature

10.3 Other information about the unit

When specified by the purchaser, the total weight of the machine and the weight of the rotor shall be supplied on the nameplate.

10.4 Other marking

When specified by the purchaser, the direction of rotation of the generator shall be shown on the machine.

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Annex A

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[7]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

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Annex B

(informative)

Guide for the basic specification of generators

B.1 Introduction

The specification of a large generator covered by this standard is a complex task. Unfortunately, it is not as simple as specifying a single point power rating and also specifying this standard. This annex is included to assist purchasers of generators covered by this standard to provide the necessary requirements and data to the generator manufacturer that will ensure that a generator designed to meet the specified requirements will meet the long-term needs of the purchaser without overspecifying and adding unnecessary costs.

The core guidelines in this annex are contained in Table B.1 through Table B.4, inclusively. These tables may be used as a checklist to show which party in the process typically originates each requirement. These tables also provide some explanation as to the basis of many requirements that must be provided by the purchaser and their potential impacts on the generator design.

This annex is not considered to be a part of this standard, but merely an adjunct. As such, the wording of the standard takes precedence where any inconsistencies between this annex and the standard might appear. This annex is primarily categorizing and summarizing requirements mentioned in the standard that are generally felt to be the major part of the functional requirements, but it cannot be guaranteed to be complete for all situations. Further, this standard generally does not cover requirements that go beyond functional requirements that may dictate design practices of a manufacturer, nor does it specify that specific materials or design configurations be used or not used.

B.2 Sources of requirements

There are a number of parameters that must be supplied by the purchaser that relate to site conditions and those that relate to power system requirements. These are listed in Table B.1.

There are the turbine output capabilities that are usually supplied by the turbine manufacturer. However, the purchaser may want to specify the degree that the generator capability meets or exceeds the turbine capability, whether to allow adjustments in power factor or use of a peaking capability to meet maximum requirements, or to specify margin to allow for future turbine upratings. If the turbine manufacturer is the same as the generator manufacturer, the supply of turbine output capability may be an internal matter for the manufacturer. In other cases, the purchaser may have to coordinate the supply of this information. In many cases, this is not a simple point of highest kilowatt output, but a kilowatt output available for a given ambient-temperature condition where combustion turbines are part of the plant, either as simple cycle, or in combined cycle with a steam turbine unit(s). This and other information provided by the turbine manufacturer are listed in Table B.2.

There are data that are normally supplied by the generator manufacturer once the generator has been selected in response to the specified requirements. This data may become part of an agreement once evaluated to be satisfactory by the purchaser, but are usually not specified in request for quotation. This information is listed in Table B.3.

Lastly, there are those minimum requirements that are specified by this standard that a purchaser can assume are met by specifying this standard. These requirements are listed in Table B.4.

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Table B.1—Information typically specified by the purchaser

Parameter	Typical value	Notes	IEEE Std C50.13 Subclause
Rules for matching turbine output	Statement(s) as to preferred criteria for matching or coordinating with turbine output.	There may or may not be a desire for the generator not to be the limiting component in the TG set or to allow for future upratings of the turbine. See B.3.1.	4.1.1, 5.1, 5.2
Secondary coolant type	Typical choices include the following: a) 100% fresh water b) 50/50 mixture of fresh water and glycol c) 100% sea water	This is usually the cooling liquid at site that will be available to the generator coolers. Mineral or biological content would also be important to know for cooler material selection and design. See B.3.1.	4.1.2
Secondary coolant temperature	Typically 5 °C to 35 °C	For ambient-following turbines it would be important to know the dependence of secondary coolant temperature(s) upon the ambient temperature. For nonambient-following turbines it is usually sufficient to know the maximum secondary cooling water temperature that could occur during the year. See B.3.1.	4.1.2
Altitude	Usual range from 0 m to 1000 m. A higher altitude can be specified.	A given air-cooled generator capability will decrease with altitude.	4.1.4
Sound emissions	<95 dB (A) sound pressure (default in the standard). Purchaser may specify lower values.		4.1.14
Type of operational duty	3 000 total start capability for base load units. 10 000 total start capability for peaking or frequently cycled units.	It should be specified whether this is a base load unit or a peaking unit or a frequently cycled unit. Any additional details regarding operational duty could be useful to the manufacturer to ensure that the design is adequate.	4.1.5.1
Rapid reclosure duty	If contemplating this type of operation, purchaser should supply specific scenarios for the manufacturer to evaluate.	No specific capability specified.	4.2.4.4
Subsynchronous resonance (SSR)	If contemplating system conditions where SSR may exist, purchaser should supply specific scenarios for the manufacturer to evaluate shaft torques and effects.	No specific capability specified.	4.2.5
Environmental conditions	Purchaser should provide environmental conditions to the manufacturer per 4.3 of including indoor or outdoor, site climate if outdoors, air or water contaminates, etc. Includes some general requirements on housings for hydrogen-cooled and for air-cooled generators.		4.3

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Table B.1—Information typically specified by the purchaser (continued)

Parameter	Typical value	Notes	IEEE Std C50.13 Subclause
Rated power factor	Typical selection values of 0.80, 0.85, and 0.90 are provided depending upon generator type. Minimum rated power factor will be 0.90 (default) if not specified by the purchaser.	Purchaser must determine MEGAVAR supply requirements to the system. Lower power factors will increase generator rated MVA and physical size.	5.4
SCR	A typical range of 0.35 to 0.58 is provided. A minimum value of 0.35 is set if not specified by purchaser.	Purchaser must determine requirement based on system steady-state stability requirements, use of automatic voltage regulators, and operational philosophy. Higher SCRs may increase generator physical size or excitation requirements (and resulting loss) or both.	5.5
Recommended site testing	Listed in Table 10.	Purchaser should determine the scope-of-supply responsibility and requirements for site testing.	9.1.2
Special performance testing	Listed in Table 11.	Purchaser should determine whether or not these tests are required. Many manufacturers recommend performing this testing only when verifying a new design or type of machine.	9.1.3

Table B.2—Information typically specified by the turbine manufacturer

Parameter	Typical value	Notes	IEEE Std C50.13 Subclause
Turbine shaft output	MW with associated ambient or secondary cooling water temperatures.	For nonambient-following turbines this is usually a maximum output point. For ambient-following machines, this capability is usually shown as MW output as a function of ambient temperature or MW output as a function of cooling water temperature. See B.3.1.	4.1.1, 5.2
Method of starting for combustion turbine: Static start or motor start:	Drive-train loss and inertia, starting speed as a function of time, restart intervals, etc.	Static starting of a combustion turbine using the generator as a motor requires coordination of start-up requirements with generator design particularly the rotor damper system and rotor winding ventilation.	4.1.5.2
Direction of rotation	Clockwise or counter clockwise from reference end specified, to match the turbine rotation.	This shall match turbine rotation.	4.1.9
Critical speeds	No exact numbers specified.	Shaft train typically analyzed by turbine manufacturer. Purchaser should clarify responsibility of verifying shaft train dynamics.	4.1.10

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Table B.3—Information typically specified by the generator manufacturer

Parameter	Typical value	Notes	IEEE Std C50.13 Clause/subclause
Phase sequence	Sequence of timing of voltage peaks at main terminals. Two phase sequences are possible. Typically the manufacturer's standard is used. Occasionally, a purchaser may wish to consider specifying the phase sequence to accommodate a plant physical arrangement.	It is usually good practice to specify this geometrically such as "left-center-right" as viewed from a position or to show on a drawing to ensure clarity rather than using terminal numbering such as "T1-T2-T3".	4.1.11
Capability at reduced hydrogen pressure	Reactive capability curves at selected reduced gas pressures.		4.1.12
Capability at reduced (or zero) stator cooling water flow	Not typically supplied but may be supplied by manufacturer by agreement.		5.2.1, 5.2.2
Transient volts/hertz excursions	Volts/hertz variation as a function of time.	Typically supplied if requested.	4.2.7
Rated terminal voltage	Typically supplied by the manufacturer in the range of 10 kV to 30 kV. Occasionally, purchaser may wish to consider specifying voltage to standardize transformer usage or other reasons.	Depending upon MVA rating and the manufacturer's design philosophy, there are usually limited winding combinations available, thus limiting the number of economic voltage selections. Station transformers can usually match any reasonable generator voltage to the system.	5.3.1
Rated rotor voltage and current	Rotor voltage and current at rated and other important conditions.	Usually decided by the generator manufacturer.	5.3.2
Reactances and time constants	Reactances in per unit or percent and time constants in seconds. Applies ± 15% tolerance on transient and subtransient reactance's supplied by the manufacturer. Specifies tolerances of 0% to 30% on transient and subtransient reactances where purchaser specifies minimum or maximum values.	Normally supplied by the manufacturer. If specified requirements are necessary because of system requirements, it would be advisable to review with manufacturers prior to specification as limited choices may be available and/or equipment costs may be impacted.	5.6
Efficiency	Typically supplied by the manufacturer, but only guaranteed for a generator procured separately from the turbine. Specifies which losses are included when supplied and provides reference temperatures for statement of I^2R losses. A +10% tolerance is specified for provided losses when compared to test values.	Where the turbine and generator are procured as a set, the generator losses are normally incorporated into the overall turbine-generator heat rate. In this case, stand-alone generator efficiency is not typically guaranteed separately.	8
Hydrogen consumption	5 m^3/day to 15 m^3/day	Hydrogen consumption usually depends upon the total volume of hydrogen in the generator, the rated hydrogen pressure, the type of shaft seals, and the type of seal oil supply system.	4.3.2.1

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Table B.4—Requirements established by IEEE Std C50.13

Parameter	Value	Notes	IEEE Std C50.13 Clause/subclause
Ambient-temperature range	–20 °C to 50 °C		4.1.3
Application of load	Generator not limiting		4.1.6
Voltage and frequency variation	±5% continuous on voltage at rated frequency ±2% continuous on frequency at rated voltage Other combinations per Figure 1	Step-up transformers may have more restrictive limits. Turbines may have more restrictive limits on frequency variation. Some applications may require larger variations in voltage, for example to control power system stability.	4.1.7
Steady-state I_2	< 5% to <10% depending upon rating		4.1.8.1
Harmonic currents	$I_{2\,eq}$ < 25% I_2 requirement Harmonic $I_{2\,eq} + I_2$ < total I_2 requirement		4.1.8.2
Hydrogen purity	Efficiency based on 98% purity Can meet full load at 95% purity		4.1.13
Stator winding short-time thermal capability	150% rated current for 30 s; table/formula for other times.		4.2.1
Rotor winding short-time thermal capability	125% rotor current for 60 s; table/formula for other times		4.2.2
Unbalanced fault capability—I_2^2t	5 to 30 (per unit $I)^2$ • s depending on rating for times up to 120 s; table/formula in standard	See 4.2.3 for clarification of definition of I_2^2t	4.2.3
Sudden short-circuit mechanical capability	Three-phase short circuit at generator terminals with 1.05 per unit voltage not exceeding short-time stator winding thermal capability		4.2.4.1
Routine synchronizing capability	±10°; 0% to 5% overvoltage; ±0.067 Hz		4.2.4.2
Faulty synchronizing capability	Coast down safely only.	Inspection may be required.	4.2.4.2
Line switching capability	≤0.5 per unit power		4.2.4.3

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Table B.4—Requirements established by IEEE Std C50.13 (continued)

Parameter	Value	Notes	IEEE Std C50.13 Clause/subclause
Asynchronous oeration	Asynchronous operation not recommended. No requirement to accommodate this type of operation.	If this inadvertently occurs, inspection should be considered to check for damage to rotor because of overheating. The likelihood of damage and its severity will be greater for higher slip speeds and longer times.	4.2.6
Hydrogen containment	Withstand internal explosion		4.2.8
Shaft overspeed capability	120% during load rejection transient		4.2.9
Output rating primary cold coolant temperature	40 °C	It may be necessary to specify output capability at other cold gas temperatures to clarify coordination with site secondary coolant temperatures and turbine output.	5.1
Voltage wave shape	Not to exceed 0.1 deviation factor		5.7.1
TIF	Balanced and residual TIF requirement based on rating. Tables in standard.		5.7.2
Temperature limits—hot spots	≤130 °C—Class 130 (B) insulation ≤155 °C—Class 155 (F) insulation ≤180 °C—Class 180 (H) insulation	This applies at rated conditions and over operating range at maximum capability. Standard requires test of similar machine for verification.	7
Temperature limits—observables	Table 7 and Table 8 for Classes 130 (B), 155 (F), and 180 (H) insulation and at 40 °C primary coolant.	C50.13 7 and Table 7 and Table 8 also describe methods of measurement and locations of temperature detectors.	7
Manufacturing proof testing	Minimum proof testing is provided in Table 10.	Procedural requirements of certain testing are provided in 8.2.	9.1.1, 9.2
Nameplate	Data as given in this standard.		10.1

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B.3 Expanded discussions of selected requirements

B.3.1 Discussion 1—rated primary coolant (cold gas) temperature

Users of this standard need to be aware that there has been a change in the specification of rated cold primary coolant temperature listed in Table 8. Temperature rises are now based on a single 40 °C cold primary coolant. Previous revisions of this standard based temperature rises on a 45 °C to 50 °C cold primary coolant for hydrogen-cooled generators and 40 °C for air-cooled generators. It is recognized that this is only one of the changes incorporated in this revision of this standard, but it is one, which if not recognized, could lead a purchaser to specifying a generator that will be unsuitable for the intended application. With all other things being equal, a generator rated at a higher primary cold coolant temperature will require a larger generator than a generator with the same rating at a lower primary cold coolant temperature.

It is important for this standard to specify a single cold primary coolant temperature from which to base a temperature rise and output since this establishes a standard by which a purchaser may compare generators of various manufacturers and also to provide a single point on which to base the temperature tables. A temperature of 40 °C was chosen to be consistent with IEC 34-1-1996 [B7], which also standardizes on this cold primary coolant temperature. This 5 °C to 10 °C change may not seem significant, but close study of the available cooling water temperatures at many intended generation sites indicates that a 40 °C cold primary coolant may not be achievable at many sites particularly during warmer seasons. This would restrict output capability below that of the 40 °C primary coolant MVA rating. Therefore it is very important to specify the secondary coolant temperatures to the manufacturer and relate the availability of these temperatures to expected turbine output. It is reasonable to specify that the generator have the capability to meet or exceed the maximum turbine output under all conditions unless there is agreement that the generator can limit output under some conditions. With that requirement, the manufacturer can coordinate the generator output at "available" cold primary coolant temperatures to ensure that the generator has the capability to match turbine output at these "available" coolant temperatures whether that output may be below or above the rated capability at 40 °C primary cold coolant. It is therefore extremely important that a purchaser carefully examine the operating environment of the intended generation site and turbine output characteristics, and specify the generator output requirements on specific site needs rather than just rely on the single point MVA output at 40 °C cold primary coolant that is used as the basis for the generator rated point and temperature tables in this standard.

For combustion turbine applications, purchasers traditionally could expect a reduction of output from a combustion turbine with increasing ambient temperatures, and could rely on a connected generator, while having similar reductions with respect to base rating, still having a capability exceeding that of the combustion turbine. This tendency is usually still true but may not be to the extent it has been in the past. With the unregulated market and resulting high prices paid for power on high ambient-temperature days, purchasers are installing turbine inlet air cooling. If generators are not receiving such additional cooling, purchasers need to be aware that a generator that is temperature-limited on a hot day may be no longer well matched with its prime mover. Again, the advice of the previous paragraph should be followed in ensuring that the generator output capabilities are well coordinated with the turbine output capabilities based on the actual site conditions and source of secondary coolant.

Another consideration is that of the maintenance associated with subjecting generator internal components to a wider range of operating temperatures. Most modern generators are now capable of Class 155 (F) temperature operation. While there should be no temperature related problems with materials properties associated with operating such a generator with windings at the higher Class 155 (F) temperatures, higher rises may cause greater relative temperature excursions of some components. When an additional 5 °C to 10 °C is added to these rises, some degree of additional differential thermal expansion between internal winding components can be expected. This resulting differential expansion between components must be accommodated or controlled in the design to avoid magnitudes of thermal stresses that might lead to increased maintenance because of wear or winding component bond breakage.

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B.3.2 Discussion 2—insulation thermal class and specified temperatures

When specifying generator performance, some purchasers may specify a maximum winding operating temperature that is one temperature class lower than the insulation class of the winding. It should be understood that by doing this, the purchaser is gaining some degree of margin regarding the thermal stress of the insulation but is not necessarily gaining any more capability in generator rating. There are such things as differential thermal expansion limits and cooling limitations that are unrelated to the insulation class that usually limit generator output beyond its original rating. If it is desired to have some margin in output performance built into a generator, it is best to indicate that margin in the rating within the insulation class in the specification and to not expect additional thermal margin in the insulation system to accomplish this.

If there is an advantage to specifying a temperature rise to a class lower than that of the winding insulation, it would be to limit the total temperature excursion a winding is exposed to over its complete operating range. Such a limitation would limit differential expansion between the winding and its support system and thereby may lead to reduced maintenance. It is understood that such differential expansion between components can be allowed for with a proper generator design but past experience indicates that this has not always been accomplished.

B.3.3 Discussion 3—specifying a generator that can be used at multiple sites

Where a generator set is being specified for a specific site, it is usually somewhat straightforward, even if tedious, to determine the appropriate set of requirements pertaining to that site whether it be cooling water temperatures, ambient conditions, or grid requirements. Since the great majority of units covered by this standard are not portable, most units are specified for specific sites. However, there are situations where generating equipment must be ordered at the same time that multiple sites are being considered because of manufacturers' lead times and backlogs. There is also the situation where a purchaser might desire a standard set of equipment for multiple sites. This does complicate the situation, as many of the requirements are site specific. One approach to this is to take the information in Table B.1 that is site related and tabulate the parameters for each site being considered for the generator set being specified. The generator could then be specified using the most limiting parameters.

A similar approach must be considered as to impact of different sites on the turbine and its impact on generator requirements. In one nicely compatible case, a typical combustion turbine output is reduced with altitude just a little more than a typical OV air-cooled generator. Because other situations may be more complicated, the requirements in Table B.2 must also be tabulated.

If all specific sites have not actually been identified, then the purchaser would have to determine the maximum range of possibilities for each requirement.

The generator manufacturer can then determine the impact of the multiple requirements. Several examples of scenarios that might occur are as follows:

a) A single generator might cover all requirements with increased size or complexity.

b) A larger or more complex generator might cover all the most stringent requirements but may add otherwise unnecessary costs where applied at a site with less stringent requirements.

c) Possibly a single generator could be used and differences made up by a related piece of equipment such as a heat exchanger, evaporative cooler, different blower, etc.

The ultimate decision made as to keeping with one unit size or considering several different size units would depend on the alternatives available and the strategy or philosophy of the purchaser.

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Annex C

(normative)

TIF weighting factors

Table C.1 and Table C.2 provide the single-frequency telephone influence weighting factors (TIF_f).

Table C.1—1960 single-frequency TIF_f weighting factors for 60 Hz systems

Frequency	TIF_f	Frequency	TIF_f
60	0.5	1 860	7 820
180	30	1 980	8 330
300	225	2 100	8 830
360	400	2 160	9 080
420	650	2 220	9 330
540	1 320	2 340	9 840
660	2 260	2 460	10 340
720	2 760	2 580	10 600
780	3 360	2 820	10 210
900	4 350	2 940	9 820
1 000	5 000	3 000	9 670
1 020	5 100	3 180	8 740
1 080	5 400	3 300	8 090
1 140	5 630	3 540	6 730
1 260	6 050	3 660	6 130
1 380	6 370	3 900	4 400
1 440	6 650	4 020	3 700
1 500	6 680	4 260	2 750
1 620	6 970	4 380	2 190
1 740	7 320	5 000	840
1 800	7 570	—	—

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Table C.2—1960 single-frequency TIF_f weighting factors for 50 Hz systems

Frequency	TIF_f	Frequency	TIF_f	Frequency	TIF_f
16.66	0.005	1 350	6 290	2 700	10 405
50	0.25	1 400	6 463	2 750	10 324
100	4	1 450	6 655	2 800	10 243
150	15	1 500	6 680	2 850	10 113
200	63	1 550	6 801	2 900	9 950
250	144	1 600	6 922	2 950	9 795
300	225	1 650	7 058	3 000	9 670
350	371	1 700	7 203	3 100	9 153
400	567	1 750	7 362	3 200	8 632
450	818	1 800	7 570	3 300	8 090
500	1 097	1 850	7 778	3 400	7 523
550	1 398	1 900	7 990	3 500	6 957
600	1 790	1 950	8 203	3 600	6 430
650	2 182	2 000	8 413	3 700	5 842
700	2 593	2 050	8 622	3 800	5 121
750	3 060	2 100	8 830	3 900	4 400
800	3 525	2 150	9 038	4 000	3 817
850	3 938	2 200	9 247	4 100	3 383
900	4 350	2 250	9 458	4 200	2 988
950	4 675	2 300	9 670	4 300	2 563
1 000	5 000	2 350	9 882	4 400	2 146
1 050	5 250	2 400	10 090	4 500	1 929
1 100	5 477	2 450	10 298	4 600	1 711
1 150	5 665	2 500	10 427	4 700	1 493
1 200	5 840	2 550	10 535	4 800	1 275
1 250	6 015	2 600	10 568	4 900	1 058
1 300	6 157	2 650	10 486	5 000	840

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