C50.12™

IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 MVA and Above

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 C50.12™-2005
(Previously designated as
ANSI C50.12-1982)

Recognized as an
American National Standard (ANSI)

IEEE Std C50.12™-2005
(Previously designated as
ANSI C50.12-1982)

IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 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

The working group thanks the International Electrotechnical Commission (IEC) for permission to reproduce information from its International Standard IEC 60034-3. All such extracts are copyright of IEC, Geneva, Switzerland. All rights reserved. Further information on the IEC is available from www.iec.ch. IEC has no responsibility for the placement and context in which the extracts and contents are reproduced by the author, nor is IEC in any way responsible for the other content or accuracy therein.

Abstract: The requirements in this standard apply to all types of 50 Hz and 60 Hz salient-pole synchronous generators and generator/motors rated 5 MVA and above to be used for hydraulic turbine or hydraulic pump/turbine applications.

Keywords: ac generator, generator, hydro generator, salient-pole rotor, synchronous generator

---

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Print: ISBN 0-7381-4826-1 SH95385
PDF: ISBN 0-7381-4827-X SS95385

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.
The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied "**AS IS**."

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board

445 Hoes Lane

Piscataway, NJ 08854

USA

NOTE—Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

This introduction is not part of IEEE Std C50.12-2005, IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 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], [B11], [B15], [B16].[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 ANSI 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.

The SMSC WG No. 4 has periodically reported their progress [B3], [B4], [B5], [B12]. As has been communicated in these papers, where it has been possible for this group to agree to the appropriateness of requirements recorded in IEC 60034 standards [B6], [B7], those requirements have been incorporated into the revised ANSI C50.1X series of standards.

As the most workable approach to clarify and modernize the IEEE/ANSI 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/).

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.

Notice to users

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: http:// standards.ieee.org/reading/ieee/updates/errata/index.html. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: http://standards.ieee.org/reading/ieee/interp/index.html.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents or patent applications for which a license may be required to implement an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Participants

At the time this standard was completed, the Synchronous Machines C50.12 Working Group had the following membership:

James R. Michalec, *Chair*

Glenn Mottershead, *Vice-chair*

Christopher A. Kaminski, *Secretary*

William H. Bartley
Katherine E. Blanchard
Michael W. Brimsek
Robert E. Fenton
Brian E. B. Gott
Reinhard E. Joho
Geoffrey S. Klempner
William R. McCown
William M. McDermid
Arezki Merkouf
Lon W. Montgomery
Nils E. Nilsson
Paul I. Nippes
James A. Oliver
Thomas R. Wait
Lawrence A. Wall

The following people also contributed to the preparation of this standard:

Frank Barnard
Jon Gardell
Swarn Kalsi
Bruce Lonnecker
Michel Rioual

The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Bruce Barrow
William H. Bartley
Ray Bartnikas
Thomas H. Bishop
Steven R. Brockschink
Tommy P. Cooper
Guru Dutt Dhingra
Gary Donner
James H. Dymond
James S. Edmonds
Stanley L. Ehrlich
Franklin T. Emery
Gary R. Engmann
Robert E. Fenton
Jorge Fernandez-Daher
Nirmal K. Ghai
Brian E. B. Gott
James Grant
Glenn L. Griffin
John Travis Griffith
Randall C. Groves
Paul S. Hamer
Thomas J. Hammons
Gary A. Heuston
Ajit K. Hiranandani
David W. Jackson
Reinhard E. Joho
Christopher A. Kaminski
Haran C. Karmaker
Geoffrey S. Klempner
Thomas E. Laird
William R. McCown
William M. McDermid
Donald G. McLaren
Nigel P. McQuin
James R. Michalec
Gary L. Michel
G. Harold Miller
Charles Millet
Rihong Mo
Lon W. Montgomery
Glenn Mottershead
Krste I Najdenkoski
Beant S. Nindra
James A. Oliver
Paul J. Pillitteri
Madan Rana
Johannes G. Rickmann
Jesus Martinez Rodriguez
James A. Ruggieri
Lori Rux
Mahesh J. Shah
Manoj R. Shah
Greg C. Stone
James E. Timperley
Gerald L. Vaughn
Lawrence A. Wall
Theodore Wildi
John Yale
Karim Younsi
Hugh Zhu

When the IEEE-SA Standards Board approved this application guide on 22 September 2005, it had the following membership:

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Jennie Steinhagen
IEEE Standards Project Editor

Contents

IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 MVA and Above

1. Scope

The requirements in this standard apply to all types of 50 Hz and 60 Hz salient-pole synchronous generators and generator/motors rated 5 MVA and above to be used for hydraulic turbine or hydraulic pump/turbine applications.

Salient-pole generators and generator/motors below this rating are generally covered by NEMA MG 1-2003 [B13].[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 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.

[2] The IEEE standards or products referred to in this standard are trademarks of the Institute of Electrical and Electronics Engineers.

[3] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

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 286™, IEEE Recommended Practice for the Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation.

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 1043™, IEEE Recommended Practice for Voltage-Endurance Testing of Form-Wound Bars and Coils.

IEEE Std 1310™, IEEE Recommended Practice for Thermal Cycle Testing of Form-Wound Stator Bars and Coils for Large Generators.

IEEE Std 1434™, IEEE Guide to Measurement of Partial Discharges in Rotating Machinery.

IEEE Std 1553™, IEEE Standard for Voltage-Endurance Testing of Form-Wound Coils and Bars for Hydrogenerators.

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.[1]

ISO 7919-5, Mechanical Vibration of Non-Reciprocating Machines—Measurements on Rotating Shafts and Evaluation Criteria—Part 5: Machine Sets in Hydraulic Power Generation and Pumping Plants.

3. Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B8] should be referenced for terms not defined in this clause.

Cooling classification

Salient-pole synchronous machines are classified with regard to cooling by one of the following stator and rotor types.

3.1 directly cooled windings: Directly cooled stator windings or rotor windings are those in which coolant flows in close contact with the conductor so that the heat generated within the principal portion of the windings reaches the cooling medium without flowing through the major ground insulation.

---

[1] 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/).

3.2 indirectly cooled windings: Indirectly cooled stator windings or rotor windings are those in which the heat generated within the principal portion of the windings must flow through the major ground insulation before reaching the cooling medium.

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. For open ventilated air-cooled synchronous machines, the primary coolant is the air entering the machine. For closed circuit cooled synchronous machines, the primary coolant is the air or water entering the machine from the coolers.

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.

General

3.5 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

Salient-pole open ventilated (OV) air-cooled synchronous generators and generator/motors shall operate successfully when and where the temperature of the cooling air is between 10 °C and 40 °C, and the altitude does not exceed 1000 m.

Salient-pole totally enclosed water to air cooled (TEWAC) including direct-cooled synchronous generators and generator/motors shall operate successfully when and where the secondary coolant temperature at the inlet to the machine or heat exchanger is between 5 °C and 35 °C.

4.1.1 Generators

Generators shall operate successfully at rated MVA, frequency, power factor, and terminal voltage. Generators may operate at other service conditions specified in Clause 4 but not necessarily in accordance with the standards of performance established at rated conditions.

4.1.2 Generator/motors

Generator/motors shall operate successfully at rated MVA as a generator and at rated shaft megawatts as a motor, and at rated frequency, power factor, and terminal voltage. Generator/motors may operate at other service conditions specified in this clause but not necessarily in accordance with the standards of performance established for operation at rated conditions.

4.1.3 Altitude

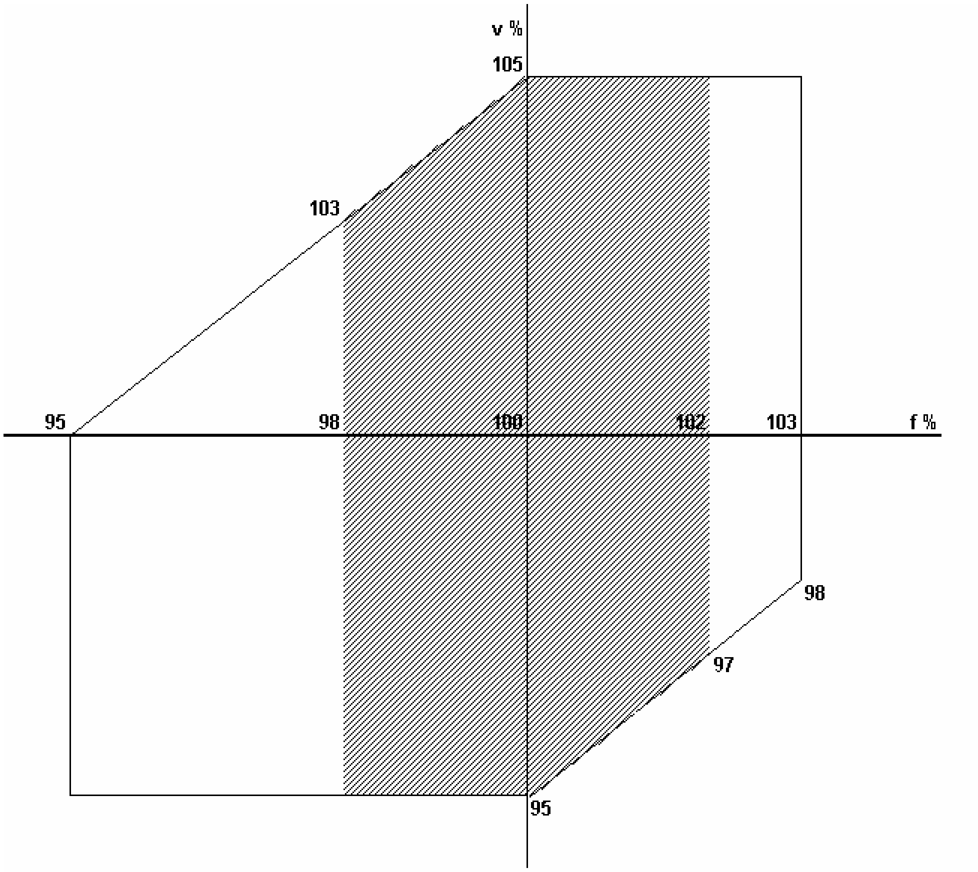
The altitude should be specified by the purchaser. The usual range of altitude is from 0 m to 1000 m.

4.1.4 Number of starts and application of load

The purchaser should specify the anticipated number of starts and maximum MVA, power, and reactive power loading rate of change requirements for the manufacturer to take into account in the machine design. The method of starting must be identified in the case of generator/motor applications.

4.1.5 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.



NOTE—Reprinted with permission from the International Electrotechnical Commission. Copyright © 2005 IEC, Geneva, Switzerland. www.iec.ch.[1]

Figure 1—Operation over ranges of voltage and frequency

---

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

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.

c) To minimize the reduction of the generator's lifetime due to 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 voltz per hertz.

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.

4.1.6 Rotor surface heating

4.1.6.1 Continuous phase current unbalance (I_2)

A generator or generator/motor 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, providing the rated MVA is not exceeded and the maximum current does not exceed 105% of rated current in any phase. In Table 1, negative-sequence current is expressed as a percentage of rated stator current.

Table 1—Continuous negative-sequence current capability

Type of generator or generator/motor	Permissible I_2 (%)
Nonconnected amortisseur winding	5
Connected amortisseur winding	10

These values also express the negative-sequence current capability at reduced generator MVA capabilities, as a percentage of the stator current corresponding to the reduced capability.

Continuous performance with nonconnected amortisseur windings is not readily predictable. Therefore, if unbalanced conditions are anticipated, machines with connected amortisseur windings should be specified.

4.1.6.2 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 rotor surface and amortisseur bar currents. 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.

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:

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

where

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

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

If “$I_{2\ \mathrm{eq}}$” 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-sequence current and harmonic currents ($I_{2\ \mathrm{eq}}$) should not exceed the values given in Table 1 unless other values are agreed upon by the manufacturer and purchaser.

4.1.7 Direction of rotation

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

4.1.8 Rotor assembly critical speeds

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 to have this analysis. Critical speeds of the generator rotor assembly shall not cause unsatisfactory operation within the speed range corresponding to the frequency range agreed in accordance with 4.1.5. 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. The turbine generator set shaft vibration at operating speed should be within limits specified by ISO 7919-5[2] for machine sets in hydraulic power generating and pumping plants.

4.1.9 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.

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.

4.1.10 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 or generator/motor 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 are expected to occur only infrequently during the service life of a generator. These conditions include transient 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 Sudden short circuit at the generator terminals, $I_2{}^2t$

A generator or generator/motor shall be capable of withstanding, without injury, a 30 s, three-phase short circuit at its terminals when operating at rated MVA and power factor and at 5% overvoltage, with fixed excitation.

With the voltage regulator in service, the allowable duration "*t*" of the short circuit shall be determined from Equation (2) in situations where the regulator is designed to provide ceiling voltage continuously during a short circuit:

$$t = \left(\frac{\text{Nominal collector ring voltage}}{\text{Exciter ceiling voltage}} \right)^2 30\,\text{s} \tag{2}$$

where nominal collector ring voltage is the voltage across the collector rings at rated load.

The machine shall also be capable of withstanding, without injury, any other short circuits at its terminals of 30 s duration or less, provided the machine's phase currents under fault conditions are such that the per unit negative phase sequence current I_2, expressed in terms of rated stator current, and the duration "*t*" of the fault in seconds are limited to values that give an integrated product $I_2{}^2t$ less than or equal to 40, and

---

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

also provided that the maximum phase current is limited by external means to a value that does not exceed the maximum phase current obtained from the three-phase fault.

CAUTION

Machines subjected to faults for which I_2^2t is between 40 and 80 may suffer varying degrees of damage; for values of I_2^2t in excess of 80, serious damage should be expected.

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 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.

b) For the rotor the term "minor repairs" implies that some attention to coupling bolts, couplings, and rotor balancing may be necessary to ensure that shaft dynamic motion and bearing vibration will be within acceptable limits after the repairs. The term "minor repairs" does not imply modification of the journals or bearings, adjustment of the shrink fits of components other than couplings, or replacement of the rotor or rotor components.

4.2.2 Synchronizing

Generators shall be designed to be fit for service without inspection or repair after synchronizing that is within the limits listed in Table 2.

Table 2—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™-1995 [B8].

CAUTION

Faulty synchronizing is that which is outside the limits in Table 2. Under some 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 damage to the generator.

Generators shall be designed so that they are capable of coasting down from synchronous speed to a stop after being immediately tripped off-line following a faulty synchronization. Any generator that has been subject to a faulty synchronization shall 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.

4.2.3 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. The successful mitigation of the oscillations may be accomplished by equipment selection, control, and protection techniques.

4.2.4 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 or generator/motor 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 4.1.6 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.

4.2.4.1 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 unacceptable levels, and operators may have a short period available in which they can react to the situation, if relaying fails to protect the machine.

4.2.4.2 Operation at or near standstill

Some generator/motors are designed to be started from standstill to synchronous speed using the power system (line start); however, most synchronous machines are not designed for this. 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.

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.

4.2.5 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 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 4.1.5 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.

4.2.6 Overspeed

Hydraulic turbine-driven generators or generator/motors shall be capable of withstanding, without mechanical injury, the specified maximum speed of the combined unit for 5 min, unless otherwise agreed upon between the purchaser and the manufacturer.

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—The generator will be exposed to ambient air, either indoors or outdoors. Contaminated content including but not limited to the following should be discussed with the manufacturer:
    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) Lint
    6) Flammable gases
    7) Oil vapor

b) Cooling water contamination
    1) Mineral content
    2) Chemical content
    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

4.3.2 Enclosure types and environmental control

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 so 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 appropriate mitigating measures are included in procurement requirements.

5. Rating and performance characteristics

5.1 Output rating

The output rating of a machine shall consist of the megavolt amperes (MVA) and/or shaft megawatts (MW) together with any other characteristics, such as speed, voltage, frequency, current, power factor, and primary coolant temperature assigned to it by the manufacturer. The continuous output rating defines the load that can be carried indefinitely, and, in the absence of any specification as to the kind of rating, the continuous output rating shall be implied.

5.1.1 Generator

The output rating of synchronous generators shall be expressed on a continuous duty basis. The rating shall be expressed in MVA available at the terminals at a specified speed, frequency, voltage, and power factor. The generator's characteristics shall be defined with respect to this rating.

5.1.2 Generator/motors

In addition to meeting the requirements given in 5.1.1, generator/motors shall have a continuous output rating expressed in kilowatts available at the shaft at a specified speed, frequency, voltage, power factor, and primary coolant temperature.

5.1.3 Power for auxiliaries

If power for excitation and ventilation auxiliaries of the specific unit is taken from the machine terminals, generator output power or motor input power shall be determined on the line side of these auxiliaries.

5.1.4 Primary coolant temperature

The primary coolant temperature should be established at 40 °C. Capabilities for other primary coolant temperatures may be provided for on the nameplate.

5.2 Capability

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.

5.3 Stator voltage rating

The rated voltage is the voltage at the terminal of the machine at rated output. Stator voltage ratings for all synchronous machines shall be fixed by agreement; (see 4.1.5). Voltages above 13 800 V may be desirable in machines of large capacity. Such large machines are usually connected directly to their own step-up transformers, and voltage is selected on the basis of economic and technical considerations.

5.4 Power factor and reactive power capability

Power factor at output rating and across the range of capability shall be fixed by agreement. Specifying a lower power factor results in an increased capability to supply reactive power to the system but requires a generator with a larger MVA rating. The power factor at output rating is typically set at 0.90, 0.85, or 0.80 overexcited.

Figure 2 illustrates a typical reactive power capability diagram. Operation when the generator supplies reactive power to the power system is overexcited; operation where the generator absorbs reactive power from the power system is underexcited.

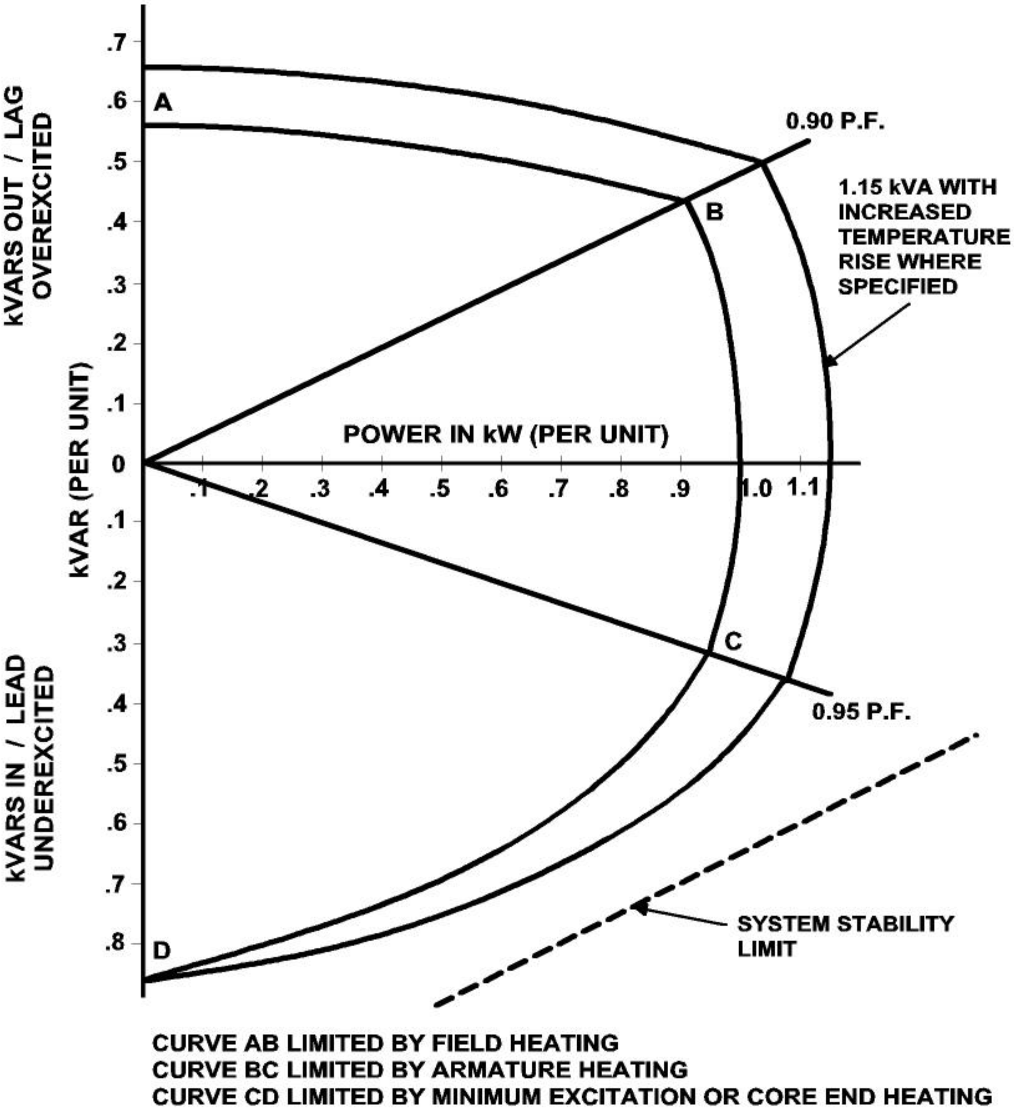


Figure 2—Typical reactive power capability curve

5.5 Rotor voltage ratings

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.)

5.6 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.

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 based upon the steady-state stability limits. With modern automatic voltage regulators this limit can be significantly extended, particularly if sophisticated features such as a "power system stabilizer" 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.

If not specified by the purchaser, the minimum SCR will be 0.8.

5.7 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* [B8].

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

When values of transient or subtransient reactances have been specified or agreed upon, these limits shall be subject to the tolerances recommended in Table 3.

Table 3—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%.

5.8 Voltage wave shape

5.8.1 Maximum allowable deviation factor

The maximum allowable deviation factor (refer to *The Authoritative Dictionary of IEEE Standards Terms* [B8] for the definition of deviation factor) of the open-circuit terminal voltage wave of synchronous machines shall not exceed 0.1.

5.8.2 Telephone influence factor

5.8.2.1 Balanced telephone influence factor

The balanced telephone influence factor (TIF) of synchronous generators [B1], based on the single-frequency weighting factors given in Annex B, shall not exceed the values given in Table 4.

Table 4—Balanced TIF limits

MVA rating of machine	Balanced TIF
5 ≤ MVA < 20	100
20 ≤ MVA < 100	70
100 ≤ MVA	40

5.8.2.2 Residual component

The residual component of TIF, based on the weighting factors given in Annex B shall not exceed the values given in Table 5.

Table 5—Residual TIF limits

MVA rating of machine	Residual TIF
5 ≤ MVA < 20	75
20 ≤ MVA < 100	50
100 ≤ MVA	30

5.8.2.3 Weighting factors

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

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

5.9 Torques

The locked-rotor, pull-in, and pull-out torques should be specified by the purchaser to suit the pump/turbine requirements.

6. Insulation systems

6.1 Insulation systems defined

An insulation system is an assembly of insulating materials. For definition purposes, the 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 tying cord, slot fillers, slot groundwall insulation, and pole body 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, and also 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 collars, the slot wedges, the filler strips under the support ring insulation, the nonmetallic support for the winding, the space blocks used to separate the coil ends and connections, the lead cleats, bushings, and the terminal boards.

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 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 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 6 and Table 7 of this standard. Insulation systems of synchronous machines shall be classified as Class 130 (B) or Class 155 (F).

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 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 usual service conditions, described in 4.1.

7. Temperatures and temperature limits

7.1 Temperature limits

When designing generators or generator/motors to meet the temperature rises shown in Table 6 and Table 7, it is intended that the hottest-spot total temperature should not exceed 130 °C for Class 130 (B) and 155 °C for Class 155 (F) insulation systems. (The Class 130 (B) insulation system applies to both indirectly and directly cooled machines, while the Class 155 (F) insulation system applies only to indirectly cooled machines.)

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. Large machines have a significant thermal gradient between the hottest spot, which is usually not measurable, and the observed temperature as measured by detector. However, the machines covered by this standard are maximum-rated at the temperature rise specified and should be operated within the limits of the applicable capability curves. It should not be assumed that overloading capability is available if maximum permissible temperatures are not reached at rated MVA or shaft megawatts.

For machines that are subjected to frequent cyclic loading or are started more frequently than twice per day, consideration should be given to reducing the temperature rises shown in Table 6 and Table 7 by 5 °C to 10 °C, since these conditions represent a more severe duty than normal.

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

7.1.1 Temperature limits—indirectly cooled machines

The observable temperature rise of each part of the machine above the temperature of the cooling air, referred to as the cold air temperature, shall not exceed the values given in Table 6 when the machine is operated at output rating conditions as described in 5.1. The temperature rises in Table 6 are based on a maximum cold air temperature of 40 °C.

Observable temperature limits for indirectly cooled stator windings in Table 6 are for line voltages at or below 12 kV. Based on the following chart, these limits are to be reduced for line voltages above 12 kV.

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

For open machines and for parts of enclosed machines, such as collector rings that are cooled by open ventilation passages, the cold air temperature is the average temperature of the external air as it enters the ventilating openings of the machine.

Table 6—Limiting observable temperature rises of indirectly cooled salient-pole synchronous generators and generator/motors for hydraulic turbine applications

Item	Machine part	Method of temperature determination	Temperature rise (°C) at 40 °C cold coolant	
			Class 130 (B)	Class 155 (F)
1	Stator windings			
	V_n = 12 kV or less	Embedded detector[a]	85[b]	105[b]
	12 kV < V_n^c < 24 kV	Embedded detector[a]	85[c]	105[c]
	V_n^c > 24 kV	Embedded detector[a]	by agreement	by agreement
2	Rotor windings	Resistance	80	100
3	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	
4	Collector rings	Thermometer	85	85
5	Miscellaneous parts (such as brush holders, 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 130 (B) and Class 155 (F) 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) > 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

TEWAC machines are normally designed for the maximum temperature of the cooling water encountered at the location where each machine is to be installed. The temperature of the cooling air is considered to be the average temperature of the air leaving the coolers. For any specified temperature of cooling water up to 30 °C, the average temperature of the air leaving the coolers shall not exceed 40 °C. For water temperatures above 30 °C, the average temperature of the air leaving the coolers may exceed 40 °C, provided the temperature rises of the machine parts are limited to values less than those given in Table 6 by the same number of degrees by which the average temperature of the air leaving the cooler exceeds 40 °C.

Machines that operate under prevailing barometric pressure are designed not to exceed the specified temperature rise of Table 6 when operated at altitudes from 1000 m to 4000 m. The temperature rise of a machine installed at elevations between 1000 m and 4000 m, when measured at altitudes under 1000 m, shall be less than the values listed in Table 6 by 1% of the specified temperature rise for each 100 m of installed altitude in excess of 1000 m. For example, a machine to be installed at 1900 m, when tested in a factory below 1000 m, will have a factory test temperature rise limit that is 9% below the values in Table 6 in order for the temperature rise at 1900 m not to exceed the values in Table 6. For machines installed above 4000 m, the manufacturer must be consulted.

7.1.2 Temperature limits—directly cooled machines

The observable temperature rise for each of the parts of the machine above the temperature of the cold coolant shall not exceed the values given in Table 7 when the machine is operated at output rating conditions as described in 5.1. The temperature of the cold coolant shall be the average temperature of the coolant leaving the coolers. The cold coolant temperature shall not exceed the appropriate value as listed in Table 7.

Table 7—Limiting observable temperatures and temperature rises of directly water-cooled salient-pole synchronous generators and generator/motors for hydraulic turbine applications[a]

Item	Coolant and machine parts	Method of temperature determination	Temperature rise (°C) at 40 °C cold coolant
			Water-cooled windings Class B insulation temperature or temperature rise (°C)
1	Directly cooled stator windings	Coolant [c]	50[b] (temperature rise)
2	Directly cooled rotor windings	Resistance	50[b] (temperature rise)
3	Cores and mechanical parts whether or not in contact with insulation	Detector or thermometer	Not detrimental to insulation of that part or any adjacent part [d]
4	Collector rings	Thermometer	85 (temperature rise)
5	Miscellaneous parts (such as amortisseur windings, rotor surface, brushholders, brushes, etc.) shall be permitted to attain such temperatures that will not injure the machine in any respect.		

[a] The method of measuring the coolant temperature shall be optional with the manufacturer unless otherwise agreed upon. Only one method of temperature measurement shall be required in any particular case.

[b] Cold coolant temperatures may be provided within the range of 40 °C to 50 °C at the manufacturers' option, with compensating adjustments made in the temperature rise of the respective parts so that the sum of the cold coolant temperature and the temperature rise of the part does not exceed 90 °C for water-cooled machines.

[c] The temperature rise of the coolant at the outlet of the hottest coil shall be considered the observable temperature rise of the directly cooled stator winding.

[d] The temperature of the core and mechanical parts in contact with or adjacent to insulating material, including that of the winding and of the core laminations, shall not exceed the values in Table 7. The temperature of other metal parts, including structural members and shielding devices in the end region, is not required to be within the limits shown, provided that these parts do not appreciably influence the temperature of the insulating material either by contact or by radiation. These parts shall be permitted to attain such temperatures that are considered safe for the particular metals used.

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 mercury or alcohol thermometers, resistance thermometers, or thermocouples, with any of these instruments being applied to the hottest part of the machine accessible to suitably accurate thermometers.

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.

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 cooled stator windings, measurement of the temperature of the coolant shall be made in the coolant exit streams of at least 600 kPa and the temperature sensing elements shall be located so as to be thermally as near as possible to the hottest spot of the bar conductor.

8. Efficiency

8.1 Methods

Methods for determining efficiency and losses shall be as described in IEEE Std 115. The efficiencies of contained 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 balanced load conditions.

In determining I^2R losses, the resistance of windings shall be corrected to the reference temperature in Table 8. This reference temperature shall be used for determining I^2R losses at all loads.

Table 8—Reference temperatures for use in determining I^2R losses

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

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 with the generator unexcited at rated cold gas temperature.

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

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 its resistance in ohms as measured with direct current and corrected in accordance with reference temperatures in Table 8 and the square of its current in amperes.

8.3.2 Rotor winding I^2R loss

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

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 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 of the synchronous machine. Where common equipment is provided in the excitation system for two or more machines, the common equipment loss shall not be included in the evaluation of the synchronous machine efficiency. Motor loss shall be included if a unit motor-generator exciter set is used; if a unit rectifier is used, the rectifier and rectifier transformer losses shall be included. 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 that portion of the loss that results from the following:

a) Forcing the air through any part of the ventilating system that is external to the machine and cooler (if used).

b) The driving of direct-connected flywheels or other direct connected apparatus. However, when requested by the purchaser, these additional losses will be furnished as a separate item.

c) In the case of machines furnished with a complete set of bearings, only that portion of the friction and windage loss produced by the bearing load due to the generator or generator/motor itself shall be included. In the case of machines not furnished with a complete set of bearings, only that portion of the friction and windage loss associated with the equipment supplied with the generator or generator/motor shall be included. Where losses are apportioned between equipment or between manufacturers, the method of allocation of the losses shall be subject to agreement between the manufacturer and purchaser.

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. The power consumption of a separate blower system used for a specific unit and necessary for continuous operation of the unit shall be included.

8.4 Test tolerance on losses

The tolerance on the generator- or generator/motor-declared losses shall be +10% in comparison to acceptance test values. The generator or generator/motor losses determined by acceptance test shall not exceed the declared losses by more than 10%.

9. Tests

9.1 Categories and scope of tests

There are the following three primary categories of generator and generator/motor tests:

a) Required manufacturing tests
b) Recommended site tests
c) Special performance tests

These tests are specified in Table 9 and Table 10, 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 or generator/motor has been acceptably manufactured. These tests, which do not involve running the assembled machine, are listed in Table 9. Manufacturers may supplement these required tests with their own set of recommended tests, and other tests 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 9. Suppliers may supplement these tests with other tests, and tests may be added or eliminated from Table 9 by agreement. The responsibility to perform these site tests shall be defined by agreement.

Table 9—Required manufacturing proof tests and recommended site tests on salient-pole synchronous generators and generator/motors

Description	Required manufacturing proof tests[a]	Recommended site tests[a]
Resistance of stator and rotor windings	X[b]	X
Dielectric tests of stator and rotor windings[c]	X[b]	X
Voltage balance	—	X
Phase sequence	—	X
Mechanical balance[d]	—	X
Measurement of insulation resistance of stator and rotor windings[e]	X[b]	X
Measurement of bearing insulation resistance[e]	—	X
Open and short-circuit saturation curves	—	X

[a] An X indicates that test shall be made on each unit.

[b] For units not completely wound in the factory, tests are required only on the portion of the winding assembled in the factory.

[c] Field high-potential tests on complete windings previously subjected to a factory high-potential test shall be performed in accordance with 9.2.2.10.

[d] A field check of the mechanical balance of all machines is recommended after installation.

[e] If a machine is disassembled for shipment, it is recommended that these tests be repeated after reassembly in the field.

9.1.3 Special performance tests

Special performance tests provide performance parameters of a generator and supplement the testing of Table 9. These running tests, which are conducted with the generator fully assembled, are listed in Table 10. 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. Suppliers may also supplement these special performance tests with other running tests, and tests may be added to or eliminated from Table 10 by agreement. Typically these tests are performed at the site.

Table 10—Special performance tests on salient-pole synchronous generators and generator/motors

Current balance
No load/open-circuit saturation curve
Synchronous impedance curve [a] (short-circuit saturation curve)
Overspeed
Impedance of rotor coils
Harmonic analysis and measurement of TIF
Heat runs
Short-circuit tests at reduced voltage to determine reactance and time constants [b]
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.

[b] If the winding of the machine is replaced, it may not be necessary to repeat all of the original tests since installed winding of an equivalent arrangement will not change the machines reactances and time constants.

9.2 Test procedural requirements

9.2.1 Noise tests

When agreed upon by the manufacturer and the purchaser, sound measurements will be made in accordance with ISO 3746.

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 testing, as given in IEEE Std 433, of 1.63 times the ac rms test voltage may also be used by agreement. (For further information regarding insulation testing of large ac rotating machinery with high direct voltage, see IEEE Std 95.) Completely rewound windings shall be tested at the full test voltage for new machines.

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.

9.2.2.1.3 Generator/motors rotor windings that utilize induction start

Rotor windings of synchronous machines, including motors that are to be started with alternating current, shall be tested as follows:

a) A machine to be started with its rotor short circuited or with its field closed through an exciter stator shall be tested at ten times the rated excitation voltage, but in no case at less than 2500 V nor more than 5000 V.

b) A machine to be started with an external resistor in series with its rotor winding shall be tested at a voltage equal to twice the rms value of the *IR* drop across the resistor, but in no case with less than 2500 V. The *IR* drop shall be taken as the product of the resistance and the current that would circulate in the rotor winding at standstill, if it short circuited on itself at the specified starting voltage.

c) A machine to be started with its rotor winding open circuited and sectionalized shall be tested at 1.5 times the maximum rms voltage that can occur between the terminals of any section under the specified starting conditions, but in no case with less than 2500 V, or ten times the rated excitation voltage per section, whichever is larger.

d) A machine to be started with its rotor winding open circuited and connected in series shall be tested at 1.5 times the maximum rms voltage that can occur between the rotor winding terminals under the specified starting conditions, but in no case with less than 2500 V, or ten times the rated excitation voltage, whichever is the larger.

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 the test 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 5.8.1.

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

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 Assembled group of machines and apparatus

When the test is performed on an assembled group of several pieces of new apparatus, each one of which has previously passed its dielectric test, the test on such assembled group shall not exceed 85% of the lowest test voltage appropriate for any part of the group.

9.2.2.10 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.

9.2.2.11 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. The test details are described in IEEE Std 522.

9.2.2.12 Other insulation tests

9.2.2.12.1 Voltage endurance test on stator coils and bars

When agreed upon by the manufacturer and the purchaser, voltage endurance tests may be made on individual stator coils and bars in accordance with the method described in IEEE Std 1043 and using the voltage, temperature, and pass/fail criteria specified in IEEE Std 1553.

9.2.2.12.2 Thermal cycling test on stator coils and bars

When agreed upon by the manufacturer and the purchaser, thermal cycling tests may be made on individual stator coils and bars in accordance with the method described in IEEE Std 1310. Some purchasers specify that the voltage endurance tests be made after the stator coil or bar has been subjected to thermal cycling tests.

9.2.2.12.3 Diagnostic tests

Various diagnostic techniques are available for testing and developing trend data for electrical insulation systems. These test techniques include but are not limited to insulation resistance and polarization index tests as described in IEEE Std 43, power factor and power factor tip-up tests as described in IEEE Std 286, direct high-voltage tests as described in IEEE Std 95 and various partial discharge (corona) test methods as described in IEEE Std 1434. Partial discharge tests can be performed on individual coils and bars or on complete stator windings. Acceptable limits for the measured values tend to vary from one insulation system to another. The magnitude of the measured partial discharge can be expected to vary a great deal depending on the particular measuring circuit, its bandwidth, and test conditions.

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) may 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.

10. Marking

10.1 Nameplate

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

The following information at output rating shall be supplied:

a) Output MVA
b) Voltage
c) Number of phases
d) Output kilowatts
e) Power factor
f) Revolutions per minute
g) Stator current
h) Frequency
i) Temperature of primary cold coolant
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)
p) Rotor voltage
q) Rotor current
r) Required cooling water flow

If the winding of the machine is changed or other major changes are made, an additional plate shall be provided to indicate the contractor’s name, year of change, and changes made.

10.2 Other marking

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

10.3 Terminal markings

10.3.1 Purpose

Markings shall be placed on or adjacent to the terminals of synchronous machines to identify the phases. The purpose of the markings is to aid in making connections to other parts of the electric power system and to avoid improper connections that may result in unsatisfactory operation or damage. They are not intended to be used for internal machine connections.

10.3.2 Terminal letters and subscript numerals

The terminal markings shall consist of a capital letter followed by a subscript numeral. The letter identifies the function of the winding, T for stator and F for rotor. The subscript numerals 1, 2, or 3 indicate, for a three-phase machine, the order in which the voltages at the terminals reach their positive maximum value (phase sequence) with clockwise shaft rotation when facing the connection end of the winding, unless otherwise specified. The subscript numeral 0 indicates a neutral connection. For a three-phase synchronous machine with one stator winding per phase with each end of each winding brought out externally, the subscript numerals 4, 5, or 6 denote, in sequence, the opposite ends of the windings (relative to 1, 2, or 3). For synchronous machines with additional terminals (such as machines with two or more windings per phase, or dual voltage windings), machines to be delta-connected, and machines with a different number of phases, terminal markings shall be as specified in NEMA MG 1-2003, Terminal Markings, Part 2 [B13].

10.3.3 Installation precautions

Because of possible serious damage to equipment, it is desirable to test for phase rotation, phase relation, polarity, and equality of voltage before connecting synchronous machines to power systems.

Annex A

(informative)

Bibliography

[B1] Ball, W. C. and Poarch, C. K., "Telephone influence factors (TIF) and its measurement," *AIEE Transactions*, vol. 79, pt. I, pp. 659–664, Jan 1961.

[B2] Bartheld, R., "Organizational structure of IEC TC2," *Conference Proceedings of the IEEE Winter Power Meeting*, New York, NY, 1999.

[B3] Gott, B. E. B., McCown, W. R., Montgomery, L. W., and Michalec, J. R., "Implications of differences between the ANSI C50 series and the IEC 60034 series standards for large cylindrical rotor synchronous machines," Panel Discussion at the IEEE-PES Summer Meeting, Berlin, Germany, July 1997.

[B4] Gott, B. E. B., McCown, W. R., Montgomery, L. W., and Michalec, J. R., "Progress in revision of IEEE/ANSI C50 series of standards for large steam and combustion turbine generators and harmonization with the IEC 34 series," *International Conference on Electric Machines and Drives*, Boston, MA, June 2001.

[B5] Gott, B. E. B., McCown, W. R., Montgomery, L. W., and Michalec, J. R., "Update of revision of ANSI C50 series of standards for large synchronous machinery and harmonization with IEC 34 series," *Conference Proceedings of the IEEE Winter Power Meeting*, New York, NY, 1999.

[B6] IEC 60034-1-1996, Rotating Electrical Machines—Part 1: Ratings and Performance.[3]

[B7] IEC 60034-3-1988, Rotating Electrical Machines—Part 3: Specific Requirements for Turbine-Type Synchronous Machines.

[B8] IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

[B9] IEEE Std C37.102™-1995, IEEE Guide for AC Generator Protection.

[B10] IEEE Std 492™-1999, IEEE Guide for the Operation and Maintenance of Hydrogenerators.

[B11] Kaminski, C. A., "Panel discussion of issues related to harmonization of standards for electrical machines," Panel Discussion at the IEEE-PES Winter Meeting, New York, NY, 1999.

[B12] McCown, W. R., Montgomery, L. W., Kaminski, C. A., Gott, B. E. B., and Michalec, J. R., "Working group report on revised IEEE C50.12 and C50.13 standards for large generators," *International Conference on Electric Machines and Drives*, Madison, WI, June 2003.

[B13] NEMA MG 1-2003, Motors and Generators.[4]

[B14] Nippes, P. I. and Nilsson, N. E., "International harmonization of standards detailed report," *IEEE Transactions on Energy Conversion*, vol. 14, no. 4, pp. 1318–1322, Dec. 1999.

[B15] Woods, E. J., "Standards harmonization: What next?" *Conference Proceedings of the IEEE Winter Power Meeting*, New York, NY, 1999.

---

[3] 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.

[4] NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

Annex B

(normative)

TIF weighting factors

Table B.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	—	—

Table B.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