



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

IEEE Power Engineering Society

Sponsored by the
Electric Machinery Committee

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

Keywords: ac generator, combustion gas turbine generator, cylindrical-rotor generator, steam turbine generator, synchronous generator, turbine generator

The Institute of Electrical and Electronics Engineers, Inc.
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Introduction

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

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

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

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

- a) ANSI C50.10-1990, Rotating Electrical Machinery—Synchronous Machines.^b
- b) ANSI C50.12-1982 (Reaff 1989), Requirements for Salient-Pole Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications.
- c) ANSI C50.13-1989, Requirements for Cylindrical-Rotor Synchronous Generators.
- d) ANSI C50.14-1977, Requirements for Combustion Gas Turbine Driven Cylindrical Rotor Synchronous Generators.
- e) ANSI C50.15-1989, Hydrogen-Cooled, Combustion-Gas-Turbine-Driven, Cylindrical-Rotor Synchronous Generators—Requirements.

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

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

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

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

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

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

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Participants

At the time this standard was completed, the Synchronous Generators C50.13 Working Group had the following membership:

James Michalec, *Chair*

Lon W. Montgomery, *Vice-chair*

Christopher A. Kaminski, *Secretary*

William H. Bartley
Michael W. Brimsek
Robert E. Fenton
Brian E. B. Gott
Reinhard E. Joho

Geoffrey S. Klempner
William R. McCown
William M. McDermid
Arezki Merkouf
Glenn A. Mottershead

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:

Stan Burns
Samuel Drinkut
Jon Gardell

Joseph Hurley
Swarn Kalsi
Bruce Lonnecker
Robert Putnam

Michel Rioual
Klaus Sedlazeck
John Yagielski

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

Adewole C. Akpose
Bruce Barrow
William H. Bartley
Ray Bartnikas
Thomas H. Bishop
Thomas Blair
E. A. Boulter
Michael W. Brimsek
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
Trilok C. Garg
Nirmal K. Ghai
Brian E. B. Gott

James Grant
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
Peter H. Landrieu
Roger Lawrence
William R. McCown
William M. McDermid
Nigel P. McQuin
James R. Michalec
Gary L. Michel
G. Harold Miller
Rihong Mo

Lon W. Montgomery
Glenn A. Mottershead
Krstel I. Najdenkoski
Beant S. Nindra
James A. Oliver
Paul J. Pillitteri
Madan Rana
Johannes G. Rickmann
Jesus Martinez Rodriguez
James A. Ruggieri
Mahesh J. Shah
Manoj R. Shah
Chris D. Shultz
Greg C. Stone
James E. Timperley
Gerald L. Vaughn
Lawrence A. Wall
Theodore Wildi
John Yale
Karim Younsi
Hugh Zhu

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Joseph L. Koepfinger*
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Paul Nikolich

T. W. Olsen
Glenn Parsons
Ronald C. Petersen
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Frank Stone
Malcolm V. Thaden
Richard L. Townsend
Joe D. Watson
Howard L. Wolfman

*Member Emeritus

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Jennie Steinhagen
IEEE Standards Project Editor

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

1. Scope

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

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

2. Normative references

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

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

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

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

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

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

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

¹The numbers in brackets correspond to those of the Bibliography in Annex A.

²IEEE 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/>).

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IEEE Std 275™, IEEE Recommended Practice for Thermal Evaluation of Insulation Systems for Alternating-Current Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900 V and below.

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

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

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

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

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

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

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

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

3. Definitions

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

Cooling classification

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

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

Coolant types

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

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

⁴ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembe, 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/>).

Generator capability

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

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

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

Operational duty

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

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

Turbine type

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

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

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

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

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

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

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

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

General

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

4. Operational requirements

4.1 Service conditions and steady-state duty

4.1.1 Matching the generator to the turbine power output

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

4.1.1.1 Simple cycle steam turbines

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

4.1.1.2 Simple cycle combustion turbines

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

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

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

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

4.1.1.3 Combined cycle combustion and steam turbines

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

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

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

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

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

4.1.2 Coolant temperatures

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

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

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

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

4.1.3 Ambient air temperature

The generator shall be designed to operate with surrounding ambient temperatures in the range from $-20\text{ }^{\circ}\text{C}$ to $+50\text{ }^{\circ}\text{C}$. Note that capability may vary with ambient temperature (see Clause 5 and Clause 7).

4.1.4 Altitude

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

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

4.1.5 Starting

4.1.5.1 Number of starts

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

- 3 000 starts for base load units
- 10 000 starts for peaking units or other frequently cycled units

4.1.5.2 Use of generator as a starting motor

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

4.1.6 Application of load

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

4.1.7 Variation from rated voltage and frequency

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