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American National Standard

requirements for salient-pole synchronous generators and generator/motors for hydraulic turbine applications

ANSI C50.12-1982

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American National Standard Requirements for Salient-Pole Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications

Secretariat

Institute of Electrical and Electronics Engineers, Inc
National Electrical Manufacturers Association

Approved September 2, 1981

American National Standards Institute, Inc

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Foreword

(This Foreword is not a part of American National Standard Requirements for Salient-Pole Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications, ANSI C50.12-1982.)

Developed over a period of more than four years within a working group that reflected wide industrial experience in both the manufacture and use of salient-pole synchronous generators, ANSI C50.12-1982 received the unanimous approval of the C50.1 Subcommittee on Synchronous Machines as well as the full endorsement of American National Standards Committee C50 on Rotating Electrical Machinery.

Suggestions for the improvement of this standard will be welcome. They should be sent to the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.

This standard was processed and approved for submittal to ANSI by American National Standards Committee on Rotating Electrical Machinery, C50. Committee approval of this standard does not necessarily imply that all committee members voted for its approval. At the time it approved this standard, the C50 Committee had the following members:

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American National Standard Requirements for Salient-Pole Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications

1. Scope

The requirements in this standard apply to all types of 60-hertz salient-pole synchronous generators and generator/motors rated 5000 kVA (kilovolt amperes) and above to be used for hydraulic turbine or hydraulic pump/turbine applications.

Definitions, characteristics, and test methods not specifically covered in this standard shall comply with the following documents insofar as they are applicable:

American National Standard General Requirements for Synchronous Machines, ANSI C50.10-1977

Test Procedures for Synchronous Machines, IEEE 115-1982 (available from the Institute of Electrical and Electronics Engineers, 345 East 47 Street, New York, N.Y. 10017)

2. Classification

Salient-pole synchronous machines are classified with regard to cooling[1] by one of the stator and one of the rotor types.

2.1 Stator Types. The type of stator is defined by the method of armature winding cooling, either direct or indirect.

2.2 Rotor Types. The type of rotor is defined by the method of field winding cooling, either direct or indirect.

3. Usual Service Conditions

Salient-pole synchronous generators and generator/motors shall operate successfully under the usual service conditions given in ANSI C50.10-1977. In addition, synchronous machines shall meet the following requirements:

3.1 Generators. Generators shall operate successfully at rated kVA, frequency, and power factor at any voltage not more than 5 percent above or below rated voltage, but not necessarily in accordance with the standards of performance established for operation at rated voltage.

3.2 Generator/Motors. Generator/motors shall operate successfully at rated kVA as a generator and at rated horsepower as a motor, and at rated frequency and power factor, at any voltage not more than 5 percent above or below rated voltage, but not necessarily in accordance with the standards of performance established for operation at rated voltage.

4. Rating

4.1 Output Rating

4.1.1 The output rating of synchronous generators shall be expressed on a continuous duty basis. The rating shall be expressed in kVA 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.

4.1.2 In addition to meeting the requirements given in 4.1.1, generator/motors shall have a continuous output rating expressed in horsepower available at the shaft at a specified speed, frequency, voltage, and power factor.

4.1.3 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.

[1] Refer to ANSI C50.10-1977 for definitions of cooling.

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Table 1
Limiting Observable Temperature Rises of Indirectly Cooled Salient-Pole Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications

Item	Machine Parts	Method of Temperature Determination	Temperature Rise (°C) Class B	Class F
1	Armature winding[1]			
	7000 volts and less	embedded detector[2]	80	100
	over 7000 volts through 15 000 volts	embedded detector[2]	75	90
	over 15 000 volts	embedded detector[2]	70	85
2	Field winding	resistance	80	100
3	Collector rings	thermometer	85	85
4	Cores and mechanical parts in contact with or adjacent to insulation	thermometer or detector	not to exceed the value for the associated adjacent insulation[3]	
5	Miscellaneous parts (such as amortisseur windings, rotor surface, brushholders, brushes, etc) shall be permitted to attain such temperatures as will not injure the machine in any respect.			

[1] The temperature rise limits listed are for insulation systems with thermosetting materials. For thermoplastic materials the temperature rise limit shall be 70°C.
[2] Embedded detectors are located within the slot of the machine and can be either resistance elements or thermocouples.
[3] When core temperatures are measured at the outside diameter of the core, the limiting temperature rise shall be 5°C less than the limiting temperature rise for the associated armature winding insulation.

4.2 Armature Voltage Rating. Preferred armature voltage ratings are:

2 400 volts	6 900 volts
4 160 volts	13 800 volts
4 800 volts	

NOTE: Voltages above 13 800 volts 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.

Intermediate ratings between 6900 and 13 800 volts may be desirable to interface with other equipment.

4.3 Power Factor Rating. Preferred power factor ratings are 0.80, 0.85, 0.90, and 0.95 (all overexcited); and 1.00.

4.4 Excitation Voltage Rating. Preferred excitation voltages for field windings are 62.5, 125, 250, 375, and 500 direct voltage. These preferred excitation voltages do not apply to generators of the brushless type with direct-connected exciters.

5. Temperatures and Temperature Rises

5.1 General. When designing generators or generator/motors to meet the temperature rises shown in Tables 1 and 2, it is intended that the hottest-spot total temperature should not exceed 130°C for Class B and 155°C for Class F insulation systems. (The Class B insulation system applies to both indirectly and directly cooled machines, while the Class F insulation system applies only to indirectly cooled machines.)

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 kVA or horsepower.

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 Tables 1 and 2 by 5°C to 10°C, since these conditions represent a more severe duty than normal.

Unless otherwise specified, all machines shall be supplied with embedded temperature detectors, in accordance with the requirements of ANSI C50.10-1977.

5.2 Indirectly Cooled Machines. The observable temperature rise of each of the parts of the machine above the temperature of the cooling air, referred to as the cold air temperature, shall not exceed the values given

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Table 2
Limiting Observable Temperatures and Temperature Rises of Directly Water-Cooled Salient-Pole Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications

Item	Coolant and Machine Parts	Method of Temperature Determination	Water-Cooled Windings Class B Insulation Temperature or Temperature Rise (°C)
1	Cold coolant	Detector or Thermometer[1]	45–50[2] (temperature)
2	Directly cooled armature windings	Coolant[3]	55–50[2] (temperature rise)
3	Directly cooled field windings	Resistance	55–50[2] (temperature rise)
4	Core and mechanical parts in contact with or adjacent to insulation	Detector or Thermometer	85–80[4,5] (temperature rise)
5	Collector rings	Thermometer	85 (temperature rise)
6	Miscellaneous parts (such as amortisseur windings, rotor surface, brushholders, brushes, etc) shall be permitted to attain such temperatures as will not injure the machine in any respect.		

[1] 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.

[2] Cold coolant temperatures shall be provided within the range of 45°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 100°C for water-cooled machines.

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

[4] 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 2. 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 as are considered safe for the particular metals used.

[5] The values shown for Item 4 are limiting regardless of the operating power factor.

in Table 1 when the machine is operated at output rating conditions as described in 4.1.1 and 4.1.2. The temperature rises in Table 1 are based on a maximum cold air temperature of 40°C.

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.

Totally enclosed water-air-cooled 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 (86°F), 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 1 by the same number of degrees by which the average temperature of the air leaving the cooler exceeds 40°C.

For machines that operate under prevailing barometric pressure and are designed not to exceed the standard temperature rise at altitudes from 3300 feet (1000 meters) to 13 000 feet (4000 meters), the temperature rises, as checked by test at altitudes less than 3300 feet (1000 meters), shall be less than those listed in Table 1 by 1 percent of the specified temperature rise for each 330 feet (100 meters) of altitude in excess of 3300 feet (1000 meters).

5.3 Directly Cooled Machines. The observable temperature rise of each of the parts of the machine above the temperature of the cold coolant shall not exceed the values given in Table 2 when the machine is oper-

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ated at output rating conditions as described in 4.1.1 and 4.1.2. 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 2.

6. Abnormal Conditions

6.1 Short Circuits. A generator or generator/motor shall be capable of withstanding, without injury, a 30-second, three-phase short circuit at its terminals when operating at rated kVA and power factor and at 5 percent overvoltage, with fixed excitation. The machine shall also be capable of withstanding, without injury, any other short circuits at its terminals of 30 seconds'[2] 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 $I_2^2 t$ less than or equal to 40,[3] and provided also 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.

6.2 Continuous Current Unbalance. A generator or generator/motor shall be capable of withstanding, without injury, the effects of a continuous current unbalance corresponding to a negative-phase-sequence current I_2 of the following values, providing the rated kVA is not exceeded and the maximum current does not exceed 105 percent of rated current in any phase. (Negative-phase-sequence current is expressed as a percentage of rated stator current.)

Machines with connected amortisseur windings:

I_2 = 10 percent

Machines with nonconnected amortisseur windings:

I_2 = 5 percent

These values also express the negative-phase-sequence-current capability at reduced generator kVA 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.

7. Efficiency

The following losses shall be included in determining efficiency:

(1) I^2R losses of armature and field (7.2.2 and 7.3.4 of ANSI C50.10-1977)

(2) Core loss (7.3.3 of ANSI C50.10-1977)

(3) Stray load loss (7.3.2 of ANSI C50.10-1977)

(4) Friction and windage loss. 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.[4]

(5) Excitation system loss. This loss 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.

(6) Ventilating power 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. Overspeeds

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 minutes, unless otherwise agreed upon between the purchaser and the manufacturer.

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[2] With the voltage regulator in service, the allowable duration t of the short circuit shall be determined from the following equation in situations where the regulator is designed to provide ceiling voltage continuously during a short circuit:

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

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

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

[4] 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.

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Table 3
1960 Single-Frequency TIF_f Weighting Factors

Frequency	TIF_f	Frequency	TIF_f
60	0.5	1860	7820
180	30	1980	8330
300	225	2100	8830
360	400	2160	9080
420	650	2220	9330
540	1320	2340	9840
660	2260	2460	10 340
720	2760	2580	10 600
780	3360	2820	10 210
900	4350	2940	9820
1000	5000	3000	9670
1020	5100	3180	8740
1080	5400	3300	8090
1140	5630	3540	6730
1260	6050	3660	6130
1380	6370	3900	4400
1440	6650	4020	3700
1500	6680	4260	2750
1620	6970	4380	2190
1740	7320	5000	840
1800	7570		

9. Telephone Influence Factor (TIF)

9.1 Balanced and Residual-Components of TIF (Telephone Influence Factor). The balanced and residual-components shall be based on the single-frequency telephone influence weighting factors (TIF_f) in accordance with the 1960 single-frequency weighting shown in Table 3.

9.1.1 Balanced Component. The balanced component of TIF of synchronous generators and generator/motors shall not exceed the following values:

kVA Rating of Machine	*Balanced Component of TIF*
5 000 to 19 999	100
20 000 and above	70

9.1.2 Residual Component. The residual component of TIF of synchronous generators having voltage ratings 2000 volts and higher shall not exceed the following values:

kVA Rating of Machine	*Residual Component of TIF*
5 000 to 19 999	75
20 000 and above	50

9.2 Measurement. Methods of measurement for TIF shall be in accordance with IEEE 115-1982.

9.3 Reduction of TIF Limits. Special consideration of the need to reduce TIF limits of large machines (over 100 000 kVA) may be necessary where communication problems are known to exist or are anticipated.

10. Maximum Deviation Factor

The deviation factor of the open-circuit, line-to-line terminal voltage shall not exceed 0.1.

11. Torques

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

12. Tests

The tests to be made shall be determined from Table 4 and shall be conducted in accordance with IEEE 115-1982 and ANSI C50.10-1977.

The machines may be assembled for testing either in the factory or in the field, as agreed upon by the purchaser and the manufacturer.

The extent of the tests to be required in multiple-unit orders should be mutually agreed upon by the purchaser and the manufacturer.

The responsibility for conducting the tests made in the field shall be as agreed upon by the purchaser and the manufacturer.

13. Nameplates

The following information, as a minimum, shall be given on all nameplates:

(1) Manufacturer's name and serial number or other suitable identification
(2) Kilovolt-ampere output
(3) Horsepower output*
(4) Voltage rating
(5) Speed rating in r/min
(6) Direction of rotation†
(7) Armature amperes†
(8) Frequency
(9) Temperature rise of armature winding
(10) Temperature rise of field winding
(11) Number of phases

*Applies only to generator/motor units.

†For generator/motor units, two values shall be designated for items 6, 7, 13, and 14. If a single nameplate is used, the value for generator operation shall be given first.

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(12) Phase sequence
(13) Power factor†
(14) Field amperes†
(15) Excitation voltage

†For generator/motor units, two values shall be designated for items 6, 7, 13, and 14. If a single nameplate is used, the value for generator operation shall be given first.

14. Revision of American National Standard Referred to in This Document

When American National Standard Requirements for Synchronous Machines, ANSI C50.10-1977, is superseded by a revision approved by the American National Standards Institute, Inc, the revision shall apply.

Table 4
Tests on Salient-Pole Synchronous Generators and Generator/Motors

Tests	Machines Completely Assembled for Test in Factory	Machines Not Completely Assembled in Factory	
		Factory Tests	Field Tests
Resistance of armature and field windings	X	X[1]	X
Mechanical balance	X[2]	–	X
Voltage balance	X	–	X
Phase sequence	X	–	X
No-load saturation curve	X	–	X
Measurement of insulation resistance of armature and field windings	X[3]	X[1]	X
High-potential tests[4]	X[3]	X[1]	X
Measurement of bearing insulation resistance (if insulation has been provided)	X[3]	–	X

X – This test shall be made on each unit.

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

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

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

[4] Field high-potential tests on complete windings previously subjected to a factory high-potential test shall be performed in accordance with 9.3.11 of ANSI C50.10-1977.

NOTE: Other factory or field tests may be made as agreed upon by the purchaser and the manufacturer. These tests may include:
(1) Short-circuit saturation curve
(2) Temperature test
(3) Segregated losses
(4) Overspeed
(5) Short-circuit tests at reduced voltages to determine reactances and time constants
(6) Impedance of field coils
(7) Telephone influence factor (balanced and residual components)
(8) Deviation factor

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