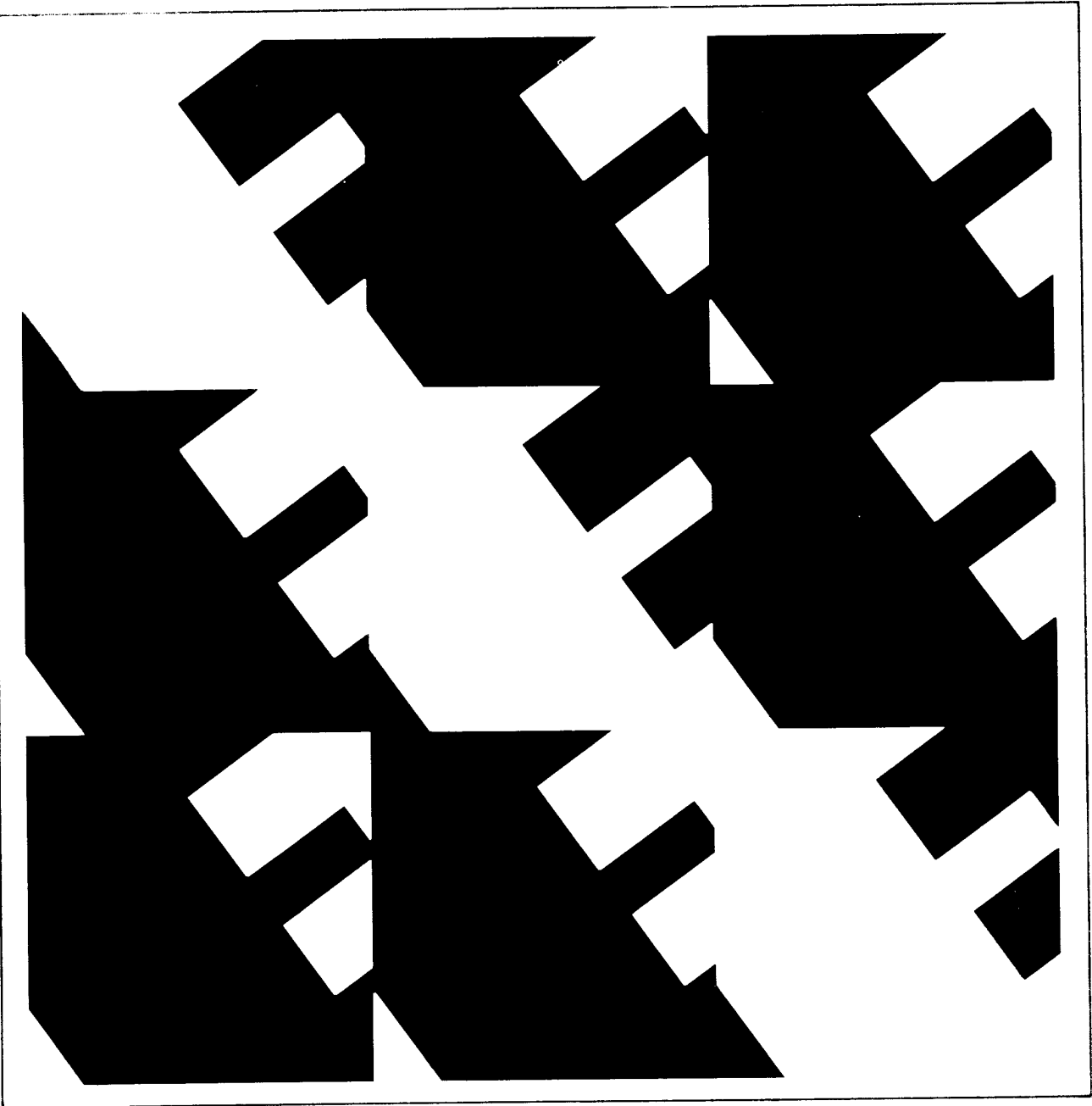


IEEE Guide for Operation and Maintenance of Turbine Generators

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Turbine Generators**

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Foreword

(This foreword is not a part of the IEEE Guide for Operation and Maintenance of Turbine Generators)

Originally published in July 1957 as a trial-use document, the Guide for Operation and Maintenance of Turbine Generators was updated and issued as a full-status IEEE Guide in 1963. In March 1969 a working group was appointed within the Synchronous Machinery Subcommittee of the IEEE Rotating Machinery Committee to begin work on an extensive revision of the 1963 edition.

In the course of this revision, the guide was enlarged to include directly cooled machines and to stress the importance of generator operation using the generator capability curve and other related operating curves. It also emphasizes the undesirability of operation of a generator by means of stator winding temperature indications. The bibliography section has been updated and has been grouped by subject to facilitate its use.

The IEEE will maintain this guide current with the state of the technology. Comments are invited on this guide, as well as suggestions for additional material that should be included. These should be addressed to:

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IEEE Guide for Operation and Maintenance of Turbine Generators

1. Scope

This guide covers general recommendations for the operation, loading, and maintenance of turbine-driven synchronous generators of the types specified in Section 4 below, having cylindrical rotors. It does not apply to generators having salient-pole rotors.

This guide is not intended to supplant specific or general instructions contained in the manufacturer's instruction book or in any contractual agreement between a manufacturer and a purchaser of a given machine.

Because of the rapid development in generator design and because of the ingenuity of individual generator designers, many variations are incorporated in existing machines. It is therefore not possible in this guide to assign specific values or fixed methods. The most that this guide can accomplish is to offer accepted and tried values or methods and give warning where hazards might be encountered. The user should keep in mind that this guide is written in terms of the turbine generator, and that certain considerations herein have been included because of their importance in directing attention to other related matters. This guide is not intended to apply in any manner to the prime mover.

NOTE: It is often practice in industry to refer to various types of power in terms of the units in which these types of power are normally measured. To avoid the possibility of confusion, units of measure are shown in parentheses when the terms reactive power (kvar), apparent power (kVA), and active power (kW) are used.

2. Caution

It must be recognized that loads more severe than those permitted by the nameplate should not be applied without a thorough study of the various considerations pertinent to the specific condition. It is recommended that in all such cases the specific condition be discussed with the manufacturer of the unit.

3. Manufacturer's and User's Responsibility

3.1 Some suggestions made in this guide in-

volve operation under conditions not covered by nameplate or specification conditions. The purpose of a generator nameplate is to identify the machine with respect to manufacturer and to indicate basic rating as fixed by the purchaser's specification. The temperatures stated on the nameplate are in accordance with applicable industry standards and/or purchaser's specifications. It should not be assumed that the generator is capable of safe operation up to these temperature levels. The range of safe operation is defined by the generator capability curves.

3.2 When a generator is operated within its capability, the user may expect maximum reliability and life. On occasions, consideration must be given to operation beyond the range of the capability curves. In those cases, all of the various factors involved must carefully be considered in determining the user's risks.

4. Methods of Cooling

This guide applies to turbine generators of the following types, distinguished according to methods of cooling:

4.1 **Indirectly-Cooled Types.** Indirectly-cooled generators are those in which the heat generated within the principal portion of the windings must flow through major ground insulation before reaching the cooling medium. Cooling air or hydrogen is circulated through passages in the generator by one of two methods:

(1) *Self-Ventilated Generator.* A self-ventilated generator has cooling air or hydrogen circulated by means integral with the machine.

(2) *Separately-Ventilated Generator.* A separately-ventilated generator has cooling air or hydrogen circulated by an independent fan or blower external to the machine.

4.1.1 *Air-Cooled Generators.* Air-cooled generators are designed to use air for cooling and they are classified according to the method of enclosure.

(1) *Open Generator.* An open generator is a self-ventilated machine, open to the surrounding air, having no restriction to ventilation other than that necessitated by mechanical construction and any silencing and filtering equipment.

(2) *Enclosed Generator.* An enclosed generator is either self-ventilated or separately ventilated with openings for the admission and discharge of the ventilating air, the machine being otherwise totally enclosed. These openings are so arranged that inlet and outlet ducts or pipes may be connected to them.

(3) *Totally-Enclosed Generator.* A totally-enclosed generator is so enclosed as to prevent exchange of air between the inside and the outside of the case, but not sufficiently enclosed to be termed airtight. Heat created by the generator losses is removed from the cooling air by heat exchangers.

4.1.2 Hydrogen-Cooled Generator. A hydrogen-cooled generator is designed to use hydrogen for cooling instead of air. It is a totally enclosed machine having a strong gastight enclosure. Heat created by the generator losses is removed from the hydrogen by heat exchangers.

4.2 Directly-Cooled Types. Directly-cooled generators are those in which the coolant or coolants (hydrogen or liquid) for the windings flows in close contact with the conductors so that the heat generated within the principal portion of the windings reaches the cooling medium without flowing through the major ground insulation. Coolants may be circulated either by means integral with the machine or by circulating equipment external to the machine.

4.2.1 Directly-Cooled Stators. Directly-cooled stators are classified according to the type of coolant used to remove heat from the stator windings.

4.2.1.1 Hydrogen. Hydrogen coolant flows within insulated ducts which are part of the stator winding structure inside of the major ground insulation. The heat generated within the conductors flows through the thin layers of conductor insulation and duct insulation to the cooling hydrogen in the ducts.

4.2.1.2 Deionized Water. Deionized water coolant flows within hollow conductor strands. The heat generated within the con-

ductors flows in either of two ways:

(1) Directly into the cooling water flowing within hollow conductor strands

(2) Through thin layers of strand insulation to the hollow strands carrying the water coolant if some solid strands are nested within the stator winding structure

4.2.1.3 Insulating Oil. Insulating oil coolant flows in the same manner as for the deionized water types in 4.2.1.2 above.

4.2.2 Directly-Cooled Rotors. Directly-cooled rotors are classified according to the types of coolant used to remove heat from the rotor windings and the flow pattern of the coolant within the slot portion of the windings.

4.2.2.1 Hydrogen Coolant With End Supply. Hydrogen is supplied to each end of the rotor and flows into conductor passages near the ends of the rotor body and/or into subslots which carry coolant to supply conductor inlet passages at intervals along the rotor body length. The hydrogen coolant is discharged into the generator air gap.

4.2.2.2 Hydrogen Coolant With Gap Supply. Hydrogen coolant is fed into conductor passages from the gap by short inlet sections along the length of the rotor body either by self-pumping or by pressurized gap zones maintained by gap baffles. The hydrogen coolant is discharged through short outlet sections between the inlet sections along the length of the rotor body. The end positions of the winding are supplied with hydrogen coolant from each end.

4.2.2.3 Water Coolant. Deionized water coolant is fed axially through piping inside the rotor shaft to radial connections that enter an inlet water box. The water coolant then flows axially through hollow field conductors or tubing nested in the field windings to the opposite end of the rotor. The water coolant may then exit at that end or return to the inlet end of the rotor. The water coolant exits by way of radial connections to outlet piping inside the rotor shaft.

5. Bases of Rating

5.1 General Considerations. The bases upon which turbine generators are rated for normal operation are distinctly different from the

consideration with regard to the turbine driving unit. In the case of the steam turbine, for instance, one of the principal load limitations is the maximum torque that the steam turbine can deliver under certain conditions of steam pressure, temperature, and vacuum. In the case of the generator to which it is connected, there is in most cases no torque limitation to the generator loading. However, the generator rating is limited by considerations related to the useful life of the insulation and other machine parts; principally, these considerations are the effects of temperature, differential expansion, and vibration.

5.2 Temperature Limits. IEEE Std 1-1969, General Principles for Temperature Limits in the Rating of Electric Equipment, discusses the general principles upon which temperature limits are based. In considering limits for the temperature of machine parts, the following points must be remembered:

(1) Deterioration of the insulation is a function of the time during which it is subjected to high temperature, as well as magnitude of the temperature

(2) The insulation is subjected to considerable mechanical stresses due to expansion and contraction of the windings and surrounding parts with changes in load and temperature

(3) In most cases, the maximum insulation temperature cannot be measured directly, and correction must be made to the measured temperatures to approximate the hot-spot temperature.

Generally, in considering turbine-generator loadings to insure normal insulation life expectancy, it is important that hot-spot temperatures of the machine do not exceed the limiting temperatures of the insulation system as established by test procedures developed in accordance with IEEE Std 99-1970, Guide for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment, or as derived from the temperature limits of the component materials given in IEEE Std 1-1969.

Some generators, such as those driven by gas turbines, are operated for short-time duty periods at higher than normal temperature in such a way as to make the average rate of

thermal deterioration over the total elapsed time consistent with the designed life expectancy.

5.3 Temperature Rise. Temperature rise of a machine component is defined as the difference between the temperature of that component and the cold coolant temperature. ANSI C50.13-1965 specifies the observable rises which the manufacturer guarantees will not be exceeded when the generator is operated at nameplate rating. It must not be construed as specifying allowable operating temperature rises.

On some applications, such as air-cooled 2-pole open-ventilated generators, greater output is achieved with lower cold coolant temperatures, permitting higher temperature rise without exceeding established total temperature limitations.

5.4 Methods of Temperature Measurement.

5.4.1 Coolant Temperatures. Coolant is defined as the medium used to remove heat from the active parts of the machine. The number and location of coolant temperature sensors vary considerably depending on the type of cooling system employed. The instruction book of the manufacturer should be consulted in each individual case.

The cold coolant temperature is measured by resistance or thermocouple detectors located either in thermometer wells in the side of the generator or inside the generator in the cold coolant streams.

In addition, coolant temperature detectors are frequently employed for the control of heat exchanger raw water flow. See Section 6.5.1 for definition of "raw water."

The cold coolant temperature should not exceed the maximum value specified on the generator nameplate. Maximum values as specified in ANSI C50.13-1965 range from 40°C to 50°C, depending on the type of cooling employed and on the manufacturer's practice. On some applications, such as air-cooled 2-pole open-ventilated generators, the cold coolant temperature may be outside this range.

5.4.2 Stator Windings. The method of measuring stator winding temperatures depends on the type of cooling employed.

5.4.2.1 Indirectly-Cooled Stator Windings. Winding temperature is measured by means of embedded detectors of the resistance or thermocouple type placed between the upper and lower coil sides, as shown in Fig. 1. Resistance detectors are used in most indirectly-cooled machines and are preferred since they indicate the mean temperature of the coils over a length of several core packs rather than at only one point. The resistance detectors consist of a coil of standard copper wire or of some suitable alloy material. This coil is wound on a suitable form to make it thin in the direction of the depth of the slot, and make its width some fraction of the total width of the slot. Leads are brought out from the end of the resistance detector coil to the end of the slot between stator coils, or to the side of the coil through one of the ventilating ducts, and hence to terminals suitable for connection to the temperature indicator leads.

Length and resistance of the resistance detector may be as specified in ANSI C50.10-1965 (resistance is 10 ohms at 25°C) or as otherwise specified by the purchaser. At least six detectors are built into the machine, suitably distributed around the circumference, located between the coil sides, and in positions along the length of the slots normally having the highest temperature. The detector is located, wherever possible, in the center of the slot with respect to the slot width and in intimate contact with the insulation of the upper coil side. Each detector is installed and the leads brought out in such a manner that the detector is effectively protected from contact with cooling air or gas.

While resistance detectors are most commonly used at present, and preferred for the reasons noted above, thermocouple-type detectors are sometimes utilized.

5.4.2.2 Directly-Cooled Stator Windings. The difference in temperature between stator winding strands and the coolant is a consistent function of load, permitting the temperature of the warm discharge coolant to serve as a dependable means of determining the hot-spot temperature by use of appropriate curves or calculations. Measurement of the warm discharge coolant temperature is therefore generally employed in preference to the use of detectors embedded between coils in the slot.

Either resistance or thermocouple-type temperature detectors are commonly employed for directly-cooled windings. In the case of gas-cooled windings, the coolant temperature detectors are mounted at the end of an insulating duct at the warm coolant discharge. In the case of liquid-cooled windings, the coolant temperature detectors are mounted at the ground potential end of insulating hoses at the warm coolant discharge.

5.4.3 Rotor Windings. No simple method has been devised for measuring rotor hot-spot temperatures; the practice is therefore to measure the average temperature of the winding by resistance using simultaneous voltage and current readings at the collector rings, and interpreting these values in conjunction with the known cold-resistance value into the operating temperatures. If the rotor voltage is measured at the brushes, there may be a total error of 2 to 4V due to brush voltage drop. To compensate for this effect, pilot brushes that carry no field current are sometimes used for measuring the potential of the rings. However, some users have experienced difficulty with pilot brushes due to a rapid film buildup that causes inaccuracy of the temperature measurement and in some cases interferes with the operation of the other brushes.

More practical methods of compensation are to:

(1) Provide a bias voltage equal to the brush voltage drop, or

(2) Calibrate the temperature-indicating or recording device for a value of resistance equal to the sum of the expected full-load temperature resistance of the rotor winding plus the equivalent resistance of the brush voltage drop at full-load rotor current.

For excitation systems that do not employ stationary rotor current-carrying components, no simple method for measuring rotor winding temperatures is currently available.

5.5 Limitations in the Methods of Measuring Temperature.

5.5.1 Stator Winding Temperatures by Embedded Detectors. The detector element is located between the surfaces of the upper and lower coil sides and is separated from the copper of these coils by the insulating wall of the coil, as indicated in Fig. 1. The difference between the temperature of the hot spot and

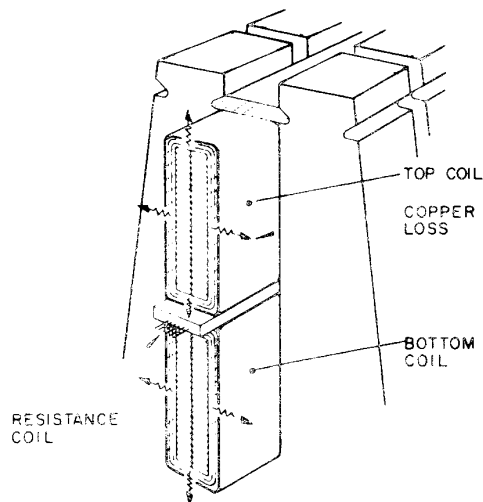


Fig. 1
Heat Flow and Typical Temperature
Detector Location

the detector element is a function of the proportions of the slot, the thickness of the insulating wall of the coils, the amount of heat to be conducted through the insulation, etc. It is impossible to generalize correctly as to what the difference between the detector and the hot spot temperature will be for all machines.

In the case of indirectly-cooled units, the embedded detector will always indicate temperatures somewhat lower than the temperature of the insulated copper of the windings. The difference between the hottest spot of the copper in the stator coil and the resistance detector of a hydrogen-cooled generator may be considerably higher than the 10°C allowance originally established for air-cooled generators. Tests made on large hydrogen-cooled turbine generators would indicate that the difference between the copper temperature and the detector temperature is practically unaffected by a change in gas pressure in a hydrogen-cooled generator, but is largely a function of the heat flow from the copper to the cooler parts surrounding the coil as indicated in Fig. 1.

In the case of directly-cooled units, the coolant enters one end of the stator coil at a low temperature and discharges from the other end at a higher temperature, causing the copper to have a similar temperature pattern.

In this case, the embedded detectors may indicate either higher or lower than the temperature of the insulated copper of the winding, depending upon their axial location in the slot and the relative temperature of the core at that point.

5.5.2 Stator Winding Temperature by Discharge Coolant Temperature. In the case of directly-cooled stator windings, the temperature of the discharge coolant is measured by means of resistance or thermocouple detectors. The temperature difference between this discharge coolant temperature and the hot spot varies widely for different machines. This difference depends on the coolant gas or liquid, winding construction, and design practice, and may be specified for a given design as a function of load.

5.5.3 Rotor Winding Temperatures. The rotor temperature measured by resistance gives an indication of the average temperature throughout the winding. As such, it does not indicate the magnitude of the hot-spot temperature with respect to the average temperature. The hot-spot temperature will be somewhat higher with respect to the average temperature in longer rotors than in shorter rotors of the same general design, except for long rotors with multiple parallel gas-flow circuits. To compensate for this factor, ANSI C50.13-1965 calls for a lower temperature rise for the larger machines. The lower temperature rise will also counteract the increased differential expansion between conductor and steel in the larger rotors.

6. Loading

6.1 Relation of Load and Temperature Rise-Stator and Rotor. As a primary guide to the loading of a generator, each generator is provided with a nameplate that states the operating conditions for which the generator has been designed and constructed. When operating within nameplate conditions of electric output and standard cooling-medium temperature, pressure, and flow, many machines will not reach the temperature rises that are given as maximal limits in ANSI C50.13-1965, but will be found to operate at considerably lower observable temperature rises. The reason for such a situation lies in the basic fact that temperature rise alone does not con-