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Proposed Guide
for
OPERATION AND MAINTENANCE OF
TURBINE-GENERATORS

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Proposed Guide
for
OPERATION AND MAINTENANCE OF
TURBINE-GENERATORS

1. SCOPE

1.1 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 and conventional cooling systems (in distinction from conductor-cooled systems). It does not apply to generators having salient-pole rotors.

1.2 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.

1.3 Because of the rapid development in generator design and because of individual ingenuity of generator designers, many variations are incorporated in existing machines. It is not, therefore, possible in this Guide to assign specific values or fixed methods in its various sections. The most that this Guide can accomplish is to provide guideposts which, on one hand, disclose accepted and tried values or methods and, on the other hand, 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.

2. CAUTION

2.1 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 involve operation under conditions not covered by nameplate or specification condition. The usual conception of a generator nameplate is to identify the machine with respect to manufacturer and to indicate basic rating as fixed by specification. It does not guarantee that the generator is capable of safe operation up to temperature limits set by standards, irrespective of all other operating conditions.

3.2 When a generator is operated within its nameplate rating the user normally may expect maximum

reliability and life. On occasions, consideration must be given to operation beyond the nameplate rating. In that case, all of the various factors involved must carefully be considered in determining the user's risks.

3.3 While a nameplate does not signify more than specified characteristics, it should be recognized that manufacturers must have some guide in designing a generator which will indicate probable conditions under which the generator will operate. With this in mind, the manufacturer's desire to stay within nameplate rating should be appreciated.

3.4 In investigating occasional cases of generator failure, it is interesting to note that nearly every failure brings out some new point with regard to generator design and operation. If generators are to be operated above nameplate rating, the manufacturer's advice should be obtained in determining risks.

4. TYPE OF UNITS

4.1 **Methods of Cooling.** This Guide applies to turbine-generators of the following types, distinguished according to methods of cooling:

4.1.1 **Air-Cooled Machines.** Air-cooled machines are those which use air for cooling. Such machines are classified according to enclosure and method of ventilation.

4.1.1.1 **Self-Ventilated Machine.** A self-ventilated machine is one which has its ventilating air circulated by means integral with the machine.

4.1.1.2 **Separately-Ventilated Machine.** A separately-ventilated machine is one which has its ventilating air supplied by an independent fan or blower external to the machine.

4.1.1.3 **Enclosed Self-Ventilated Machine.** An enclosed self-ventilated machine is a machine having openings for the admission and discharge of the ventilating air, which is circulated by means integral with the machine, the machine being otherwise totally enclosed. These openings are so arranged that inlet and outlet ducts or pipes may be connected to them.

4.1.1.4 **Enclosed Separately-Ventilated Machine.** An enclosed separately-ventilated machine is a machine having openings for the admission and discharge of the ventilating air, which is circulated by means external to and not a part of the machine, the machine being otherwise totally enclosed. These openings are so arranged that inlet

and outlet ducts or pipes may be connected to them.

4.1.1.5 Open Machine. An open machine is a self-ventilated machine having no restriction to ventilation other than that necessitated by mechanical construction.

4.1.1.6 Totally-Enclosed Machine. A totally-enclosed machine is one 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.

4.1.2 Hydrogen-Cooled Machine. A hydrogen-cooled machine is a machine which 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 is removed from the hydrogen by heat exchangers.

5. BASIS OF RATING

5.1 General Considerations. The basis upon which steam turbine-generators are rated for normal operation are distinctly different from the considerations with regard to the steam turbine driving unit. In the case of the steam turbine, one of the principal load limitations is the maximum torque which 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 and the temperatures reached by the various parts of the generator windings and other machine parts govern the permissible loading.

5.1.1 Over the years, certain limitations regarding the temperatures of the generator parts have been established through AIEE and ASA channels, and two of the principal standards which affect this are as follows:

5.2 Temperature Limits. AIEE Standard No. 1 defines the maximum safe temperature at which different insulating materials may be operated. In considering limits for the temperatures of machine parts the following points must be remembered:

- (a) 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.
- (b) 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.
- (c) In most cases the maximum insulation temperature cannot be measured directly and correction must be made to the measured temperatures to approximate the hotspot temperature.

5.2.1 In considering turbine-generator loadings, it is important to see that hot-spot temperatures of the machine do not exceed the limits assigned in AIEE No. 1.

5.3 Temperature Rise. American Standard C50 specifies the observable temperature 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 temperature rises.

5.4 Methods of Temperature Measurement. The commonly-used methods for determining temperatures are described below.

5.4.1 Stator Windings. In general the temperatures of stator windings of turbine-generators cannot be measured by liquid-in-glass thermometers on the windings. It is, therefore, necessary to employ embedded detectors of the resistance thermometer or thermocouple thermometer type between the upper and lower coil sides, as shown in Figure 1. Resistance thermometers are used in most modern machines. The resistance thermometer consists of a coil of standard copper wire or of some alloy material which has the same temperature coefficient of resistance as copper, wound on a suitable form to give a thin coil in the direction of the depth of the slot, and the width of this coil some fraction of the total width of the slot. Leads are brought out from the ends of the resistance thermometer coil to the end of the slot between stator coils, or to the side of the coils through one of the ventilating ducts and hence to terminals suitable for connection to the temperature indicator leads.

5.4.1.1 Length and resistance of the resistance thermometer or detector are specified in American Standard C50. Resistance is 10 ohms at 25C except possibly in some old machines. 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 having normally 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 with both the upper and lower coil sides. 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.

5.4.1.2 While resistance thermometers are almost universally used at present, thermocouple type thermometers are permissible.

5.4.1.3 Instruments used at the switchboard for measuring the temperature of the stator winding by resistance thermometer operate on the basis of change in resistance of the detector element, and may be made to record the temperatures

of a large number of thermometers on a continuous recording meter or indicate the temperatures on a common meter with a selector switch to connect the individual coils. It is common practice to provide multi-point recorders with adjustable alarm contacts.

5.4.2 Rotor Windings. No suitable method has been devised for measuring rotor hot-spot temperatures and the universal practice is, therefore, to measure the average temperature of the winding by resistance by taking 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 two to four volts due to brush drop. To compensate for this effect pilot brushes which carry no field current are sometimes used for measuring the potential of the rings. However some users have experienced difficulty with pilot brushes including inaccuracy of the temperature measurement due to rapid film build up and in some cases interference with the operation of the other brushes.

5.4.2.1 If a record of rotor temperatures is wanted, continuous chart recorders are available.

5.4.3 Ambient Gas Temperatures. The ambient gas temperature is considered to be the cool air or gas entering the machine.

5.4.3.1 In the case of self-ventilated air-cooled machines with coolers it is common practice to measure the ambient temperature near the inlet to the generator fans. Temperatures of the air are measured by a liquid-in-glass or a fluid-in-metal thermometer with remote indicating meter or by a resistance or thermocouple thermometer. These thermometers are customarily located in the duct wall of the ventilating system at the cold air point.

5.4.3.2 In hydrogen-cooled generators the ambient temperature is measured by resistance or thermocouple thermometers located either in thermometer wells in the side of the generator or inside the generator in the cold gas stream. In addition a fluid-in-metal thermometer may be used to provide an indication for cooling water control.

5.4.3.3 It is usual practice to furnish at least one temperature detector or other temperature measuring device at each end of the generator, as the temperature of the ambient gas may not be the same at the two ends of the machine.

5.4.3.4 In air-cooled generators the maximum ambient temperature shall not exceed 40C. In hydrogen-cooled generators the ambient temperature can exceed 40C. American Standard C50

gives the following maximum values for machines rated:

- (a) At 0.5 psig hydrogen pressure 40C.
- (b) At 15 psig hydrogen pressure 44C.
- (c) At 30 psig hydrogen pressure 46C.

5.5 Limitations in the Methods of Measuring Temperatures. It should be recognized that there are limitations in the methods of measuring temperatures. These are discussed below.

5.5.1 Stator Winding Temperatures by Embedded Detectors. As the detector element is located between the surfaces of the upper and lower coil side and is separated from the copper of these coils by the insulating wall of the coil, the embedded detector will always read somewhat lower temperatures than the temperature of the insulated copper of the windings.

5.5.1.1 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 10C 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 Figure 1.

5.5.1.2 The difference between the temperature of the copper and the detector element is a func-

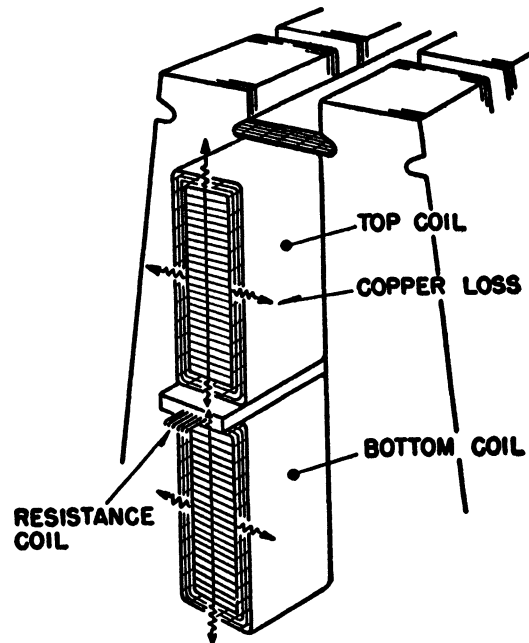


Fig. 1—Heat Flow and Typical Temperature Detector Location

tion of the proportions of the slot and the thickness of the insulating wall of the coils, and it is impossible to generalize correctly as to what the difference between the detector and the copper will be for all machines. **It is, therefore, necessary to use discretion in loading machines on the basis of observed resistance detector readings, as these readings may appear to indicate considerable temperature margin which may not exist, particularly in the case of hydrogen-cooled turbine-generators operating at higher gas pressures.**

5.5.2 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. In the longer rotors the hot-spot temperature will be somewhat higher with respect to the average temperature than in the case of the shorter rotors of the same general design. To compensate for this factor, the American Standards now call for a lower temperature rise on the largest machines. The lower temperature rise will also counteract the increased differential expansion of the copper and steel in the larger rotors. In considering the temperature at which the rotor is to be operated in any particular case, it is therefore important that the hot-spot temperature be considered.

6. LOADING

6.1 Relation of Load and Temperature Rise—Stator and Rotor. As a primary guide to the loading of a generator there is provided on each generator a nameplate, which states the operating conditions for which the generator has been designed and constructed.

6.1.1 When operating within nameplate conditions of electric output and standard cooling-medium temperature, and, for hydrogen-cooled machines, at the specified hydrogen pressure, many machines will not reach the temperature rises which are given as maximal limits in American Standard C50, but will be found to operate at considerably lower apparent temperature rises.

6.1.2 For hydrogen-cooled generators, which are capable of operating at higher than the nominal $\frac{1}{2}$ psig pressure, it is well known that the measured stator temperature rise by temperature detector must decrease as the loading is increased with increasing hydrogen pressure. In this case too, there will be found in practice considerable variations between individual machines, which also must be considered in the light of the preceding discussion.

6.1.3 The reason for such a situation lies in the basic fact that temperature rise alone does not constitute a sufficient basis for the design of a generator. Other information, such as strength of metals and insulating materials, magnitudes of frictional forces

resulting from expansion and contraction of machine elements because of temperature change, accuracy of the means available for the determination of the magnitudes of pertinent physical phenomena, and other data, accumulated as the result of experience, generally force compromises upon the designers.

6.1.4 To assure reasonable life expectancy, trouble-free operation and minimum maintenance, generator designers allow certain margins of safety in their designs. The realization of the designers' intentions depends to a large degree upon methods of operation.

6.1.5 In summary, any loading in excess of that permissible by the nameplate, must be approached with full awareness of all of the factors which are affected by such loading and not only by consideration of limiting temperature rise, as given by these Standards.

6.2 Loading Within Rating. Optimum operating methods from the standpoint of maximum life expectancy for a generator are those that result in a minimum temperature change at the lowest practicable temperature level. This involves controllability of the cooling system.

6.2.1 For open, air-cooled generators there is usually no means provided for the control of the air temperature through the unit. If there are means provided, the succeeding discussion applies.

6.2.2 For closed cooling system generators, whether air-cooled, or hydrogen-cooled, control of the cooling system is available through the control of the cooling water flow.

6.2.3 Although the considerations here presented apply particularly to a hydrogen-cooled generator, a considerable portion of the fundamentals developed are applicable to operation of air-cooled generators, having closed cooling system.

6.2.4 Conveniently located temperature indicating or recording instruments for obtaining the temperatures of the stator windings and of the rotor windings will provide valuable information in the loading of the machine.

6.3 Loading—Kilowatt and Kilovar Relationship. When one generator alone supplies an isolated load, the power factor and the reactive kva are determined by the load. In a system whose load is supplied by a number of generators in parallel, the division of the reactive kva load between the generators is determined by the relative excitation of each machine. In such a system, the principal effect of a change in excitation on one generator will be to vary the amount of reactive current supplied by that machine, and the voltage will be held level by the other generators connected to the system since they will collectively balance the reactive kva so shifted. Increasing the excitation will tend to make a generator supply more