ANSI/IEEE Std 43-1974
(Reaffirmed 1979)
(Revision of IEEE Std 43-1961)

An American National Standard

IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery

Sponsor

Rotating Machinery Committee of
The IEEE Power Engineering Society

Approved September 7, 1977
American National Standards Institute

Reaffirmed December 20, 1979
IEEE Standards Board

An American National Standard IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery

1. Scope

1.1 This document describes the recommended procedure for the measurement of insulation resistance of windings of rotating machines rated 1 hp, 1 kW or greater.

It applies to synchronous machines, induction machines, direct-current machines, and synchronous converters.

It applies to armature windings and field windings.

It does not apply to fractional-horsepower machines.

1.2 This document describes insulation resistance characteristics of rotating-machine windings, the manner in which these characteristics may serve to indicate the condition of the winding, and the testing procedure for obtaining insulation resistance values. It gives the recommended minimum value of insulation resistance of alternating-current and direct-current rotating-machine windings. The Appendix gives maintenance information relative to dry-out procedure.

1.3 Other IEEE publications which include information on insulation resistance measurement are listed in Section 10.

2. Purpose

The purpose of this publication is to:

(1) Describe and define insulation resistance as applied to the winding of a rotating machine

(2) Review the factors which affect or change insulation resistance characteristics and recommend uniform test conditions

(3) Outline and recommend uniform methods for measuring insulation resistance together with precautions for avoiding erroneous results

(4) Provide a basis for interpreting insulation resistance test results to estimate the suitability of the winding for service or for overpotential test.

(5) Present equations, based on machine ratings, for the calculation of recommended minimum insulation resistance values for various types of rotating machines.

3. Insulation Resistance—General Theory, Use, Limitations

3.1 Insulation resistance is the term generally used to describe the quotient of the applied direct potential divided by the current at some given time measured from the start of voltage application; thus reference will be found in this recommended practice to 1 min or 10 min insulation resistance.

3.1.1 The current that results from the applied direct potential consists of two parts: that in leakage paths over the surface of the insulation and that within the volume of the insulation. The current within the volume of the insulation may be further subdivided as follows (see IEEE Std 62-1958, Guide for Making Dielectric Measurements in the Field).

(1) The capacitance charging current, of comparatively high magnitude and short duration, usually has effectively disappeared by the time the first data are taken, and it does not affect the measurements.

(2) The absorption current decays at a decreasing rate from a comparatively high initial value to nearly zero. The resistance - time relationship is a power function which may be

plotted on log-log graph paper as a straight line. Usually the resistance measured in the first few minutes of a test is largely determined by the absorption current.

(3) The conduction current, which, with the surface leakage current, is nearly constant. These currents predominate after the absorption current has become insignificant.

3.1.2 After removal of the impressed direct potential and the provision of a suitable discharge circuit, there will be evident a discharge which is of two parts:

(1) The capacitance discharge current which will decay nearly instantaneously, depending upon the discharge resistance

(2) The absorption discharge current which will decay from a high initial value to nearly zero, as does the absorption current in Section 3.1.1.

3.2 The insulation resistance of a rotating-machine winding is a function of the type and assembly of insulating material. In general, it varies directly with the thickness of the insulation and inversely with conductor surface area. To obtain meaningful insulation resistance measurements on water-cooled machines, water should be removed and the internal circuit thoroughly dried.

3.3 Insulation resistance measurements are affected by several factors discussed in Section 4:

(1) Surface condition
(2) Moisture
(3) Temperature
(4) Magnitude of test direct potential
(5) Duration of application of test direct potential
(6) Residual charge in the winding

3.4 Readings of insulation resistance are usually taken after test direct potential application of 1 min and, if facilities are available, after 10 min to provide data for obtaining the polarization index.

3.5 The polarization index (ratio of 10 min to 1 min insulation resistance) is described in Section 4.5.2.

3.6 The interpretation of insulation resistance measurements of machine windings and the calculated polarization index is described in Section 8.

4. Factors Affecting Insulation Resistance

4.1 Effect of Surface Condition

4.1.1 Foreign matter, such as carbon dust deposited on creepage surfaces, may lower the insulation resistance. This factor is particularly important in the case of direct-current machines which have relatively large exposed creepage surfaces.

4.1.2 Dust on insulation surfaces which is ordinarily nonconducting when dry may, when exposed to moisture, become partially conducting and lower the insulation resistance.

4.1.3 If the insulation resistance is reduced because of contamination or excessive surface moisture, it can usually be brought up to its proper value by cleaning and by drying to remove the moisture (see Appendix).

4.2 Effect of Moisture

4.2.1 Regardless of the cleanliness of the winding surface, if the winding temperature is at or below the dew point of the ambient air, a moisture film will form on the insulation surface and may lower the insulation resistance. The effect is more pronounced if the surface is contaminated. It is important to make resistance measurements when the winding temperature is above the dew point.

4.2.2 Many types of winding insulation are hygroscopic, and moisture may be drawn into the body of the insulation from the humid ambient air. Absorbed moisture will have a large effect on the insulation resistance. Machines in service are usually at a temperature high enough to keep the insulation comparatively dry. Machines out of service may be heated to keep the winding temperature above the dew point.

4.2.3 When tests are to be made on a machine that has been in service, the tests should be made before the machine winding temperature drops to room temperature. The opportunity may be taken to test at several temperatures to establish the applicable temperature coefficient (see Section 4.3.4).

4.3 Effect of Temperature

4.3.1 Insulation resistance of most materials varies inversely with temperature.

4.3.2 To minimize the effect of temperature when comparing insulation resistance tests or when applying the recommended minimum value of insulation resistance as given by Eq 2, it is important that the test be corrected to a 40°C base. The correction may be made by use of Eq 1:

$$R_c = K_t \times R_t \qquad \text{(Eq 1)}$$

where

R_c = insulation resistance (in megohms) corrected to 40°C

R_t = measured insulation resistance (in megohms) at temperature t

K_t = insulation resistance temperature coefficient at temperature t

4.3.3 The correction of insulation resistance to 40°C may be done by making measurements at several temperatures, all above the dew point, and plotting the results. When a logarithmic scale is used for insulation resistance and a linear scale for temperature, test points should approximate a straight line which will indicate the 40°C value. For any temperature, K_t can be determined from such a plot by inversion of Eq 1.

4.3.4 An approximate value for the temperature coefficient K_t may be obtained by using Fig 1 which is based on doubling of insulation resistance for each 10°C reduction in temperature (above dew point) and has been found typical of some new windings.

4.3.5 When the polarization index is used to determine the insulation condition, it is not necessary to make a temperature correction to 40°C.

4.3.6 The effect of temperature on the polarization index is usually small if the machine temperature does not change appreciably between the 1 and 10 min readings; but, when temperature is high, the temperature characteristics of the insulation system may indicate a reduced polarization index in which case measurement below 40°C is recommended as a check of the real insulation condition.

4.4 Effect of Test Potential Magnitude

4.4.1 The measurement of insulation resistance constitutes a potential test, and must be restricted to a value appropriate to the volt-

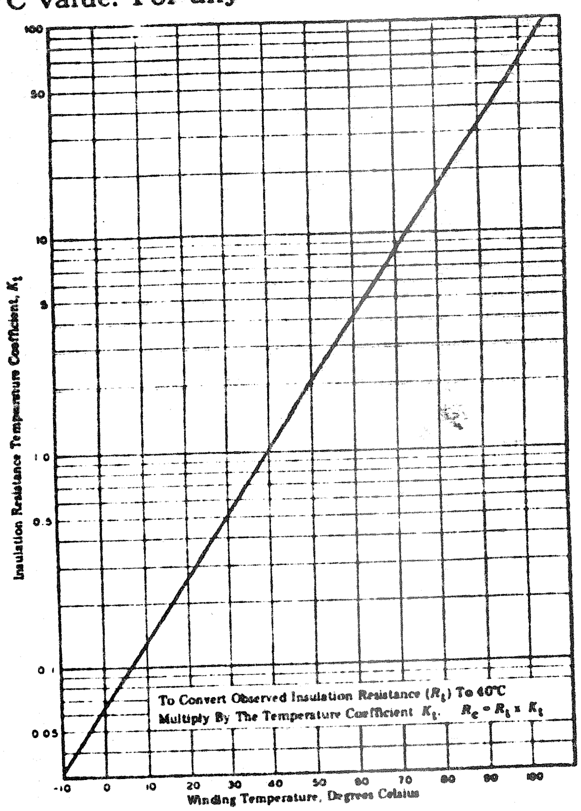

Fig 1
Approximate Insulation Resistance Variation with Temperature for Rotating Machines

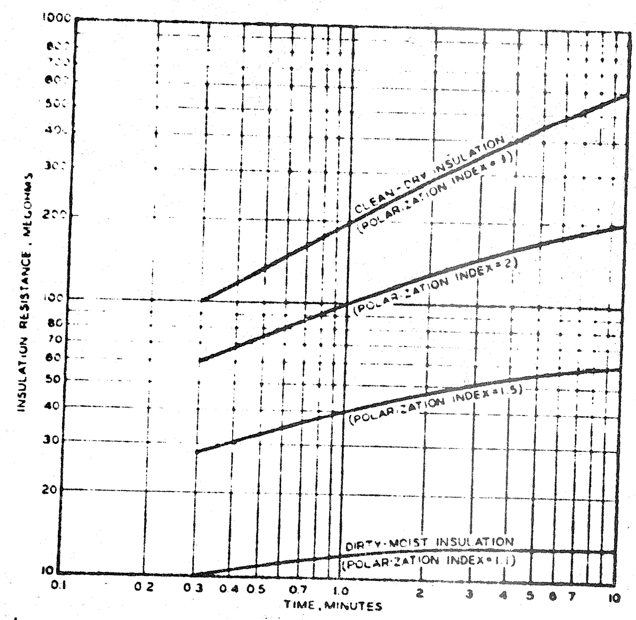

Fig 2
Typical Variation of Insulation Resistance with Time for Class B Insulated Alternating-Current Armature Windings

age rating of the winding and the basic insulation condition. This is particularly important in the case of small, low-voltage machines, or wet units. If the test potential is too high, the applied test potential may overstress the insulation.

4.4.2 Insulation resistance tests are usually made at direct potentials of 500 to 5000 V. The value of insulation resistance may decrease somewhat with an increase in applied potential; however, for insulation in good condition and thoroughly dry, substantially the same insulation resistance will be obtained for any test potential up to the peak value of the rated operating potential.

4.4.3 If the insulation resistance decreases significantly with an increase in applied potential, it may be an indication of imperfections or fractures of the insulation aggravated by the presence of dirt or moisture, or may be due to the effects of dirt or moisture alone, or may result from other deteriorating phenomena. The change in resistance is more pronounced at potentials considerably above operating potential.

4.5 Effect of Duration of Application of Test Potential: Polarization Index

4.5.1 The measured insulation resistance of a winding will normally increase with the duration of application of the direct test potential (see Fig 2). The increase will usually be rapid when the potential is first applied, and the readings gradually approach a fairly constant value as time elapses. The measured insulation resistance of a dry winding in good condition may continue to increase for hours with constant test potential continuously applied; however, a fairly steady value is usually reached in 10 to 15 min. If the winding is wet or dirty, the steady value will usually be reached in one or two minutes after the test potential is applied. The slope of the curve is an indication of insulation condition.

4.5.1.1 The change in insulation resistance with the duration of the test potential application may be useful in appraising the cleanliness and the dryness of a winding. If facilities are available, the test potential may be applied for 10 min or more to develop the dielectric absorption characteristic. This characteristic may be used to detect moisture or dirt in the windings.

4.5.2 The polarization index is the ratio of the 10 min resistance value to the 1 min resistance value. The polarization index is indicative of the slope of the characteristic curve (see Section 4.5.1.1 and Figs 2 and 3). The polarization index may be useful in the appraisal of the winding for dryness and for fitness for

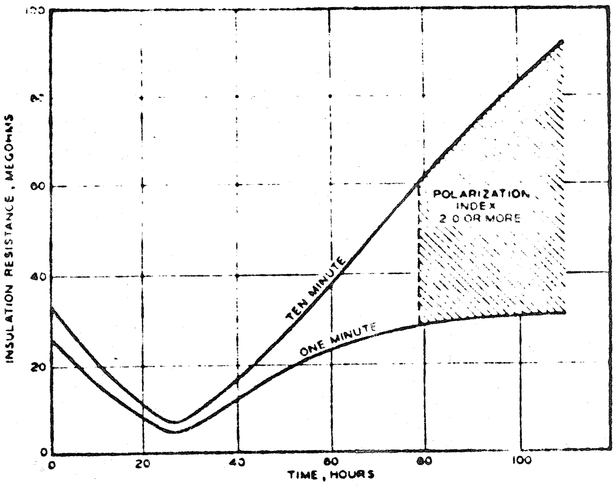

Fig 3
Change in 1 Min and 10 Min Insulation Resistance During the Drying Process of a Class B Insulated Alternating-Current Armature Winding
Initial Winding Temperature 25 °C
Final Winding Temperature 75 °C

overpotential tests. The measurements for determining the polarization index should be made just prior to making the overpotential test (see Sections 8 and 9).

4.5.3 The 1 min insulation resistance is useful for evaluating insulation condition where comparisons are to be made with earlier and later data, similarly obtained.

4.6 Effect of Existing Charge on Winding Resistance Measurements

4.6.1 Insulation resistance measurements will be in error if residual charges exist in the insulation. Therefore, before measuring the insulation resistance or polarization index, windings must be completely discharged to the grounded machine frame. If any doubt exists as to the sufficiency of discharge, the discharge current should be measured. This will show as a reverse deflection of the insulation resistance measuring meter after connections are made but before the voltage is applied. Such deflection should be negligible compared to the expected test current.

4.6.2 After application of high direct potential, grounding of windings is important for safety as well as for accuracy of subsequent tests. The grounding time should be a minimum of four times the charge time.

5. Conditions for Measuring Insulation Resistance

5.1 The insulation surface must be clean and dry if the measurement is to provide the information on the condition within the insulation as distinguished from the surface condition. Surface cleanliness is of great importance when tests are made in humid weather.

5.2 The winding temperature should be a few degrees above the dew point to avoid condensation of moisture on the winding insulation. It is also important that for comparing insulation resistances of machine windings, a 40 °C basis be used. (For converting insulation resistance values to this temperature see Section 4.3 and Fig 1.)

5.3 It is not necessary that the machine be at standstill when insulation resistance tests are made.

5.3.1 It is often desirable to make insulation resistance measurements when the rotating winding is subject to centrifugal forces similar to those occurring in service.

5.3.2 In certain cases it is practical to make periodic insulation resistance measurements while machines are rotating on short-circuit dry-out (see Appendix A3.3).

5.3.3 Whenever machines are not at standstill during measurement of insulation resistance, precautions should be taken to avoid damage to equipment or injury to personnel.

5.3.4 Test records of a given machine should indicate any special test conditions.

6. Winding Connections for Insulation Resistance Tests

6.1 It is recommended that each phase be isolated and tested separately, when feasible.

6.2 The neutral end of each phase winding should be disconnected when practicable. Testing each phase individually gives a comparison between phases which is useful in evaluating the condition of the winding now and in the future.

6.3 Tests may be made on the entire winding at one time, under certain conditions, such as when time is limited; however, this procedure is not the preferred method. One objection to testing all phases at a time is that only ground insulation is tested and no test is made of the phase-to-phase insulation. The phase-to-phase insulation is tested when one phase is tested at a time with other phases grounded.

6.4 The connection leads, brush rigging, cables, switches, capacitors, lightning arresters, and other external equipment may influence the insulation resistance test reading on a machine winding to a marked degree. Thus it is desirable to measure the insulation resistance of a winding exclusive of the external equipment of the machine.

7. Methods of Measuring Insulation Resistance; Precautions

7.1 Direct measurement of insulation resistance may be made with the following instruments:

(1) Direct-indicating ohmmeter with self-contained hand or power-driven generator

(2) Direct-indicating ohmmeter with self-contained battery

(3) Direct-indicating ohmmeter with self-contained rectifier using an external alternating-current supply

(4) Resistance bridge with self-contained galvanometer and batteries

7.2 Insulation resistance may be calculated from readings of a voltmeter and microammeter using an external direct-current supply.

7.2.1 The voltmeter–ammeter method is a simple method for the determination of the insulation resistance by measurement of the potential impressed across the insulation and the current through it. A source of direct potential is required, and the voltmeter must be selected to fit the maximum and minimum potentials which may be used. The ammeter is usually a multirange microammeter selected to measure the full range of leakage currents which may be encountered at the potentials used.

7.2.2 The microammeter must be on the highest range or short circuited during the first few seconds of charge so that it will not be damaged by the capacitance charging current and the initial absorption current.

7.2.3 If the microammeter is at test potential, precautions should be taken to ensure safety to the operator. To avoid measurement errors, the instrument should be guarded (see IEEE Std 62-1958).

7.2.4 For test potentials above 5000 V, the lead between the test set and the winding must be well insulated, shielded, of large diameter and spaced from ground; otherwise, leakage currents and corona loss may introduce errors in the test data (see IEEE Std 62-1958).

7.2.4.1 Both ends of the winding should be connected together to minimize surges if the insulation should fail during test.

7.2.5 Resistance is calculated from the equation $R = E/I$, where R is insulation resistance in megohms, E is the voltmeter reading in volts, and I is the ammeter reading in microamperes at a stated time after application of test potential.

7.3 In general, a finite amount of time is required to bring the potential impressed on the insulation to the desired test value. Full potential should be applied as rapidly as possible.

7.4 Instruments in which the test potential is supplied by motor-operated generators, batteries or rectifiers are usually used for making tests of over 1 min duration, that is, for tests for dielectric absorption or polarization index (see Sections 8 and 9).

7.5 It is essential that the potential of any test source be constant to prevent fluctuation in the charging current. Stabilization of the supplied voltage may be required.

7.6 Where protective resistors are used in test instruments, their effect on the magnitude of the potential applied to the insulation under test should be taken into account. The potential drop in the resistors may be an appreciable percentage of the instrument potential when measuring a low insulation resistance.

7.7 To compare with previous and future tests, the same potential should be applied by the same method to permit a proper comparison of results.

8. Interpretation of Insulation Resistance Test Results

8.1 Insulation resistance history of a given machine, made and kept under uniform conditions so far as the controllable variables are concerned, is recognized as a useful way of monitoring the insulation condition. Estimation of the suitability of a machine for the application of appropriate overpotential tests or for operation may be based on a comparison of present and previous values of the polarization index or insulation resistance values corrected to 40°C (see Section 4.3.4).

8.2 When the insulation resistance history is not available, recommended minimum values of the polarization index or of the 1 min insulation resistance may be used to estimate the suitability of the winding for application of an overpotential test or for operation. The 1 min insulation resistance (corrected to 40°C) should be at least that of the recommended minimum insulation resistance value obtained from Eq 2 (see Section 9.3).

8.3 The observed value of insulation resistance is a useful guide in evaluating the condition of a machine winding. It should not be considered as an exact criterion. It has several limitations:

8.3.1 Insulation resistance of a winding is not directly related to its dielectric strength. It is impossible to specify the value of insulation resistance at which a winding will fail electrically.

8.3.2 Windings having an extremely large surface area, large or slow-speed machines, or machines with commutators may have values of insulation resistance that are less than the recommended minimum value.

8.4 A single insulation resistance measurement at one particular potential does not indicate whether foreign matter is concentrated or distributed throughout the winding.

8.5 Polarization index (see Section 4.5.2).

8.5.1 Typical resistance versus time characteristics are shown by Figs 2 and 3, illustrating behavior of insulation under different conditions. The curves illustrate the significance of polarization index.

8.5.2 Depending upon the winding condition, insulation class, and machine type, values of 1 to 7 have been obtained for the polarization index. Class B insulation usually has a higher polarization index than Class A insulation. Moisture or conducting dust on a winding lowers the polarization index. When high-potential alternating-current machines have end windings which are treated with semiconducting material for corona elimination purposes, the polarization index may be somewhat lower than that of a similar machine which is untreated.

8.5.3 If the polarization index is reduced because of dirt or excessive moisture, it can be brought up to proper value by cleaning and drying to remove moisture. When drying insulation as described in the Appendix, the polarization index can be used to indicate when the drying process may be terminated (see Fig 3).

8.5.4 When experience demonstrates a reduction in the polarization index at an elevated temperature, remeasurement at below 40°C is recommended as a check on the real insulation condition (see Section 4.3.6).

9. Recommended Minimum Value of Polarization Index and Insulation Resistance

9.1 The recommended minimum polarization index or the recommended minimum value of insulation resistance R_m at 40°C of an alternating-current or direct-current rotating machine winding as used herein is the least value recommended which a winding should have just prior to application of an overpotential test or operation (see Sections 9.4 and 9.5).

9.1.1 It is recognized that it may be possible to operate machines with values lower than the recommended minimum value; however, it is not normally considered good practice.

9.1.2 In some cases special insulation material or designs, not injurious to the dielectric strength, will provide lower values.

9.1.2.1 When the end winding of a machine is treated with a semiconducting material, for corona elimination purposes, the observed insulation resistance may be somewhat lower than that of a similar machine which is untreated.

9.2 The recommended minimum value of polarization index for alternating-current and direct-current rotating machines is:

For Class A 1.5
For Class B 2.0
For Class F 2.0

9.3 The recommended minimum insulation resistance R_m for alternating-current and direct-current machine armature windings and for field windings of alternating-current and direct-current machines can be determined by Eq 2 (see Section 8.3.2):

$$R_m = kV + 1 \qquad \text{(Eq 2)}$$

where

R_m = recommended minimum insulation resistance in megohms at 40°C of the entire machine winding

kV = rated machine terminal to terminal potential, in rms kilovolts

9.3.1 The actual winding insulation resistance to be used for comparison with the recommended minimum value R_m is the observed insulation resistance, corrected to 40°C, obtained by applying direct potential to the entire winding for one minute.

9.3.2 Temperature corrections should always be made if the winding is not at a temperature of 40°C (see Sections 4.3.3, 4.3.4, and Fig 1).

9.3.3 The insulation resistance of one phase of a three-phase armature winding with the other two phases grounded is approximately twice that of the entire winding. Therefore, when the three phases are tested separately, the observed resistance of each phase should be divided by two to obtain a value which, after correction for temperature, may be compared with the recommended minimum value of insulation resistance.

9.3.3.1 If each phase is tested separately and guard circuits are used on the other two phases not under test, the observed resistance of each phase should be divided by three to obtain a value, which, after correction for temperature, may be compared with the recommended minimum value of insulation resistance.

9.3.4 For insulation in good condition, insulation resistance readings of 10 to 100 times the value of the recommended minimum value of insulation resistance R_m obtained from Eq 2 are not uncommon.

9.3.5 In applications where the machine is vital, it has been considered good practice to initiate reconditioning should the insulation resistance, having been well above the minimum value given by Eq 2, drop appreciably to near that level.

9.4 Machines rated at 10 000 kVA and less, to be considered in suitable condition for operation or for overpotential tests, should have either a value of the polarization index or a value of the insulation resistance (at 40°C) at least as large as the minimum recommended values.

9.5 Machines rated above 10 000 kVA should have both the polarization index and the insulation resistance above the minimum recommended values.

10. Standards References

IEEE Std 56-1958 (Reaff 1971) (ANSI C50.25-1972), Guide for Insulation Maintenance for Large AC Rotating Machinery.[1]

IEEE Std 62-1958, Guide for Making Dielectric Measurements in the Field.[1]

IEEE Std 95-1962, Guide for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage.[1]

[1] Presently under revision.

Appendix

A1. Prevention of Moisture Absorption in Winding Insulation of Rotating Machines

The following information describes suggested maintenance procedures to prevent moisture absorption in the windings of machines which are out of service. More detailed information may be found in IEEE Std 56-1958, (Reaff 1971) (ANSI C50.25-1972), Guide for Insulation Maintenance for Large AC Rotating Machinery.

A1.1 Machines which are out of service for prolonged periods may absorb sufficient moisture to reduce insulation resistance to a value below the recommended limits suggested in Section 9.

A1.1.1 This can be prevented if the winding temperature is always maintained slightly above the surrounding ambient temperature.

A1.1.2 The application of heat to the machine windings to keep the winding temperature about 5 °C above the ambient is usually sufficient.

A1.1.3 In rooms where wide and rapid temperature changes are experienced, some higher winding temperature rise may be necessary.

A1.1.4 In rooms with limited air exchange, dehumidifiers will reduce dampness in storage.

A1.2 It may not be necessary to maintain heat on the winding continuously. Generally, moisture is more likely to be absorbed in the Spring and Summer months in most parts of the United States, while the low atmospheric humidity which prevails during the winter may itself remove moisture from windings.

Heat may not be required when the polarization index or the insulation resistance is considerably above the recommended minimum values given in Section 9.

A1.3 An approximation of the heat required to raise the winding temperature of an enclosed horizontal generator or motor 5 °C above ambient temperature, where the machine is closed, is given by

$$H = \frac{DL}{35} \qquad \left(H = \frac{DL}{376}\right) \qquad \text{(Eq A1)}$$

where

H = heat, in kilowatts
D = machine end-bell diameter, in feet (in meters)
L = machine stator length between end-bell centers, in feet (in meters).

A2. Removal of Moisture from Winding Insulation of Rotating Machines

A2.1 Electric machinery should, when necessary, be dried by circulating current in the windings or by heaters maintaining a reasonably constant temperature in the windings.

A2.1.1 Sufficient heat should be provided to produce a temperature on the end windings of not higher than 80 °C by thermometer or 90 °C by resistance temperature detector.

A2.1.2 For machines which have been flooded, a prolonged drying time is expected. Cycling of temperatures often accelerates dry-out in severe cases of flooding. A temperature in excess of 80 °C by thermometer or 90 °C by resistance temperature detector may be required for satisfactory drying at atmospheric pressure in a reasonable time. The use of higher temperatures should be made with caution and after consultation with the manufacturer of the equipment.

A2.1.3 Drying under a moderate vacuum is recommended, when possible, since this method reduces the maximum temperature required, and drying can usually be accomplished without exceeding the design-temperature values.

A2.1.4 The rate of temperature rise should be limited to 5 °C per hour to avoid damage to the insulation by excessive gas or vapor formation.

A2.2 The progress of the dry-out may be observed without temperature correction by means of the polarization index values (see Fig 3). These will increase in value as moisture is expelled.

A2.3 The progress of the dry-out may also be observed by means of 1 min insulation resistance readings, but the effect of temperature variations on insulation resistance readings is significant during the drying period. Observed readings should be corrected to 40 °C (see Section 4.3, Fig 1) or readings should be taken at a constant winding temperature after the machine is heated.

A2.3.1 With the application of heat, the insulation resistance will initially drop and then will rise again over a period of time, finally approaching a constant value.

A2.3.2 Drying should be continued well beyond the time at which the insulation resistance has started to increase after reaching its minimum value and preferably until it approaches constancy (see Fig 3).

A3. Methods of Heating Machine Windings

Heat may be applied by any convenient method as long as it is safe and proper precautions are taken to prevent fire. The following methods may be considered, the choice between them being principally a matter of convenience, flexibility, cost, and availability. If the machine is enclosed to conserve heat, provision should be made to vent the moisture being removed.

A3.1 Electric Space Heaters

Electric space heaters will frequently be found to be the most suitable for heating since they are usually available in various sizes and can be placed in service quickly at low cost.

A3.1.1 The heaters should preferably be located in the air chambers under the machine and distributed so as to allow for even distribution of heat along the length of the machine.

A3.1.2 If the rotor is not in place, the ends of the machine may be closed with the end-bells or with large tarpaulins to reduce the heat loss.

A3.2 Field Winding Heating

The main field winding of a generator may be used to introduce heat into the machine when some source of direct current is available which can be separately controlled and allocated to the machine that requires heat. If the rotor of an alternating-current machine remains at stand-still, the current should be conducted to the slip rings through copper straps to prevent damage to the rings caused by pitting at the brush contacts.

A3.2.1 The field current required is

$$I = \left(\frac{1000H}{R}\right)^{1/2} \qquad \text{(Eq A2)}$$

where

I = field direct-current, in amperes
H = heat required, in kilowatts (see Eq A1)
R = resistance of field winding, in ohms at 25 °C, measured at the slip rings

A3.2.2 Normally, about 15 percent of rated full-load field current will be required and the field-winding temperature rise should be 20 °C or less above ambient temperature.

A3.3 Armature Winding Heating. The armature of the machine may be used to supply heat by passing current through the armature conductors.

A3.3.1 Alternating current at low potential may be induced in the armature, if the machine can be rotated at reduced speed (as on a hydro generator), with the generator terminals short circuited or connected to a load. Careful control of speed and field current is required.

A3.3.2 Direct current may be passed through the armature conductors.

A3.4 Steam Heating

The use of steam heaters is not recommended because of the possibility of leakage condensing, damaging the insulation system.