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TESTING SOLID INSULATION OF ELECTRICAL EQUIPMENT

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1. Purpose.- The purpose of this volume is to briefly cover the methods available for determining the insulating value of the insulation on generators, motors, transformer windings, cables, circuit breakers, and high-voltage bushings. This volume is based on operating experience of Reclamation and on a number of articles listed in the bibliography, which should be studied for more detailed information.

2. Insulation Life and Deterioration.-The useful life of a thermoplastic e.g., (asphalt-mica) insulation system is practically ended when the insulation has become brittle enough to develop cracks under the mechanical stresses to which it is subjected. A direct cause of embrittlement is from operation at high temperatures over a period of time; cracking results from mechanical stresses imposed upon conductors having brittle insulation. The mechanical stresses are caused by (a) short-circuit currents, (b) thermal expansion and contraction of the conductors, and (c) vibration. The dielectric strength of insulation is not significantly reduced by brittleness alone; however, electrical breakdown will quickly follow the development of ensuing cracks. For this reason, close inspection for cracked insulation should be made at frequent intervals, and repairs made as necessary.

The age and service history of the insulation will provide some indication of its probable condition. For example, a generator with class B insulation that has been fully loaded 24 hours every day for 15 years at a temperature of 110 EC (as measured by resistance-temperature detectors), probably has brittle insulation. Figure 1 shows the years of expected insulation life versus continuous operating temperature.

FIST Volumes 1-4 and 1-5 are guides to permissible overloading of generators and transformers, respectively, without undue acceleration of insulation embrittlement.

Another cause of failure in asphalt-mica windings is the migration of the asphalt compound when the coil operating temperature reaches the flow point of the asphalt. As the compound migrates, the space occupied by the compound becomes a void, subject to localized interior corona deterioration and resultant failure. This type of deterioration is more predominant in the phase terminal end of the winding where the voltages to ground are high enough to produce corona discharges. Evidence of asphalt compound migration would be bulges in coil tape, usually at the lowest point in the coil. It has been known for coils to remain in service, without failure, for years even if all the asphalt com-pound had migrated. This is not a healthy condition, but the only remedy is reduced load or rewinding the generator.

The useful life of thermosetting e.g., (polyester-mica or epoxy-mica) insulation systems has not yet been determined as they have not been in service long enough to determine the eventual effects of aging. To date, the main cause of failure of thermosetting insulation systems has been vibration due to looseness in the slots. Newer epoxy-mica insulation systems have proven to be especially prone to developing loose wedges and slot discharge because the "hard" nature of the insulation system does not mold itself to fit the slot as the old asphalt-mica system did. Therefore, slot discharge tests and visual inspection of the installation for loose wedges and indication of vibration are very important for thermosetting insulation systems and should be performed more frequently than previously done for thermoplastic systems.

3. Causes of Insulation Failures. - Many failures of insulation are caused by the entrance of moisture. Organic insulating materials used on generator and transformer windings have a high affinity for moisture from the surrounding atmosphere or oil. Therefore, it is of primary importance that close periodic inspections be made of the equipment to make sure no water comes in contact with the insulation through loose joints, poor gaskets, leaky cooling coils, or moisture-contaminated oil. Contamination of exposed insulation by dirt and oil also weakens the insulation and may cause failure. Another cause of ground insulation failure in rotating machines is turn-to-turn failures occurring and progressing into ground-wall breakdowns.

4. Insulation Test Methods.- The principal methods used today for testing insulation are:

a. Insulation resistance and dielectric absorption by high-voltage dc insulation test.

b. Insulation resistance and dielectric absorption by high-voltage, dc (direct-current) test.

c. Insulation current by dc, high-voltage, ramped test.

d. Power factor

e. AC (alternating-current) voltage withstand.

f. DC (voltage withstand)

Methods e. and f. are used primarily in factory tests and after initial erection of the equipment in the field. Practically all routine field tests are made using nondestructive methods a., b., c., and d. Neither the insulation resistance nor power-factor test methods can accurately predict the breakdown voltage of insulation. The results must be compared with values when the insulation was new and of known voltage withstand. Therefore, power-factor or insulation resistance measurements must be made periodically, beginning when the equipment is new and in good condition, and the trend noted of the test results. The great amount of data collected from insulation tests reveals that no single test method can be relied upon for indicating all conditions of weakened insulation. There are cases on record where transformer insulation resistance tests gave no indication of moisture, but power-factor tests on the windings definitely showed moisture. There are other cases where the reverse was found. Therefore, to minimize chance of deterioration escaping notice, it is recommended that the periodic tests on equipment be made by more than one of the following tests:

Equipment	Preferred test method (Numbers show order of preference)
Motor and generator stator and field windings	(1) Insulation current by dc high-voltage ramped test or (1) Insulation resistance and dielectric absorption
Power transformer	(1) Power factor and (2) Insulation resistance and dielectric absorption or (1) AC voltage withstand of oil and (2) Power factor
High-voltage cables	(1) Insulation current by dc high-voltage ramped test and (2) Power factor or (1) Insulation resistance and dielectric absorption and (2) Power factor
High-voltage bushings	(1) Power factor and capacitance and 2) Insulation resistance and dielectric absorption
Circuit breakers	(1) Power factor and (2) Insulation resistance and dielectric absorption

INSULATION RESISTANCE AND DIELECTRIC ABSORPTION TESTS

5. Definitions.- The **insulation resistance** of an insulation is defined as the resistance (in megohms) offered by the insulation to an impressed direct voltage. The resulting current is called **insulation current** and consists of two main components.

a. The current which flows within the volume of the insulation, and is composed of:

(1) Capacitance current

(2) Dielectric absorption current

(3) Irreversible conduction current

b. The current which flows in the leakage paths over the surface of the insulation, and is termed **leakage current.**

6. Theory of Insulation Resistance and Dielectric Absorption Measurement.- When a dc voltage from a high-voltage, dc insulation test instrument is suddenly applied to insulation, the insulation current will start at a high value, gradually decrease with time, and finally level off to a stable value. The low initial insulation resistance is partly caused by the high initial capacitance charging current. This capacitance current rapidly decreases to a negligible value (usually within 15 sec.) as the insulation becomes charged. The low initial insulation resistance is also partly caused by the high initial dielectric absoption current. This current also decreased with time, but more gradually, requiring from 10 minutes to several hours to decay to a negligible value. However, for the pupose of insulation resistance meter tests, the change in dielectric absorpiton current after 10 minutes can be disregarded. The leakage current does not change with time of voltage application, and this current is the primary factor on which insulation quality may be judged. Insulation resistance varies directly as the thickness and inversely as the area of the insulation being tested. A curve plotted between insulation current and time (or insulation resistance and time) is known as a dielectric absorption curve.

7. Skill Required in Making Insulation Resistance and Dielectric Absorption Measurements.- Unless made with a high degree of skill, insulation resistance and dielectric absorption measurements will show major fluctuations due to variations of the several factors discussed in the following paragraphs, and will consequently be of little value. Each factor causes large errors in the measurement of the insulation resistance and these errors may not be chargeable to inaccuracy of the measuring instrument. This discussion applies primarily to generator stator winding insulation, but also applies generally to the insulation of all rotating electrical machinery, cables, transformers, and other equipment except porcelain insulators, lightning arresters, and bushings, on which a favorable insulation resistance reading cannot be accepted as indicating good condition. The condition of bushings is best determined by the power- factor method.

Field windings and other low-voltage insulation should preferably be tested with a voltage source not higher than 500 volts, to avoid damage to the insulation. Before rotor fields are tested, the brushes should be raised and the slip-ring insulation carefully cleaned with a good solvent. The rotor field insulation resistance is as important as the stator insulation resistance.

8. Effect of Previous Charge.- One factor affecting insulation and dielectric absorption measurements is the presence of a previous charge on the insulation. The charge may come from normal operation of a generator with an ungrounded neutral, or from a previous measurement of insulation resistance. Time may be saved if the generator winding is kept grounded until the test on the winding is made.

9. Effect of Temperature.- Insulation resistance varies inversely with temperature for most insulting materials. To properly compare periodic measurements of insulation resistance, it is necessary either to take each measurement at the same temperature, or to convert each measurement to the same base temperature. A correction curve for conversion of each measurement can be made by taking two successive dielectric absorption curves, such as "C" and "D" in figure 2, at two well-separated temperatures by the standard procedure outlined in paragraph 12. The first or "hot" dielectric absorption curve "C" should be obtained from a test made soon after shutdown from a stable, full-load temperature condition. The second or "cold" curve should be obtained after the equipment has cooled to a considerably lower temperature. Using only the two 10-minute points of the two curves, plot a straight line on semilog paper as in figure 3. Extend the straight lines through a temperature range of 20 to 75 EC. As recommended by IEEE, 40 EC should be used as the base temperature to which all measurements are corrected. Once this conversion curve for the dry winding is established for a machine, the curve can be used as long as no rewinding or major repair work is done. By means of this curve, insulation resistance measurements taken at any temperature can be converted directly to any other temperature within the range of the curve. If this temperature conversion curve is not available, approximate conversion factors can be obtained from figure 4 which corrects to a base temperature of 40 EC. Careful measurement of temperature is important in making insulation resistance measurements. For generators with resistance temperature detectors, the average of the readings from all detectors should be used. Otherwise, the average reading of several strategically placed thermometers should be used. The elapsed time during removal of load, disconnection of associated equipment, and preparation for test will help to minimize the temperature gradient between insulation and temperature measuring device, but the time lapse should not exceed 1 hour. For transformers, a delay of about 1 hour after shutdown is recommended to reduce the temperature gradient. Any type of forced cooling should be shut off at the same time load is removed.

10. Effect of Moisture.- Moisture, which can enter the insulation of a generator or motor winding from damp air or which can enter the winding of a transformer from wet oil, will make a surprisingly large difference in the insulation resistance. This is clearly shown by the curves of figure 2 for a Grand Coulee generator. Curve "A" was taken shortly after the generator was placed in service, at a temperature of 36 EC. Curve "C" was taken after a dry-out run of 168 hours on the generator. The generator winding was, therefore, more thoroughly dried out in curve “C” than in curve "A," although evaporation of the volatile content of the insulation or other curing or aging effect may have had an appreciable effect. Low insulation resistance resulting from exposure to moisture does not mean that the insulation is unsuitable for operation, particularly if the insulation resistance value is comparable to that obtained from recent periodic tests. Dry out of thermosetting insulation is not as big a factor, and is sometimes not done, except to cure field applied insulation.

11. Effect of Age and Curing.- Insulation with semisolid binder, such as asphalt-mica, undergoes a curing process with time. This curing process increases the dielectric absorption current taken by the insulation, and thus insulation resistance meter or high-voltage, dc test measurements show a decrease in insulation resistance with increasing age. The more noticeable effect of age on the leakage current is mainly the development of cracks and contamination.

Solid insulations, such as porcelain, do not undergo a curing process and thus age, in itself, does not change their dielectric absorption or leakage current components

12. Polarization Index.- The steepness of the dielectric absorption curve taken at a given temperature indicates the relative dryness of the insulation. This steepness may be expressed as "polarization index" and is defined as follows:

Polarization index = $R_{10}/R_1 = I_1/I_{10}$
(if the voltage is constant)

where:

R_{10} = megohms insulation resistance at 10 minutes
R_1 = megohms insulation resistance at 1 minute
I_1 = insulation current at 1 minute
I_{10} = insulation current at 10 minutes

Table I shows the polarization index for the four curves of figure 2. As these data indicate, the difference in polarization index between dry and moist insulation is more pronounced at higher temperatures and therefore, the hot test is more sensitive. The increase in polarization index with dryness of insulation is also illustrated by the diverging 1- and 10-minute curves in figure 5.

13. Test Procedures and Records. The test procedure for making dielectric absorption tests is:

a. Hot resistance test - following shutdown from full-load operation of at least 4 hours, or until temperature is stabilized:

(1) Disconnect the equipment to be tested from other equipment by opening breakers, opening disconnecting switches, or unbolting connections. Disconnect any potential transformers or other devices connected between phases and ground, or neutral and ground. Any external circuits which cannot be readily disconnected should be recorded in the test record.

(2) For at least 10 minutes, ground the winding to be tested to drain off any charge.

(3) Remove the ground connection, connect the insulation resistance tester, and begin taking dielectric absorption readings. Take readings at 1 - minute intervals for 10 minutes. Make tests between entire

Table I

Curve figure 2	Condition of insulation	Temperature degrees Celsius	Polarization Index, R_{10}/R_1
A	Moist	36	1.88
B	Moist	75	2.50
C	Dry	75	3.11
D	Dry	36	2.16

IEEE Standard No. 43 indicates the recommended minimum values of polarization index for a-c (alternating current machines) are:

For class A insulation - 1.5
For class B insulation - 2.0
For class F insulation - 2.0

stator winding and ground, and between field winding and ground.

(4) Record the temperature of equipment being tested. Use average of all resistance temperature detector indications, if available, or use average reading of several thermometers placed so as to obtain best average of insulation temperature. The temperature measurements will be more representative of average insulation temperature if the test is delayed 0.5 to 1 hour after removal of load, to allow temperature gradient to level off. Generally, this period will be required to complete preparations for test.

(5) Ground the winding again for at least 10 minutes.

b. Cold resistance test.

(1) Four to eight hours after the hot resistance test or when equipment has cooled to approximately ambient temperature, make another test using same procedure as outlined for the hot resistance test.

c. Record all data on the "Oil and Insulation Test Report," form PO&M 109. Plot the dielectric absorption and temperature correction curves. Calculate polarization index. Data should include ambient temperature and humidity.

14. Temperature correction factors for insulation resistance. - The following method may be used to correct the insulation resistance at any temperature to the insulation resistance at any chosen base temperature if it is not possible to conduct the insulation resistance tests at two widely different temperatures, as suggested in paragraph 9. The method is only approximate, because the temperature coefficient of insulation resistance varies widely with different materials and conditions and is not always consistent for the same material. The insulation resistance value at the 10-minute point of the dielectric absorption curve should be used. The formula for determining insulation resistance (R_b) at some desired base temperature (T_b) when the known or tested value of resistance (R_a) at temperature (T_a) is:

$$\mathbf{R_b = f \times R_a}$$

where:

f = Temperature correction factor
(from curve fig. 4)
= $10^A(T_b - T_a)$; A = Temperature coefficient of insulation resistance from table II.

TABLE II

Apparatus or material	Average value of temperature coefficient of insulation resistance A
Transformers with oil, class A insulation	0.030
Transformer oil	0.0173
A-C armature winding, class A insulation	0.033
A-C armature winding, class B insulation	0.0168
D-C armature winding	0.024

INSULATION RESISTANCE METER TESTS

15. General.- The insulation resistance meter test method for determining the condition of electrical insulation has been widely used for many years as a general nondestructive test method. A serious limitation of this test is that its operating voltage of 500 to 1,000 volts will not always detect insulation punctures, whereas the higher voltages used by the high-voltage, dc testers will detect these punctures.

The insulation resistance meter test will show (a) the relative amount of moisture in the insulation, (b) the leakage current over dirty or moist surfaces of the insulation, and (c) winding deterioration or faults by means of insulation resistance versus time curves.

16. Description of Test.- A dc voltage of 500 or 1,000 volts is applied to the insulation and readings are taken to the insulation resistance versus time. Data should be recorded at the 1-and 10-minute intervals and at several other intermediate times.

17. Test Equipment.- The hand-cranked insulation resistance meter has been the standard instrument for many years for checking insulation resistance. The hand-cranked instrument is satisfactory for "spot checks" but is not recommended for routine dielectric absorption tests, because very few men can continue cranking for 10 minutes without tiring and slowing up the cranking speed toward the end of the period. Motor driven or electronic insulation resistance testers operating from a 115-volt, ac source or a self-contained battery are available and should be used for this purpose. Because the value of insulation resistance varies with applied voltage, it is important that the test instrument have sufficient capacity to maintain its rated output voltage for the largest winding being tested, and the output voltage be constant over the 10-minute test period. For this reason, some of the smaller test instruments may not be suitable for tests on large generators or transformers which draw a large dielectric absorption current. For occasional checks on the calibration and proper function of insulation test instruments, it is recommended that a resistor in the 100-megohm range be attached to the inside of the instrument cover for use as checking standard. It is recommended that the same test instrument be used for each periodic test on a certain piece of equipment, as differences in instrument output characteristics may affect the shape of the dielectric absorption curves, especially at the lower end.

18. Dielectric Absorption Curve.- Insulation resistance is not a definite measure of the voltage an insulation will withstand, but when properly interpreted affords a useful indication of the suitability of the winding for continued service. It should be remembered that values of insulation resistance, even on identical machines and for identical conditions, may vary over a wide range. Changes occurring in insulation resistance are more significant than certain absolute magnitudes. This is shown by the slope of the curve plotted between resistance readings and time, as further discussed under paragraph 10, "Effect of moisture." This curve is called the curve of dielectric absorption. The test voltage should be applied for a standard period of 10 minutes, with readings taken at intervals of 1 minute or less. Any such curve which reaches a constant and lower than normal value in about 3 minutes or less, indicates high leakage current (due to the leakage current being large in proportion to the absorption current), and the winding should be thoroughly cleaned and retested or further investigated. Such cleaning should preferably precede all insulation resistance tests. In case of very damp insulation, the dielectric absorption curve may start upward and then droop to a value lower than at the start of the test.

19. Minimum Values of Machine Insulation Resistance.-"Recommended Practice for Testing Insulation Resistance of Rotating Machinery," IEEE Standard No. 43, November 1974, indicates the recommended minimum insulation resistance R_m for armature and field windings of ac and dc machines can be determined by the equation:

$$R_m = V_t + 1$$

where:

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

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

The winding insulation resistance obtained by applying direct potential to the entire winding for 1 minute must be corrected to 40 °C to be used for comparison with the recommended minimum value R_m. 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, the resistance of each phase, when the phases are tested separately, should be divided by two to obtain a value which, after correction for temperature, may be compared with R_m. If guard circuits are used on the two phases not under test when each phase is tested separately, the observed resistance of each phase should be divided by three to obtain a value which, after correction for temperature, may be compared with R_m. For insulation in good condition, insulation resistance readings of 10 to 100 times the value of R_m are not uncommon. It should be remembered, however, that decreasing values of insulation resistance obtained from periodic tests are more indicative of deterioration of the insulation than low values. Machines rated at 10,000 kV-A or less should have either the polarization index or the insulation resistance (at 40 °C) at least as large as the minimum recommended values to be considered in suitable condition for operating or for overpotential tests. Machines rated above 10,000 kVCA should have both the polarization index and the insulation resis-tance above the minimum recommended values.

When the end turns of a machine are treated with a semiconducting material for corona elimination purposes, the insulation resistance may be somewhat lower than without such treatment.

20. Transformer Insulation Resistance.- Although the foregoing paragraphs apply more specifically to generator and motor windings, they also apply, in general, to transformers, except that no insulation values have been established for transformers. Also, the technique of measuring transformer insulation resistance is not well known or standardized. If the transformer windings are not immersed in oil, the insulation resistance will behave much like generator insulation resistance. The insulation resistance will be less after adding the oil, because the insulation resistance of the oil is in parallel with part of the solid insulation. Therefore, insulation resistance readings alone cannot be used to indicate the progress of dry out of the winding because the winding and the oil resistances cannot be separated. Tests should run on oil samples as specified in Facilities Instructions, Standards, & Techniques Volume 3-5 at the same time as the test of the transformer winding, and the oil then filtered, if necessary, to remove the moisture. The change of insulation resistance with temperature when the transformer windings are oil-immersed is similar to that in generators, and curves similar to those of figure 3 are useful for temperature standard-izing. Whether the slope of these temperature correction curves is affected by moisture content in the oil is not fully known. At the present state of the art, it is believed that the power factor test gives a better indication of transformer insulation condition than the insulation resistance test. Tests should be made between each winding, between each winding and ground with the other windings grounded, and between each winding and ground with the guard circuit connected to the other windings but not grounded.

21. Cable Insulation Resistance.-The most frequently used test on high-voltage cables is insulation resistance measured by means of an insulation resistance meter. The most informative test for high-voltage cables is the dc, high-voltage test modified to combine a modest voltage withstand with insulation current/voltage measurement as described in paragraph 46.

Insulation resistance testing of cable differs from the testing of apparatus windings mainly because of the high capacitance, if the cable is long, which takes a longer time to charge, and in the difficulty of obtaining a satisfactory temperature measurement, insulation resistance measurements are of value for comparison rather than for conformance to stated minimums. The temperature of the cable is important and should be recorded with the insulation resistance. This will be difficult if the cable is partly indoors and partly outdoors, partly underground, partly above ground, partly exposed, and partly in conduits. It may be necessary to estimate the temperature of the various lengths, and a weighted average computed. Tests should be made between each conductor, between each conductor and ground with other conductors grounded, and between each conductor and ground with other conductors connected to the guard circuit but not grounded.

HIGH-VOLTAGE, DC TESTS - ROTATING MACHINES

22. Application - Rotating Machines.- The high-voltage, dc test method is regarded as the best test presently available for machine insulation, through it must be recognized that the test also has some limitations. This test may also be carried to the point of being a high-voltage, dc withstand test.

An understanding of the value of the test is aided by considering its advantages and disadvantages:

Advantages

a. Very little supply power is required to operate the test set.

b. The test set is portable enough to be readily useful. (Although larger than an insulation resistance meter, it is far smaller than an ac, high-voltage tester.)

c. The high-voltage, dc test is less destructive than other available high-potential tests.

d. The small leakage current is not masked by ac charging current and therefore affords a quantitative measure of insulation quality.

e. Much less damage is done if breakdown should occur, because the capacity of the test set is small.

f. The insulation resistance characteristics up through the normal operating voltage range appear to afford more information on winding insulation than any other practical test known.

Limitations

a. The potential stress in some cases, such as at the generator winding end turns, is not entirely representative of that produced in normal service.

b. Longer time required to complete the dc test as compared to an ac test.

c. Care necessary to distinguish change of true leakage current from change of absorption current.

In order to obtain valid data on the condition of the machine winding using high-voltage, dc tests, it is necessary to disconnect the buswork from the unit. Unit buswork will quite often break down at a lower voltage than the winding. Figures 6 and 7 illustrate the difference in the results that can be obtained with the buswork connected and disconnected.

23. Correlation Between DC and AC Tests.- The dc puncture voltage may range from 1.41 times the rms ac puncture voltage for a cracked and abraded winding, where the puncture path is essentially an air gap, to 2.5 times the rms ac puncture voltage for well-compacted and impregnated mica insulation. IEEE Standard No. 95 mentions the factor 1.7 as appropriate for used insulation. Cases have indicated that on winding insulation with some deterioration, the application of ac overpotential tests may cause further deterioration, even though the insulation may not puncture in the 1 -minute duration of the ac test. Consequently, on any but new windings, if the dc test indicates weakness, ac overpotential test should not be applied. Deteriorated coils should be located by testing groups of individual coils by the dc method or by use of a clip-on ammeter. Ionization and power-factor tip-up tests may be useful supplements in important repair work.

HIGH-VOLTAGE, DC TESTS - STEPPED-VOLTAGE METHOD

24. Description of Test.- The stepped-voltage technique of high-voltage, dc testing of insulation consists of measuring the insulation current at scheduled times for a series of voltage steps up to an indicated insulation weakness or to well above the normal operating ac peak voltage ($\sqrt{2}$ x V rms). The insulation is then discharged through a microammeter and measurements are taken of current versus time. The data are interpreted to determine insulation quality. For interpretation, it is convenient to graphically plot the insulation current against test voltage and to calculate and plot the resistance versus test voltage.

25. Current Versus Voltage Curve. - As the data are recorded on the data sheet, a graph should be plotted of the insulation current (at the end of each voltage step) versus the test voltage, see figure 6A. This form of plotting has the advantage of employing readings taken directly from the test instrument. An incorrect reading or an incorrectly plotted point is promptly apparent and may be checked immediately. As long as the insulation current is not excessive (see paragraph 19 for standard insulation resistance values) and continues in a straight line with increasing test voltages, the test may be continued up to the recommended maximum shown in table A.

26. Resistance Versus Voltage Curve.- While the current versus voltage curve is being plotted, the insulation resistance (in megohms) can be calculated at the end of each voltage step. A resistance versus voltage curve should be plotted, as shown on figure 8B. After the final reading at the first voltage step, the megohm scale for the curve should be chosen so the first plotted point will be above the zero axis about equal to the distance from zero along the horizontal scale to the maximum test voltage. This will yield an approximately "square" plot for test of any size specimen, permitting comparison of curve shapes on a more uniform basis.

27. Log-log Plots and Discharge Curves.- In addition to the current versus voltage and resistance versus voltage curves, the following curves should be plotted on three-by-three cycle, log-log paper (K&E No. 359120): (1) current versus time for the first voltage step, and (2) the discharge current versus time after the last voltage step, see figure 9. The latter curve permits determination of the absorption exponent "n" and the proper template to be used for determination of the true leakage and absorption components of current from the current versus time curve (1). Ordinarily, the template analysis will be performed later, see figure 10.

28. Data Sheet and Voltage/Time Schedules.- Form PO&M-155 should be used for recording data as shown by example in table B. Table C gives voltage time schedules for various insulation ratings The data recorded should include the following:

Date of test
Time
Test voltage (kV)
Test current (FA)
Resistance (MO)
Temperature of winding(EC)
Identification of apparatus under test, and test instruments
Parts of winding, bus, or equipment included in test
Relative humidity

29. Test Technique.- The machine winding should be grounded for at least 1 hour immediately preceding the test, thus ensuring that any absorbed charge is drained off. The phases should be separated and tested individually. Lightning arresters and capacitors must be disconnected. Cables and/or buswork should be disconnected if it is convenient to do so. If the separation of phases is unusually difficult, the separation may be made once for the benchmark tests, and thereafter the phases may be tested together until deviation from normal is detected. Similarly, a winding and its cable or bus lead should be separated and tested individually. If separation is difficult and the leakage of the cable and of the winding are of the same order (one not more than twice the other), they may be tested together thereafter until deviation from normal is detected.

30. Polarization Index.- The voltage should be raised abruptly to the first voltage level with the start of timing for the test. Readings should be recorded of insulation current at 1 minute, at 10 minutes, and at other 2- or 3-minute intervals to the final reading The ratio of the 1-minute to the l0-minute reading of insulation current will afford useful indication of polarization index. This gives the test engineer an idea of insulation dryness early in the test. (Even though 500 volts has been the standard for determination of polarization index, the values yielded at the first voltage steps of the respective schedules are very close to those at standard voltage.)

31. Reason for Voltage/Time Schedules.- The absorption current will seldom subside to a stable value within any practical allowable time. Besides leakage current, some absorption current will be present in the final readings. This will not confuse results, however, if sufficient time is allowed at each voltage for the absorption current to subside to a proportional value. This requires a schedule of progressively shorter absorption times at successive steps of voltage, because at the beginning of each voltage step after the first, part of the absorption has already been satisfied by the preceding steps. Consequently, the proportional absorption is reached in less time. Test schedules with steps chosen to be convenient for insulation of various voltage ratings are shown in table C for stator windings.

32. Applicability of Test Schedules.-- The test schedules are arranged to include a minimum of three points up to and including approximately normal peak operating voltage. Smaller voltage steps at the higher voltages are chosen as this affords indication of any weakness with less danger of unexpected puncture. The additional points occasioned by the smaller voltage steps add very little to the total time of the test. Therefore, the same schedules are practical for routine tests. Departures from the schedules for finer steps when weakness is detected will seldom be necessary. The voltage steps are sufficiently conservative that the gradual raising of voltage in the former 30 minute test schedule is no longer necessary. **The schedules of table C allow for raising the voltage rapidly.** To protect the microammeter during the rapid voltage change, it should be switched to the next higher range.

Schedules employing only 10 minutes on the first voltage step, as shown in table C, are intended to supersede the former schedules which employed 20 to 30 minutes on the first step. The advantages of the change are: shorter overall time for testing, adequate indication of weaknesses, the resistance results for all steps will be on 10-minute basis comparable to 10-minute insulation resistance meter readings for which there is much background, and the exponent of -0.8 on which the schedule is calculated is more representative of the average machine insulation. See figure 11 for a comparison of test curves between the 10- and 30-minute schedules for the same machine.

33. Maximum Voltage for Test.-If the insulation microampere versus voltage plots are straight lines, the test may be continued to the maximum test voltages shown in table A. If curvature appears, the test should be stopped when the resistance has dropped to approximately one-third the maximum value unless it is desired to locate the weakness by puncture so that it can be repaired. Cases of abrupt breakdown before the resistance curve approached zero have occurred in insulation where mechanical abrasion, cracking, or acute mica migration existed. Hence, as a general practice, but particularly where mechanical defects are known to exist, tests should only be performed when time could be taken for bypassing a coil or other maintenance if a weak point should be punctured. This allows taking best advantage of the "proof" feature of the test. For the most conservative, nondestructive use of the test, a very abrupt increase in insulation current (excluding the random variations of absorption current often found) is also warning that the test should be stopped. An abrupt rise in insulation resistance (drop in leakage current) is rarely found, but when it occurs above the peak operating voltage for the winding, it has usually preceded breakdown of the insulation. The increase of resistance is thought to be caused by vaporization of the moisture trails in the insulation, which would immediately precede puncture.

34. Importance of Regulated Power Supply. - It is important that voltage variations in the power supply to the test set be avoided. Because of the capacitance of the winding under test, even minor fluctuations in supply voltage to the test set will cause wide fluctuations of the microammeter and contribute to a random scattering of test points. A voltage stabilizer or electronic regulator in the power supply is recommended. Magnetic voltage stabilizers usually perform better when working into a resistance load than when driving a rectifier only. A 500-volt ampere regulator is usually sufficient so that about 200 volt amperes of resistance load can be used in addition to the test set. If random variations still persist, the currents may be averaged graphically. If absorption currents are plotted against time on log-log paper, the mean will be a smooth curve and almost a straight line from which the mean reading of the appropriate time may be selected. For this plotting, the time is reckoned from zero when voltage is raised from the preceding step.

35. Discharge of Winding After Test.- Upon completion of the dc, high- voltage test, the winding should be discharged through the special discharge resistor ordinarily provided with the test set. The discharge resistor consisting of several kilohms is for the purpose of retarding the discharge current so no destructive surge is produced. The winding may be solidly grounded when the voltage has dropped to zero or after a few minutes of discharge have occurred.

36. Minimum Period of Grounding After Test Before Returning to Service.- A winding should remain solidly grounded long enough after test for the absorbed charge to be completely drained off before restoring the machine to service. Windings vary greatly in the length of time an absorbed charge will remain, but in absence of actual checks, it is recommended the winding be grounded for at least 1 hour. If the dc, high-voltage test precedes a maintenance ac overpotential test, it is advisable to double the minimum ground time to assure that absorbed charge does not contribute to puncture. Also, the time spent in making a discharge test can be credited to the total grounding time.

37. Effects of Temperature and Humidity.- The influence of temperature upon leakage current of winding insulation under dc, high-voltage test is similar to the influence of temperature on insulation resistance meter readings. However, the most significant factor of the dc, high voltage test, the position of the curvature, is not appreciably affected by temperature; consequently, correction of individual test points to the standard temperature of 40 °C is not necessary. Because the dc, high-voltage test does require appreciable time, it is desirable that the insulation be near ambient temperature during testing to minimize temperature change between test points. Experience indicates that tests at the lower temperature yield more sensitive warnings of weakness. Consequently, **there is less danger of unexpected puncture during test at ambient temperature than at elevated temperature.** Slight humidification of the winding, similarly, has been found to improve sensitivity of the test. This is believed to be caused by more rapid absorption of moisture into any weakened or porous areas of insulation than into good intact insulation.

38. Interpretation of Curves.-The quality of the insulation may be judged by the position of any curvature or knee in the plot of insulation current versus test voltage. If the plot is a straight line, the knee may be assumed to be above the maximum test voltage. The higher the test voltage at which the knee appears in the curve, the better the insulation quality is. If the knee appears below the maximum peak ac voltage which could be applied to the winding in service, the insulation may be in danger of an in-service failure. If the leakage current increases to the extent that its plotted curve becomes almost vertical, the winding is approaching failure on test and the test should be discontinued. This point is the most difficult to judge with this type of graph. Considerable experience is necessary to judge the maximum safe test voltage from plotted insulation current.

Another approximate, though useful, indication of insulation quality is given by the position of a major downward bend of the resistance versus voltage curve (see fig. 8B). Any major downward bend should occur at a voltage above the peak operating voltage ($\sqrt{2}$ x V rms). Progress of deterioration is shown by a shift of the bend to a lower voltage over a period of time and by a lowering of the overall insulation resistance. A sharp bend is most indicative of a single area of weakness, while a gradual bend is most often associated with numerous areas of weakness. While the breakdown voltage occasionally has been predicted by a projection of the resistance curve to zero, this prediction is rather inaccurate and is not the useful purpose of the test.

39. Progressive Condition of Insulation.- The dc, high-voltage test is believed to give a practical indication of the electrical quality of the insulation at the time of the test. Although a rough estimate of the puncture strength of the winding at the time of test may be made, of more concern is an estimate of the years of service remaining in a winding. Such an estimate is aided by comparing the insulation tests over a period of time, as shown in figure 12. Once satisfactory benchmark data on a machine have been established, the interval between tests may be extended to from 3 to 5 years unless an abnormality is indicated or suspected. Often when the insulation quality drops, it can be restored by cleaning and varnishing the winding. A drop in quality, which cannot be recovered, may be caused by deterioration within the slots and must be regarded as permanent. Replacement of one or more coils may then be necessary. It is not unusual that the revarnishing of winding end turns produces a drop in insulation resistance at the low and intermediate voltages. This may occur when a winding has become very dry. The insulation quality at the higher voltages is more important; and, if this is improved, the overall quality is considered improved. This is illustrated in figure 13.

HIGH-VOLTAGE, DC TESTS - RAMPED VOLTAGE METHOD

40. General.- The ramped voltage test technique automatically linearizes the dielectric absorption component of insulation current eliminating many of the problems encountered in dc, stepped-voltage testing methods. Automatic compensation of absorption current eliminates the need for extensive absorption current calculations and complex volt/time testing schedules. Further improvements have been made through utilization of state-of-the-art automatic testing equipment which has removed the uncertainty of the human factor in adjusting test voltages and in recording data. DC testing controllability, sensitivity, and repeatability are significantly improved through the use of this test method.

41. Description of Test.- The ramped technique of insulation testing uses a programmable dc, high-voltage test set and automatically ramps the high voltage at a preselected rate (usually 1 kV/min). Insulation current versus applied voltage is plotted on an x-y recorder providing continuous observation and analysis of insulation current response as the test progresses. To evaluate an insulation, it is no longer necessary to hand plot insulation current and resistance versus applied voltage. Insulation quality can be evaluated directly from the automatically recorded insulation current curves, because the observed insulation current nonlinearities are directly proportional to leakage current variations.

The test technique was designed so automated test results are similar in nature to previous data obtained using USBR's dc, step testing schedules.

The principal advantages of the ramp test over the conventional step method are that it requires only one person to perform the test and provides that person with better control and sufficient foresight of impending failure to avoid damage to the insulation. The elimination of the human factor from the time, voltage, and current parameters yields overall test results which are much more accurate and repeatable. In addition, the slow and continuous increase in applied voltage (17 volts per second) is less apt to damage insulation than the step-method voltage increments (approx. 1 kV/s).

Typical ramped-voltage test responses are shown in figures 14 through 17. These curves are a composite of the capacitive charging, absorption, and leakage currents.

For a full description of the operation and theory of the ramped-voltage method, refer to Bureau of Reclamation Report REC-ERC-78-7, "A Programmable D-C High-Voltage Ramped Test System for Electrical Insulation."

42. Ramped DC Test Schedule. - A ramp rate of 1 kV/min is normally used to test stator winding insulation. This rate produces a current response similar to the stepped test and is somewhat of a compromise between maximum sensitivity and minimum test duration.

The maximum voltage limit is the same as in the stepped test. However, the increased sensitivity and continuous-current monitoring features of the ramped test provides more information even when the test is terminated at approximately 85 percent of the maximum voltage limit. A reduced voltage test can be used to evaluate very old, weak, or problem insulation characterized by extensive corona damage, excessive abrasion, loose blocking, etc. Under no circumstances should a reduced voltage test be used for acceptance testing. Regardless of the insulation quality, a reduced voltage limit is not recommended when the dc test is also to serve as a withstand or proof test. In any event, to avoid an insulation failure, testing should be terminated whenever leakage current starts to become excessive.

The ramp test should be terminated when a 1- to 2-FA, or larger, sharp increase in insulation current is observed. If the increase is only a fraction of a microampere, testing can continue. However, if the current is unstable or there are more stepped type of increases directly following, testing should be halted.

An insulation having a gradually increasing leakage current response can tolerate much higher leakage current than an insulation having abrupt current increases in the V-I response curve, A test on an insulation having a slowly increasing leakage current response should be stopped when the total insulation current becomes three to six times larger than the capacitative charging component of current.

43. Ramped-Voltage Test Results.- Figures 14 through 17 are typical stator insulation ramped voltage test results. Actual record size is 25 x 38 cm (10 x 17 in).

The curve shown in figure 14 is the response of new epoxy mica insulation when ramp dc tested. Above 5 kV, the curve is very linear, indicating excellent insulation quality.

The curve in figure 15 is typical of new asphalt mica insulation. This curve is also linear above 4 or 5 kV, indicating high-quality insulation.

Figure 16 shows a very sharp increase in leakage current suggesting the insulation of one coil or portion of a coil is very questionable. The test was terminated early to avoid the possibility of damaging the insulation.

The nonlinear response shown in figure 17 is due to many minute discontinuities similar to the one shown in figure 16. The curve shows a very gradual increase in leakage current and implies that a general deterioration of the insulation has taken place. As the test voltage increases, the slope of the leakage current will continue to increase in a nonlinear manner. Breakdown will occur as the current asymptotically approaches the vertical. Testing should be halted well before this point is reached.

44. Grounding.- The powerplant ground mat is part of the high-voltage circuit. To minimize induced alternating-current voltages in this circuit, the test set grounds should be connected to plant ground as close to the stator core as possible. The discharge resistor and grounding stick should be tied to the ground mat in the same area where the test set grounds are attached. Do not ground these sticks at the test set ground terminals.

Due to the nature of the insulation absorption current, the winding must remain grounded for 1.5 to 2 hours, or the voltage will recover by itself to a fraction of the original dc test voltage. An ac voltage should not be applied until the winding has been thoroughly discharged (grounded for 1.5 to 2 hours). Failure to properly discharge the winding constitutes a safety hazard and could also result in failure of the insulation upon application of an ac voltage.

45. Discharging the Winding.- The highly capacitive and inductive properties of stator windings make it essential that they be discharged slowly. When the capacitively stored energy in the winding is suddenly discharged through the winding inductance, dangerously high-voltage transients are generated across the insulation. The voltage should be reduced to a value below 5 kV with a discharge resistor before applying the grounds.

46. Cable Testing.- When the cables can be isolated from other equipment, they may be tested to much higher limits than rotating machine insulation. Accordingly, a table of cable test voltages allowable for maintenance tests is included (see table D). The recommended limits for maintenance tests of cables are much higher than for rotating machine insulation because: (1) cable insulation is less subject to cracking, ionization, and erosion than rotating machine insulation; (2) a higher voltage is likely to be necessary to show up the defects; and (3) a higher voltage is allowable in manner of a proof test as there is less investment at stake and the cost in time and expense of repairing a cable failure from test is comparatively small. The deterioration of sheathed cables in service is most likely to occur at the potheads or the joints due to loss of impregnating oil or pothead compound, entrance of air, moisture, and corona action in the air voids.

WARNING

High voltage cables should be tested with negative voltage dc applied to the test specimen. **Never apply positive voltage dc.** Experiences by other utilities indicate that positive voltage dc greatly accelerates deterioration.

47. Advantages of DC High-Potential Test.- AC high-potential tests on long high-voltage cables would be impractical because of the high-charging kilovolt amperes required and nonuniform voltage distribution over the length of the cable. The DC, high-potential test method has the following advantages over the ac method: (1) direct-potential testing causes no deterioration of the insulation up to within a few percent of the breakdown point; (2) the small leakage current drawn can be readily measured and tendencies to increase and decrease noted; (3) much less damage is done if a breakdown occurs because the capacity of the equipment is small; and (4) the test equipment is relatively small and light because it needs to be only large enough to supply the insulation leakage current. A special precaution to be observed with the dc method is the long time required to drain off the charge after a test is made.

48. Test Technique.- In maintenance testing of cables, it is practical to combine the more searching ability of the step-voltage method with test to reasonable proof level (see table D). For most cable, insulation absorption is not so prominent as to require a voltage/time schedule as extensive as for generator insulation. Five to seven equal voltage steps up to the desired test level, allowing 2 minutes at each step, are usually sufficient. If the insulation is type with much absorption, a generator insulation test schedule may be used. The ramped-voltage test technique may be used for cable testing if the test set has a high enough voltage rating to reach a reasonable proof level for the cable.

49. Interpretation of Test Curve. Warning of approaching breakdown on test is usually given by upward bend of the V-I curve. However, with cables when weakness is indicated, it is less important that the test be terminated than with generators for the reasons previously pointed out.

Upward bend of the V-I curve is most often an indication of trouble in the pothead such as voids, moisture, or imperfect makeup. See figure 18.

If resealing of potheads is required, it is advised that another recheck be made a year later. Otherwise, routine tests of cables need to be conducted only at intervals of about 5 years.

POWER-FACTOR TESTS

50. Application.- The power factor of an insulation is a measure of its dielectric power loss, and is not a measure of its dielectric voltage strength. The power-factor method is used primarily for testing the insulation condition of high-voltage bushings, cables, transformer windings, and transformer oil.

51. Theory of Power-Factor Measurement.- Unless otherwise stated, the terms "power factor" and dissipation factor" are used interchangeably in this discussion. Insulation power factor is the cosine of the angle between the applied voltage and current, and is obtained from measurement of watts, volts, and amperes, usually with a specialized power-factor test set. Dissipation factor is the cotangent of the angle between the applied voltage and current, and is usually obtained from a direct reading of a dial on a capacitance bridge. The values of power factor and dissipation factor are within 1 percent of being equal between 0 and 8 percent power factor, which covers most test values, but diverge as the values increase. Thus, both have equal significance as a measure of insulation value. It should be remembered that power factor or dissipation factor is a measure of insulation dielectric power loss, and is not a direct measure of dielectric strength. Conditions which cause abnormal power loss usually also cause reduction of dielectric strength. The power-factor values are independent of insulation area or thickness, and increase only with an increase of contamination by moisture, other foreign matter, or ionization, and therefore, are easier to interpret than insulation resistance values, which additionally depend on insulation area and thickness.

52. Significance of Dielectric Losses.- An increase in dielectric loss may accelerate insulation deterioration because of the increased heating, but more commonly an increase of dielectric loss is evidence of other deterioration which also affects dielectric strength. As in insulation resistance tests, the change in periodic test readings is more indicative of insulation deterioration than is absolute magnitude of readings. Insulation power factor increases directly with temperature, and may be as much as 10 times as high at 80 EC as at 20 EC. Therefore, temperature corrections to a base temperature must be made, usually to 20 EC for a meaningful comparison between values taken at different temperatures. See table E for Temperature Correction Factors of Power Transformers.

53. Generator Windings. - The power-factor-voltage characteristic (power- factor tip-up) is used primarily as a quality-control criterion in manufacturing. It is sometimes used as an acceptance test on individual coils. Power-factor tip-up has been used as a maintenance test because a change in the tip-up value over a period of time is an indication of change of condition of the coil insulation. The sensitivity of the power-factor tip-up test decreases with the length of coil included in the measurement. Therefore, one coil, or coil side, is the preferred test unit, although coils are sometimes tested in groups of two or three to expedite testing. Refer to IEEE Standard No. 286, July 1975, "IEEE Recommended Practice for Measurement of Power-Factor Tip-Up of Rotating Machinery Stator Coil Insulation," for a description of the power-factor tip-up test.

54. Transformer windings.- The power-factor method is particularly recommended for detecting moisture and other loss-producing contaminants in transformer windings. Experience has shown that the power-factor test is more revealing than the insulation-resistance test when there is a high-loss dielectric in series (as in a transformer winding surrounded by oil), and is less influenced by surface leakage components. Users have found many cases where high-power-factor readings indicated moisture in the windings, although the oil dielectric tests were up to standard. The power factor was brought back to normal by a dry-out run. Time-saving techniques have been developed whereby the losses in transformer bushings or windings can be segregated without disconnecting the windings from the bushings.

All windings not at test potential should be grounded. Each winding should be measured to all other windings and to ground, and also all of the windings measured together to ground. All possible winding combinations should be tried. Refer to IEEE Standard No. 262, 1973, for more information concerning this test technique.

55. Cables.- The power-factor test on cables is usually an insensitive indication of deterioration except on very short lengths. Cables often require more charging current than the power-factor test set can supply. However, "hot-collar" power-factor tests on cable potheads are useful, sensitive indications of moisture and voids or other substandard conditions in the potheads. Abnormally high values of current and power indicate the presence of moisture and abnormally low values indicate a void or the absence of filling compound or oil. Hot-collar tests do not require a high-capacity test set.

56. Test Equipment.- Most of the power-factor testing done in the United States and Canada has been by means of equipment supplied by the Doble Engineering Co. The Doble test sets consist of a completely shielded, high-voltage, 60-Hz power supply which applies up to 10 kV to the equipment being tested. Readings are taken of volts, milliamperes, and watts, from which power factor is determined. The equipment is suitable for use near high-voltage circuits without interference from induced voltages. The capacitance-test bridge, a much simpler and less expensive tester, is available on some Bureau projects. It applies about 80 volts to the equipment being tested. Capacitance and dissipation factor are read directly on dials when the bridge is balanced. This equipment is not sufficiently shielded against induced voltages to be suitable for use near high-voltage circuits, thus limiting its usefulness for field maintenance work. Although shields of sheet metal or screen can be used to enclose the equipment bushings during tests, this method is not desirable because of the danger in handling these large metal parts near energized equipment.

IONIZATION TESTS

57. Application.- The ionization test is used primarily for detecting ionization (corona discharge) and slot discharge in generator windings. Both ionization and slot discharge may cause deterioration of insulation. Ionization generally occurs in voids inside the insulation within the ground shield section of the coil.

Some internal ionization is present in most higher voltage stator insulation. If it is intense enough, it produces destruction of the binder and other organic components by the chemical effects of the ozone and oxides of nitrogen generated by the discharge (plus moisture) and eventually by direct electronic bombardment. Destruction is often aggravated finally by mechanical vibration of the conductors where the insulation has been softened by the other effects.

Slot discharge is a capacitance discharge and occurs across poor contact points between the coil surface shielding and the stator iron. Deterioration is from the destructive effect of this relatively concentrated discharge. Coils which fit loosely in the slots may be subjected to this trouble.

Test apparatus for corona detection requires much higher sensitivity than detection of slot discharge. It is still of specialized category and beyond the scope of this chapter.

58. Test Methods for Slot Discharge.- A method used for detecting slot discharge in ac generator windings consists of energizing the winding from a high-potential ac test set at voltages of approximately 50 to 125 percent of normal rated machine voltage or running the unit self excited and isolated from the system and observing on an oscilloscope the resulting induced potentials from slot discharges. The detecting apparatus is essentially a band pass filter passing a band of frequencies between 1,000 and 2,000 Hz to an oscilloscope. The detecting apparatus is coupled through a condenser to the terminal of the winding being tested or to a probe which is placed ill contact with the stator coil shielding. With the oscilloscope sweep set for one-half the applied frequency, the characteristic hash indication appears at two or four places along the sweep since the discharge occurs at particular parts of the voltage cycle. Because the detector cannot distinguish between hash originating in the winding and that originating in the power source, it is essential that the stator winding be energized from a good high-potential test set or a transformer operated well below its rated voltage. Voltage of about 50 percent, normal or below which no corona occurs, is first applied as a calibration point or base. The voltage is gradually raised until there is distinct change in the hash on the oscilloscope screen. This is the point where slot discharge is considered to begin. A winding properly protected from slot discharge should not produce hash at voltages below approximately 125 percent of normal. Experience and special calibration apparatus are necessary in order to properly interpret the results.

HIGH-POTENTIAL, AC PROOF TESTS

59. Application.- High-potential, ac tests to determine the condition of insulation are used primarily on new equipment at the factory, after erection in the field, or after rewinding in the field. The only positive means of determining what voltage an insulation will withstand is to apply voltage across it until failure occurs. However, this test may be destructive and the full test voltage is not recommended for application to equipment that has been in service. In deteriorated areas, the deterioration may be advanced by such tests even though failure may not occur during the test. Thus, an unknown part of the useful life may be spent. Reduced levels are sometimes permissible as "suitability for service" tests.

In any situation where a contract is involved, have the contractor's representative present for the tests or obtain written permission from the contractor for the Government to perform the tests.

If the ac proof test is to follow a high-voltage, dc test, the precaution of allowing adequate time, about 2 hours, for the absorption charge to dissipate before application of the ac over-potential test must be observed.

The procedure to be used on all ac proof tests of stator windings is as follows:

a. Break the 'Y" connection at the generator neutral, separating the three phases from each other and the powerhouse ground.

b. Disconnect all potential transformers and surge-protection equipment, such as lightning arrestors, capacitors, etc., from the generator terminal leads.

c. Ground both ends of the two phases which are not to be tested.

d. Connect both ends of the phase to be tested together with insulated wire and bring the insulated wire to the vicinity of, but not connected to, the test set.

e. If the test set being used does not have a built-in potential transformer for high-side metering, a separate potential transformer should be used to provide high-side metering.

f. Check accuracy of test set indicating voltmeter by comparing it to a calibrated voltmeter connected to the high-side potential transformer.

g. Adjust spherical gap oil test set to flash over at the specified test voltage, as calculated from charts. Then energize the test set without connecting it to the stator-winding phase to be tested. Raise voltage until gap flashes over, noting reading of test-set voltmeter to verify reasonable agreement and that voltmeter scale and potential-trans-former ratio are correct. Some tests sets are not equipped with a spherical gap, so a separate spherical-gap voltmeter should be used in conjunction with these sets.

h. With the test set deenergized, adjust the spherical gap to flash over slightly above the required test voltage. This will provide protection in the event of a test set malfunction resulting in higher voltage.

i. Connect the test set to both ends of the stator winding phase to be tested.

j. Energize the test set and raise the voltage smoothly until the mark on the test set indicating voltmeter is reached. The rate of rise should be such that the test voltage is achieved within 1 minute. Care should be exercised so as not to overshoot the test voltage. This voltage should be held for 60 seconds. The voltage should then be lowered smoothly to zero in approximately 1 minute.

k. Repeat steps 3, 4, 9, and 10 for the other phases to be tested.

60. Induced-Potential and Impulse Tests.- Factory tests on new transformers or regulators may include (a) 120- to 400-Hz induced-potential test and (b) reduced full-wave, chopped-wave, or full-wave impulse tests. These tests require special equipment and are not performed in the field, and will not be covered in this bulletin. The standard 60-Hz high-potential test, however, are simple to perform and require only a transformer of suitable voltage and capacity, with current limiting equipment and means for controlling and measuring the output voltage.

61. Voltage Values for AC Tests.-High-potential, ac tests, if used in the field, should be performed in accordance with Standard Techniques for High- Voltage Testing, IEEE Standard No. 4, 1978, or its latest revision. The test voltage values to use are shown in table F. All values in the table apply to 1 -minute application of 60-Hz test voltage applied between winding and ground, for clean, dry windings at a temperature not below room temperature and preferably not above 40 EC. The data given in table F under "Periodic field tests on equipment in service" are manufacturers' recommendations, as no ANSI standards have been adopted for this purpose. The high-potential test voltage values for use on power cable vary with a number of conditions and should be obtained from the current cable standards. The capacity of the high-potential test set (in kilovolt amperes required to test generator stators of various ratings) is shown in figure 19.

HIGH-POTENTIAL, DC PROOF TESTS

62. General.- High-potential, dc proof tests are ordinarily limited to 1- minute duration unless otherwise specified. It is a pass or fail type of test and no particular significance is placed upon current values. The principal advantage over the more common ac proof test is the smaller, simpler test apparatus.

63. Voltages for High-Potential DC Tests on Machines.- High-potential, dc proof tests for generators, if used in the field, should be performed in accordance with Standard Techniques for High-Voltage Testing, IEEE Standard No. 4, 1978, or its latest revision. The test voltage values should be approximately 1.7 times the ac, rms, voltage values given in table F. ANSI C50.10 (1977) provides that for ac machinery windings rated 6,000 volts and above, and when agreed upon by the manufacturer and the user, the test voltage may be a direct voltage of 1.7 times the ac, rms, test voltage. IEEE No. 95 (1977) recommends that a ratio of 1.7 be used for maintenance overvoltage tests.

64. Cables.- High-potential, dc proof tests are preferred by manufacturers for tests of cables. Duration of the test is less critical than with ac proof tests. For certain tests, a duration of 5 to 15 minutes is recognized by the IPCEA (Insulated Power Cable Engineers Association). For maintenance tests of cables, it will ordinarily be advantageous to use the test technique described in paragraphs 46 to 49, inclusive.

TURN-TO-TURN TESTING

65. General.- A turn-to-turn fault in a rotating machine generally results in localized overheating due to the very high current developed within the shorted turn. Eventually the ground insulation is destroyed by the melting of the copper and a phase-to-phase or phase-to-ground fault occurs. Testing for turn-to-turn faults is generally not performed as a routine maintenance test but is used:

a. To establish the quality of the windings in new machines for warranty purposes; and

b. To establish the quality of an old winding for reliability purposes.

For more information on turn-to-turn fault testing, refer to IEEE Standard No. 522, 1977, "IEEE Guide for Testing Turn-to-turn Insulation on Form-wound Stator Coils for Alternating-current Rotating Electric Machines-For Trial Use."

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TABLES

Table A

MAXIMUM D-C TEST VOLTAGES FOR MACHINES

A-c voltage rating of winding (kilovolts)	Old insulation over 5 years old (kilovolts)		New insulation* less than 5 years old (kilovolts)
	100%	85% [1]	
2.3 - 2.5	5	4.25	6
4.16	10	8.5	12
6.9 - 7.2	15	12.75	20
11 - 13.8	20 - 25	17 - 21.25	30

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[1] Normal limit for ramp testing. See paragraph 42 for more information on maximum test voltages for machines.

* Any winding showing visible signs of deterioration should be considered old insulation for test purposes regardless of age.

PO&M-155
(OCT 55)
BUREAU OF RECLAMATION

Table B

< ILLUSTRATIVE EXAMPLE >

HIGH VOLTAGE D.C. INSULATION TEST RECORD

PROJECT__________________ PLANT______________________ UNIT NO.____________
WINDING TEMP.__________°C DATE OF TEST____________________
EQUIPMENT INCLUDED IN TEST____
____
____

TIME	KV.	MICRO-AMPS	MEG-OHMS	TIME	KV.	MICRO-AMPS	MEG-OHMS	TIME	KV.	MICRO-AMPS	MEG-OHMS
* Phase A				* Phase B				* Phase C			
0 Min	5.0	-	-								
0-1/4		23.0			Repeat test for				Repeat test for		
0-1/2		16.5									
0-3/4		10.0			Phase B				Phase C		
1-0		8.5									
1-1/2		6.5									
2		5.3									
3		4.0									
5		2.9									
8		2.5									
10		2.3	2,173								
Polarization Index = 3.70											
10+	9.0	-	-								
11		35.0									
12		10.0									
14		5.5									
16-1/2		4.2	2,142								
16-1/2+	13.0	-	-								
17-1/2		24.0									
18		13.3									
20		7.0									
21-3/4		5.5	2,364								
21-3/4+	15.0	-	-								
22-1/2		31.8									
23		17.0									
24		9.3									
25		7.8	1,923								
25+	17.0	-	-								
26		22.0									
27		11.5									
28		9.5	1,789								
28+	19.0	-	-								
28-1/2		24.5									
29		15.5									
30		10.6									
30-1/2		9.6	1,979		(Continue on another page if necessary)						

* Identify phase, coil No. etc. at head of column

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Table B--Continued

HIGH VOLTAGE D.C. INSULATION TEST RECORD

PROJECT________________ PLANT________________ UNIT NO.__________
WINDING TEMP.__________°C DATE OF TEST________________
EQUIPMENT INCLUDED IN TEST____

TIME	KV.	MICRO-AMPS	MEG-OHMS	TIME	KV.	MICRO-AMPS	MEG-OHMS	TIME	KV.	MICRO-AMPS	MEG-OHMS
* Phase A				* Phase B				* Phase C			
30-1/2+	21.0	-	-								
31-1/2		21.0									
32		15.0									
33		10.6	1,981								
33+	22.0	-	-								
33-3/4		25.5									
34		19.5									
34-1/2		13.5	1,629								
34-1/2+	23.0	-	-								
35		43.5									
35-1/2		30.1									
36		14.6	1,575								
Discharge curve				(Only one phase needed)							
0 =	37 Min	-									
0-1/4		260									
0-1/2		150									
0-3/4		110									
1-0		87.5									
1-1/2		62									
2-0		43.5									
3-0		30.9									
5-0		19.7									
8-0		12.5									
10-0		10.1									
Polarization	Index = 8.66										

* Identify phase, coil No. etc. at head of column

Table C

VOLTAGE/TIME SCHEDULE FOR HIGH VOLTAGE D-C TESTS OF STATOR INSULATION

Absorption exponent -0.8

All voltage changes with no time delay. Time tabulated are time form start of test to final reading for respective voltage steps. Voltage is then raised to next step. The times scheduled under column A are normally used. To save time, the first step may be increased as shown in Columns B, C, and D.

Dashed line indicates usual test limit for old insulation (5 years or more).

13.8-kV Insulation
Minutes from start of test

kV	A	B	C	D
5	10	-	-	-
9	16-1/2	10	-	-
13	21-3/4	10	-	–
15	25	18-3/4	13-1/2	10
17	28	21-3/4	16-1/2	13-1/4
19	30-1/2	24-1/4	19-1/4	16
21	33	26-3/4	21-3/4	18-1/2
22	34-1/2	28-1/4	23-1/4	20-1/4
23	36	29-3/4	24-3/4	21-3/4
24	37-1/4	31	26	23-1/4
25	38-1/2	32-1/4	27-1/4	24-1/2
– – –	– – –	– – –	– – –	– – –
26	39-3/4	33-1/2	28-1/2	25-3/4
27	41	34-3/4	29-3/4	27
28	42-1/4	36	31	28-1/4
29	43-1/4	37	32-1/4	29-1/2
30	44-1/2	38-1/4	33-1/4	30-1/2

6.9-kV Insulation
Minutes from start of test

kV	A	B	C	D
3	10	-	-	-
5	16-1/4	10	-	-
7	21-1/4	15-1/4	10	-
9	25-1/4	19-1/2	14-1/2	10
10	28-1/4	22-1/4	17-1/4	13
11	30-3/4	24-3/4	19-3/4	15-1/2
12	33	27	22	18
12-1/2	34-1/2	28-1/8	23-1/2	19-1/2
13	35-3/4	29-3/4	24-3/4	20-3/4
13-1/2	37	31	26	22
14	38-1/4	32-1/4	27-1/4	23-1/4
14-1/2	30-1/2	33-1/2	28-1/2	24-1/2
15	40-1/2	34-1/2	29-1/2	25-3/4
– – –	– – –	– – –	– – –	– – –

4.16-kV Insulation
Minutes from start of test

kV	A	B	C
2	10	-	-
4	47	10	-
6	22-1/2	15-3/4	10
7	26	19-1/4	13-3/4
8	29	22-1/4	16-3/4
8-1/2	30-3/4	24-1/4	18-3/4
9	32-1/2	26	20-1/2
9-1/2	34-1/4	27-1/2	20-1/2
10	35-3/4	29	23-3/4
– – –	– – –	– – –	– – –
10-1/2	37-1/4	30-1/2	25-1/4
11	38-3/4	32	26-3/4
11-1/2	40	33-1/4	28
12	41-1/4	34-1/4	29-1/4

2.3-kV Insulation
Minutes from start of test

kV	A	B	C
1	10	-	-
2	17	10	-
3	22-1/2	15-3/4	10
3-1/2	26	19-1/4	13-3/4
4	29	22-1/4	16-3/4
4-1/4	20-3/4	24-1/4	18-3/4
4-1/2	32-1/2	26	20-1/2
4-3/4	34-1/4	27-1/2	22-1/4
5	35-3/4	29	23-3/4
– – –	– – –	– – –	– – –
5-1/4	37-1/4	30-1/2	25-1/4
5-1/2	38-3/4	32	26-3/4
5-3/4	40	33-1/4	28
6	41-1/4	34-1/2	29-1/4

Table D. - Cable d-c test voltage guide
Part 1

Rubber and rubber-like insulated cable up to 28 kV
IPCEA Std. S-19-81, Fifth Edition, June 1976

Maximum rated circuit voltage (kV)	Conductor size (AWG or - kcmil)	Conductor insulation thickness Mils	mm	Insulation grade			
				Other than ozone-resisting d-c/a-c ratio = 3.0		Ozone-resisting d-c/a-c ratio = 3.0	
				Maximum conductor to ground d-c test values in kV*			
				Grounded neutral service	Ungrounded neutral service	Grounded neutral service	Grounded neutral service
0.6	18-16	30	0.76	-	-	-	-
	14-9	45	1.14	5.4	5.4	8.1	8.1
	8-2	60	1.52	6.3	6.3	10.8	10.8
	1-4/0	80	2.03	7.2	7.2	13.5	13.5
	225-500	95	2.41	9.0	9.0	15.3	15.3
	525-1000	110	2.79	10.8	10.8	18.0	18.0
	1000+	125	3.18	12.6	12.6	20.7	20.7
1.0	14-8	60	1.52	9.0	9.0	10.8	10.8
	7-2	80	2.03	10.8	10.8	13.5	13.5
	1-4/0	95	2.41	13.5	13.5	15.3	15.3
	225-500	110	2.79	16.2	16.2	18.0	18.0
	525-1000	125	3.18	18.0	18.0	20.7	20.7
	1000+	140	3.56	19.8	19.8	20.7	20.7
2.0	14-8	80	2.03	10.8	10.8	13.5	13.5
	7-2	95	2.41	13.5	13.5	15.3	15.3
	1-4/0	110	2.79	16.2	16.2	18.0	18.0
	225-500	125	3.18	18.0	18.0	20.7	20.7
	500+	140	3.56	18.0	18.0	20.7	20.7
5.0	8-4/0	155	3.94	21.0**	21.0**	21.0**	21.0**
	225-1000	170	4.32	21.0**	21.0**	21.0**	21.0**
	1000+	190	4.83	21.0**	21.0**	21.0**	21.0**
8.0	6 and over	190	4.83	-	-	27.0	-
	6 and over	250	6.35	-	-	-	27.0
15.0	2 and over	295	7.49	-	-	42.0	-
	1 and over	420	10.67	-	-	-	48.0
25.0	1 and over	455	11.56	-	-	60.0	-
28.0	1 and over	500	12.70	-	-	63.0	-

* All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

** Not applicable to shielded cables, armored cables are 80 percent test value and metallic sheathed cables are 90 percent test value.

Table D (Continued)

RECOMMENDED THICKNESS OF VARNISHED CLOTH INSULATED CABLES NEMA WC 4-1976, IPCEA STD S-65-375

Key for Part 2

Maximum rated circuit voltage (kV)	Conductor size (AWG or MCM)	Single and shielded conductor insulation thickness				Unshielded multiple conductor insulation thickness not including belt			
		Grounded neutral		Ungrounded neutral		Grounded neutral		Ungrounded neutral	
		mils	mm	mils	mm	mils	mm	mils	mm
0.6	14-8	45	1.14	45	1.14	45	1.14	45	1.14
	7-2	60	1.52	60	1.52	60	1.52	60	1.52
	1-4/0	80	2.03	80	2.03	80	2.03	80	2.03
	213-500	95	2.41	95	2.41	95	2.41	95	2.41
	501-1000	110	2.79	110	2.79	95	2.41	95	2.41
	1000+	125	3.18	125	3.18	110	2.79	110	2.79
1.0	14-2	60	1.52	60	1.52	60	1.52	60	1.52
	1-4/0	80	2.03	80	2.03	80	2.03	80	2.03
	213-500	95	2.41	95	2.41	95	2.41	95	2.41
	501-1000	110	2.79	110	2.79	95	2.41	95	2.41
	1000+	125	3.18	125	3.18	110	2.79	110	2.79
3.0	10-2	—	----	—	----	80	2.03	80	2.03
	10-4/0	95	2.41	95	2.41	—	—	—	—
	1-500	—	---	—	---	95	2.41	95	2.41
	213-1000	110	2.79	110	2.79	—	—	—	—
	501-1000	—	---	—	---	95	2.41	95	2.41
	1000+	125	3.18	125	3.18	110	2.79	110	2.79
5.0	8-4/0	140	3.56	140	3.56	95	2.41	95	2.41
	213+	155	3.94	155	3.94	110	2.79	110	2.79
8.0	6+	170	4.32	190	4.83	110	2.79	110	2.79
10.0	6+	190	4.83	235	5.97				
12.0	6+	220	5.59	250	6.35				
15.0	6+	250	6.35	330	8.38				
21.0	2+	345	8.76	455	11.56				
23.0	2+	375	9.53						
28.0	1+	455	11.56						

Table D. - Cable d-c test voltage guide (continued)
Part 2

Varnished Cloth Insulated Cable
NEMA WC 4-1976, IPCEA Std. S-65-375

d-c/a-c ratio = 2

Conductor size (AWG or kcmil)	Conductor insulation thickness		Type of cable		
	mils	mm	Single conductor, shielded multiple conductor and nonbelted**, nonshielded multiple conductor	VC belted multiple conductor cable, rated 5 kV and below 2 x 0.58 = 1.16	VC belted multiple conductor cable, rated above 5 kV 2 x 0.80 = 1.6
			Maximum conductor to sheath or ground d-c test values in kV*		
			Grounded and ungrounded neutral service	Grounded neutral service	Ungrounded neutral service
14-8	45	1.14	3.0	3.5	
14-7	60	1.52	4.2	4.9	
6-5	60	1.52	4.8	5.6	
4-2	60	1.52	6.0	7.0	
10-7	80	2.03	5.4	6.3	
6-5	80	2.03	6.0	7.0	
4-2	80	2.03	6.6	7.7	
1-4/0	95	2.41	7.2	8.4	
10-9	95	2.41	7.8	9.0	
8	95	2.41	7.8	9.0	12.5
7	95	2.41	8.4	9.7	13.4
6-5	95	2.41	9.0	10.4	14.4
4-2	95	2.41	9.6	11.1	15.4
1-4/0	95	2.41	10.2	11.8	16.3
213-1000	110	2.79	10.8	12.5	
8	110	2.79	10.8	12.5	
7	110	2.79	11.4	13.2	
6-5	110	2.79	12.0	13.9	19.2
4-2	110	2.79	12.6	14.6	20.2
1-4/0	110	2.79	13.2	15.3	21.1
213+	110	2.79	13.8	16.0	22.1

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*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

**Nonbelted or belted with material other than varnished cloth.

Table D.- Cable d-c test voltage guide (continued)
Part 2

Varnished Cloth Insulated Cable
NEMA WC 4-1976, IPCEA Std. S-65-375

d-c/a-c ratio = 2

Conductor size (AWG or kcmil)	Conductor insulation thickness mils	mm	Type of cable: Single conductor, shielded multiple conductor and non-belted**, nonshielded multiple conductor — Maximum conductor to sheath or groung d-c test values in kV* — Grounded and ungrounded neutral service
8	125	3.18	13.2
7	125	3.18	13.8
6-5	125	3.18	14.4
4-2	125	3.18	15.0
1-4/0	125	3.18	16.2
213+	125	3.18	16.8
8	140	3.56	16.2
7	140	3.56	16.8
6-5	140	3.56	17.4
4-2	140	3.56	18.0
1-4/0	140	3.56	18.6
213+	140	3.56	19.2
8	155	3.94	18.6
7	155	3.94	19.2
6-5	155	3.94	19.8
4-2	155	3.94	20.4
1-4/0	155	3.94	21.6
213+	155	3.94	22.2
6-5	170	4.32	22.2
4-2	170	4.32	22.8
1-4/0	170	4.32	23.4
213+	170	4.32	24.0
6-5	190	4.83	24.0
4-2	190	4.83	24.6
1-4/0	190	4.83	25.2
213+	190	4.83	26.4
6-5	205	5.21	26.4
4-2	205	5.21	27.0
1-4/0	205	5.21	27.6
213-500	205	5.21	28.2
501+	205	5.21	28.8
6-5	220	5.59	28.2
4-2	220	5.59	28.8
1-4/0	220	5.59	29.4
213+500	220	5.59	30.6
501+			31.2

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

**Nonbelted or belted with material other than varnished cloth.

Table D. - Cable d-c test voltage guide (continued)
Part 2

Varnished Cloth Insulated Cable
NEMA WC 4-1976, IPCEA Std. S-65-375

d-c/a-c ratio = 2

Conductor size (AWG or kcmil)	Conductor insulation thickness mils	mm	Type of cable: Single conductor, shielded multiple conductor and non-belted**, nonshielded multiple conductor — Maximum conductor to sheath or groung d-c test values in kV* — Grounded and ungrounded neutral service
6-5	235	5.97	30.0
4-2	235	5.97	31.2
1-4/0	235	5.97	31.8
213-500	235	5.97	32.4
501+	235	5.97	33.0
6-5	250	6.35	32.4
4-2	250	6.35	33.0
1-4/0	250	6.35	33.6
213-500	250	6.35	34.8
501+	250	6.35	35.4
6-5	330	8.38	45.0
4-2	330	8.38	45.6
1-4/0	330	8.38	46.2
213-500	330	8.38	46.8
501+	330	8.38	47.4
4-2	345	8.76	48.6
1-4/0	345	8.76	49.2
213-500	345	8.76	49.8
501+	345	8.76	50.4
2	375	9.53	54.0
1-4/0	375	9.53	54.6
213-500	375	9.53	55.2
501+	375	9.53	55.8
2	455	11.56	64.2
1-4/0	455	11.56	64.8
213-500	455	11.56	66.0
501*	455	11.56	66.6

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

**Nonbelted or belted with material other than varnished cloth.

NOTE: CONCERNING PAPER INSULATED CABLE

Table D. - Parts 3 to 7

Use multiplying factors (F) for cables with small conductors as follows:

Conductor size, AWG number	1	2	3	4	5	6
Factor F, stranded conductor	1.00	0.97	0.94	0.91	0.88	0.85

Table D. - Cable d-c test voltage guide - (continued)
Part 3

Solid-type Impregnated-paper Insulated Lead Covered Cable Specifications
AEIC loth Edition, April 1968

d-c/a-c ratio = 2.4 at 25 EC

Rated kV phase to phase Gr.	Rated kV phase to phase Ung.	Conductor size (AWG or kcmil)	Conductor insulation thickness mils	Conductor insulation thickness mm	Single conductor shielded and nonshielded*
1	1	6-1000	60	1.52	12.1F
		1001-2500	75	1.91	17.3
		2501-4000	90	2.29	22.4
2	2	6-1000	65	1.65	13.8
		1001-2500	80	2.03	19.0
		2501-4000	95	2.41	24.2
3	3	6-1000	75	1.91	17.3F
		1001-2500	90	2.29	22.4
		2501-4000	100	2.54	25.9
4	4	6-1000	85	2.16	20.8F
		1001-2500	95	2.41	24.2
		2501-4000	105	2.67	27.7
5	5	6-1000	90	2.29	22.4F
		1001-2500	100	2.54	25.9
		2501-4000	105	2.67	27.7
6	-	6-1000	100	2.54	25.9F
		1001-4000	105	2.67	27.7
7	-	6-4000	105	2.67	27.7F

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

Table D. -Cable d-c test voltage guide (continued)
Part 3

Solid-type Impregnated-paper Insulated Lead Covered Cable Specifications
AEIC 10th Edition, April 1968

d-c/a-c ratio = 2.4 at 25 EC

Rated kV phase to phase Gr.	Rated kV phase to phase Ung.	Conductor size (AWG or kcmil)	Conductor insulation thickness mils	Conductor insulation thickness mm	Single conductor shielded and nonshielded*
8	6	6-4	125	3.18	29.4F
		3-4000	110	2.79	29.4F
9	7	6-4	135	3.43	32.8F
		3-4000	120	3.05	32.8F
10	-	6-4	140	3.56	34.6F
		3-4000	125	3.18	34.6F
11	8	6-4	150	3.81	38.0F
		3-4000	135	3.43	38.0F
12	9	6-4	155	3.94	39.7F
		3-4000	140	3.56	39.7F
13	-	4-2	165	4.19	43.2F
		1-4000	150	3.81	43.2
14	10	4-2	170	4.32	44.9F
		1-4000	155	3.94	44.9
15	11	4-2	180	4.57	48.4F
		1-4000	165	4.19	48.4
16	12	4-2	185	4.70	50.1F
		1-4000	170	4.32	50.1
17	-	4-2	195	4.95	53.6F
		1-4000	180	4.57	53.6
18	13	2-1	200	5.08	55.3F
		1/0-4000	185	4.70	55.3
19	14	2-1	210	5.33	58.8F
		1/0-4000	195	4.95	58.8
20	15	2-1	215	5.46	60.5F
		1/0-4000	200	5.08	60.5
21	-	2-1/0	225	5.72	63.9F
		2/0-4000	210	5.33	63.9
22	16	2-1/0	230	5.84	65.7
		2/0-4000	215	5.46	65.7
23	17	2-1/0	240	6.10	69.1F
		2/0-4000	225	5.72	69.1
24	18	2-2/0	245	6.22	70.8F
		3/0-4000	230	5.84	70.8

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

Table D. - Cable d-c test voltage guide (continued)
Part 3

Solid-type Impregnated-paper Insulated Lead Covered
Cable Specifications
AEIC loth Edition, April 1968

d-c/a-c ratio = 2.4 at 25 EC

Rated kV phase to phase		Conductor size (AWG or kcmil)	Conductor insulation thickness		Single conductor shielded and nonshielded*
Gr.	Ung		mils	mm	
25	-	1-2/0	255	6.48	74.3
	26	3/0-4000	240	6.10	74.3
19		1-2/0	260	6.60	76.0
	27	3/0-4000	245	6.22	76.0
20		1-3/0	270	6.86	79.5
	28	4/0-4000	255	6.48	79.5
21		1/0-3/0	280	7.11	82.9
	29	4/0-4000	265	6.73	82.9
-		1/0-3/0	285	7.24	86.4
	30	4/0-4000	275	6.99	86.4
22		1/0-3/0	285	7.24	88.1
		4/0-4000	280	7.11	88.1
31	23	1/0-4000	290	7.37	91.6
32	24	1/0-4000	300	7.62	95.0
33	-	2/0-4000	310	7.75	98.5
34	25	2/0-4000	320	8.13	102.0

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

Table D. - Cable d-c test voltage guide (continued)
Part 4

Solid-type Impregnated-paper Insulated Lead Covered Cable Specifications
AEIC loth Edition, April 1968

d-c/a-c ratio = 2.4 at 25 EC

Rated kV phase to phase		Conductor size (AWG or kcmil) Round and sector	Conductor insulation thickness		Multiple conductor shielded*
Gr.	Ung.		mils	mm	
8	-	6-4 R	125	3.18	29.4F
		3-1000R	110	2.79	29.4F
		2/0-1000S	110	2.79	29.4
9	-	6-4 R	135	3.43	32.8F
		3-1000R	120	3.05	32.8F
		2/0-1000S	120	3.05	32.8
10	-	6-4 R	140	3.56	34.6F
		3-1000R	125	3.18	34.6F
		2/0-1000S	125	3.18	34.6
11	8	6-4 R	150	3.81	38.0F
		3-1000R	135	3.43	38.0F
		2/0-1000S	135	3.43	38.0
12	9	6-4 R	155	3.94	39.7F
		3-1000R	140	3.56	39.7F
		2/0-1000S	140	3.56	39.7
13	-	4-2 R	165	4.19	43.2F
		1-1000R	150	3.81	43.2
		2/0-1000S	150	3.81	43.2
14	10	4-2 R	170	4.32	44.9F
		1-1000R	155	3.94	44.9
		2/0-1000S	155	3.94	44.9
15	11	4-2 R	180	4.57	48.4F
		6-2 S	180	4.57	48.4
		1-1000R	165	4.19	48.4
		2/0-1000S	165	4.19	48.4
16	12	4-2 R	185	4.70	50.1F
		6-2 S	185	4.70	50.1
		1-1000R	170	4.32	50.1
		2/0-1000S	170	4.32	50.1
17	-	4-2 R	195	4.95	53.6F
		1-1000R	180	4.57	53.6
		2/0-1000S	180	4.47	53.6

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

Table D. - Cable d-c test voltage guide (continued)
Part 4

Solid-type Impregnated-paper Insulated Lead Covered
Cable Specifications
AEIC loth Edition, April 1968

d-c/a-c ratio = 2.4 at 25 EC

Rated kV phase to phase		Conductor size (AWG or kcmil) Round and sector	Conductor insulation thickness		Multiple conductor shielded*
Gr.	Ung.		mils	mm	
18	13	2-1 R	200	5.08	55.3F
		1/0-1000R	185	4.70	55.3
		2/0-1000S	185	4.70	55.3
19	14	2-1 R	210	5.33	58.8F
		1/0-1000R	195	4.95	58.8
		2/0-l000S	195	4.95	58.8
20	15	2-1 R	215	5.46	60.5F
		1/0-1000R	200	5.08	60.5
		2/0-1000S	200	5.08	60.5
21	-	2-1 R	225	5.72	63.9F
		2/0-1000R	210	5.33	63.9
		2/0-1000S	210	5.33	63.9
22	16	2-1/0 R	230	5.84	65.7F
		2/0-1000R	215	5.46	65.7
		2/0-1000S	215	5.46	65.7
23	17	2-1/0 R	240	6.10	69.1F
		2/0-1000R	225	5.72	69.1
		2/0-1000S	225	5.72	69.1
24	18	2-2/0 R	245	6.22	70.8F
		2/0	245	6.22	70.8
		3/0-1000R	230	5.84	70.8
		3/0-1000S	230	5.84	70.8
25	-	1-2/0 R	255	6.48	74.3
		2/0 S	255	6.48	74.3
		3/0-1000R	240	6.10	74.3
		3/0-1000S	240	6.10	74.3
17	19	1-2/0 R	260	6.60	76.0
		2/0 S	260	6.60	76.0
		3/0-1000R	245	6.22	76.0
		3/0-1000S	245	6.22	76.0

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

Table D. - Cable d-c test voltage guide (continued)
Part 4

Solid-type Impregnated-paper Insulated Lead Covered Cable Specifications
AEIC loth Edition, April 1968

d-c/a-c ratio = 2.4 at 25 EC

Rated kV phase to phase		Conductor size (AWG or kcmil) Round and sector	Conductor insulation thickness		Multiple conductor shielded*
Gr.	Ung.		mils	mm	
27	20	1-3/0 R	270	6.86	79.5
		2/0-3/0 S	270	6.85	79.5
		4/0-1000R	255	5.48	79.5
		4/0-1000S	255	6.48	79.5
28	21	1/0-3/0 R	280	7.11	82.9
		3/0 S	280	7.11	82.9
		4/0-1000R	265	6.73	82.9
		4/0-1000S	265	6.73	82.9
29	-	1/0-3/0 R	285	7.24	86.4
		3/0 S	285	7.24	86.4
		4/0-1000R	275	6.99	86.4
		4/0-1000S	275	6.99	86.4
30	22	1/0-3/0 R	285	7.24	88.1
		3/0 S	285	7.24	88.1
		4/0-1000R	280	7.11	88.1
		4/0-1000S	280	7.11	88.1
31	23	1/0-1000R	290	7.37	91.6
		3/0-1000S	290	7.37	91.6
32	24	1/0-1000R	300	7.62	95.0
		250-1000S	300	7.62	95.0
33	-	2/0-I000R	310	7.75	98.5
		250-1000S	310	7.75	98.5
34	25	2/0-IO00R	320	8.13	102.0
		250-1000R	320	8.13	102.0

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

Table D. - Cable d-c test voltage guide (continued)
Part 5

Solid-type Impregnated-paper Insulated Lead Covered
Cable Specifications
AEIC loth Edition, April 1968

d-c/a-c ratio = 2.4 at 25 EC

Rated kV phase to phase	Conductor size (AWG or kcmil) Round and sector	Conductor insulation thickness		Multiple conductor belted grounded and ungrounded neutral service*
		mils	mm	
1	6-500 R	55x35	1.40x0.89	10.4F
	2/0-500 S	55x35	1.40x0.89	10.4
	501-750	65x40	1.65x1.02	14.5
	751-1000	75x45	1.91x1.14	18.7
2	6-500 R	65x35	1.65x0.89	14.5F
	2/0-500 S	65x35	1.65x0.89	14.5
	501-750	70x40	1.78x1.02	16.6
	751-1000	75x45	1.91x1.14	18.7
3	6-500 R	70x40	1.78x1.02	16.6F
	2/0-500 S	70x40	1.78x1.02	16.6
	501-750	75x40	1.91x1.02	18.7
	751-1000	80x45	2.03x1.14	20.7
4	6-750 R	80x40	2.03x1.02	20.7F
	2/0-750 S	80x40	2.03x1.02	20.7
	751-1000	80x45	2.03x1.14	20.7
5	6-1000R	85x45	2.16x1.14	22.9F
	2/0-1000S	85x45	2.16x1.14	22.9

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

Table D. - Cable d-c test voltage guide (continued)
Part 6

Solid-type Impregnated-paper Insulated Lead Covered Cable Specifications
AEIC l0th Edition, April 1968

d-c/a-c ratio =2.4 at 25 EC

Rated kV phase to phase	Conductor size (AWG or kcmil) Round and sector	Conductor insulation thickness		Multiple conductor belted grounded and ungrounded neutral service*
		mils	mm	
6	6-1000R	90x50	2.29xl.27	24.9F
	2/0-1000S	90x50	2.29xl.27	24.9
7	6-1000R	100x50	2.54xl.27	29.1F
	2/0-1000S	100x50	2.54xl.27	29.1
8	6-1000R	105x55	2.67xl.40	31.3F
	2/0-1000S	105x55	2.67xl.40	31.3
9	6-1 R	130x55	3.30xl.40	35.3F
	1/0-1000R	115x55	2.92xl.40	35.3
	2/0-1000S	115x55	2.92xl.40	35.3
10	4-1 R	135x60	3.43xl.52	37.4F
	1/0-1000R	120x60	3.05xl.52	37.4
	3/0-1000S	120x60	3.05xl.52	37.4
11	4-1 R	140x65	3.56xl.65	39.5F
	1/0-1000R	125x65	3.18xl.65	39.5
	3/0-1000S	125×65	3.18xl.65	39.5
12	4-1 R	150x65	3.81xl.65	43.6F
	1/0-1000R	135x65	3.43x!.65	43.6
	3/0-1000S	135x65	3.43xl.65	43.6
13	4-1 R	155x70	3.94xl.78	45 .SF
	1/0-1000R	140x70	3.56xl.78	45.8
	4/0-1000S	140x70	3.56xl.78	45.8
14	4-1 R	165x70	4.19xl.78	49.SF
	1/0-1000R	150x70	3.81xl.78	49.8
	4/0-1000S	150x70	3.81xl.78	49.8
15	4-1 R	170x75	4.32xl.91	52.0F
	1/0-1000R	155x75	3.94xl.91	52.0
	4/0-1000S	155x75	3.94xl.91	52.0

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

Table D. - Cable d-c test voltage guide (continued)
Part 7

Solid-type Impregnated-paper Insulated Lead Covered Cable Specifications
AEIC I0th Edition, April 1968

d-c/a-c ratio =2.4 at 25 EC

Rated kV phase to phase	Conductor size (AWG or kcmil) Round and sector	Conductor insulation thickness		Multiple conductor belted grounded and ungrounded neutral service*
		mils	mm	
6	6-1000R	90x100	2.29x2.54	34.6F
	2/0-1000S	90x100	2.29x2.54	34.6
7	6-1000R	100x100	2.54x2.54	40.3F
	2/0-1000S	100x100	2.54x2.54	40.3
8	6-1000R	105x110	2.67x2.79	43.2F
	2/0-1000S	105x110	2.67x2.79	43.2
9	6-1 R	130x110	3.30x2.79	49.0F
	1/0-1000R	115x110	2.92x2.79	49.0
	2/0-1000S	115x110	2.92x2.79	49.0
10	4-1 R	135x120	3.43x3.05	51.8F
	1/0-1000R	120x120	3.05x3.05	51.8
	3/0-1000S	120x120	3.05x3.05	51.8
11	4-1 R	140x130	3.56x3.30	54.7F
	1/0-1000R	125x130	3.18x3.30	54.7
	3/0-1000S	125x130	3.18x3.30	54.7
12	4-1 R	150x130	3.81x3.30	60.5F
	1/0-1000R	135x130	3.43x3.30	60.5
	3/0-1000S	135x130	3.43x3.30	60.5
13	4-1 R	155x140	3.94x3.56	63.3F
	1/0-1000R	140x140	3.56x3.56	63.3
	4/0-1000S	140x140	3.56x3.56	63.3
14	4-1 R	165x140	4.19x3.56	69.1F
	1/0-1000R	150x140	3.81x3.56	69.1
	4/0-1000S	150x140	3.81x3.56	69.1
15	4-1 R	170x150	4.32x3.81	72.0F
	1/0-1000R	155x150	3.94x3.81	72.0
	4/0-1000S	155x150	3.94x3.81	72.0

*All test values rounded off to 1 decimal place, and voltages are 60 percent of factory test.

Table E. - Temperature correction factors for the power factor of power transformer windings*

$$F_{P20} = \frac{F_{PT}}{K}$$

where:

F_{P20} = power factor corrected to 20 EC
F_{PT} = power factor measured at T EC
T = test temperature
K = correction factor from table

Test temperature T ^{O}C	Correction factor K
10	0.80
15	0.90
20	1.00
25	1.12
30	1.25
35	1.40
40	1.55
45	1.75
5O	1.95
55	2.18
60	2.42
65	2.70
70	3.00

* From IEEE Standard No. 262, 1973.

Table F. - ANSI standard test voltages for 60-hertz, 1-minute, high-potential tests

Equipment	Factory test on new equipment or on equipment completely assembled in field	Test on new equipment after installation having previously passed factory test	Periodic field test on equipment in service
Synchronous machines - ANSI Standard C50.10-1977			
A-C generator or motor (see exceptions below)	1000 + 2 x rated voltage	85% of factory test for hydraulic turbine generators, reversible generator/motor units, and synchronous condensers rated 10 000 kVA and above and more than 5000 V	125 to 150% of rated line to line voltage
A-C generator, field and armature windings, single phase, polyphase, less than 250 watts and not exceeding 250 volts	1000 volts	75% of factory test	
A-C generator field up to and including 500 volts	10 x exciter voltage but not less than 1500 volts	75% of factory test	1000 volts for 125-volt field 1500 volts for 250-volt field
A-C generator field over 500 volts	4000 volts + 2 x rated excitation voltage	75% of factory test	
Synchronous motor field - shorted or connected through exciter for starting	10 x exciter voltage but not less than 2500 volts or more than 5000 volts	75% of factory test	1500 volts

Table F. - ANSI standard test voltages for 60-hertz, 1-minute, high-potential tests - Continued

Equipment	Factory test on new equipment or on equipment completely assembled in field	Test on new equipment after installation having previously passed factory test	Periodic field test on equipment in service
Synchronous machines - ANSI Standard C50.10-1977			
Synchronous motor field - shorted through resistor for starting	2 x rms voltage drop across resistor but not less than 2500 volts	75% of factory test	1500 volts
Synchronous motor field - open circuited, sectionalized	1-1/2 x maximum rms terminal voltage but not less than 2500 or 10 x rated excitation voltage per section, whichever is larger	75% of factory test	
Synchronous motor field - field open-circuited and connected in series	1-1/2 x maximum rms terminal shorting voltage, but not less than 2500 nor less than 10 x rated excitation voltage, whichever is larger	75% of factory test	
Synchronous motor armature or field windings for connection to 35-volt circuits or less	500 volts	75% of factory test	
Induction machines - ANSI/NEMA Standard MG 1 - 1978			
Induction machines rated 1/2 hp and larger (see exceptions below)	1000 + 2 x rated voltage	75% of factory test	

Table F. - ANSI standard test voltages for 60-hertz, 1-minute, high-potential tests - Continued

Equipment	Factory test on new equipment or on equipment completely assembled in field	Test on new equipment after installation having previously passed factory test	Periodic field test on equipment in service
Induction machines - ANSI/NEMA Standard MG 1 - 1978 - Continued			
Induction armatures or rotors not connected to the line, rated 1/2 hp and larger	1000 volts	75% of factory test	
Induction machines rated less than 1/2 hp and not exceeding 250 volts	1000 volts	75% of factory test	
Universal motors not exceeding 250 volts (see exceptions below)	1000 volts	75% of factory test	
Secondary winding of induction motors, wound rotor, 1/2 hp and larger	1000 + 2 x maximum voltage induced between slip rings on open circuit at standstill	75% of factory test	
Secondary windings of reversing motors	1000 + 4 x maximum voltage induced between slip rings on open circuit at standstill	75% of factory test	
D-C Machines - ANSI/NEMA Standard MG 1 - 1978			
D-C generator of 250 watts or more output (see exceptions below)	1000 + 2 x rated voltage		
D-C generator of less than 250 watts output and not exceeding 250 volts	1000 volts		

Table F. - ANSI standard test voltages for 60-hertz, 1-minute, high-potential tests - Continued

Equipment	Factory test on new equipment or on equipment completely assembled in field	Test on new equipment after installation having previously passed factory test	Periodic field test on equipment in service
D-C Machines - ANSI/NEMA Standard MG 1 - 1978 - Continued			
D-C generators for use on circuits of 35 volts or less	500 volts	75% of factory test	
D-C motors rated 1/2 hp and larger (see exceptions below)	1000 + 2 x rated voltage	75% of factory test	
D-C motors rated less than 1/2 hp and not exceeding 240 volts	1000 volts	75% of factory test	
D-C motors rated less than 1/2 hp and above 240 volts	1000 + 2 x rated voltage	75% of factory test	
Exciters for sunchronous machines - ANSI/NEMA Standard MG 1 - 1978			
Brushless exciter, rated excitation voltage 350 volts d-c or less	10 x rated voltage, minimum of 1500 volts and maximum of 3500 volts	75% of factory test	
Brushless exciter, rated excitation voltage above 350 volts d-c	2800 volts + 2 x rated excitation voltage	75% of factory test	
Exciters with a-c excited stators	1000 volts + 2 x rated stator voltage	75% of factory test	
Transformers, regulators, and reactors			
See ANSI Standard C57.12.90 - 1973			

FIGURES

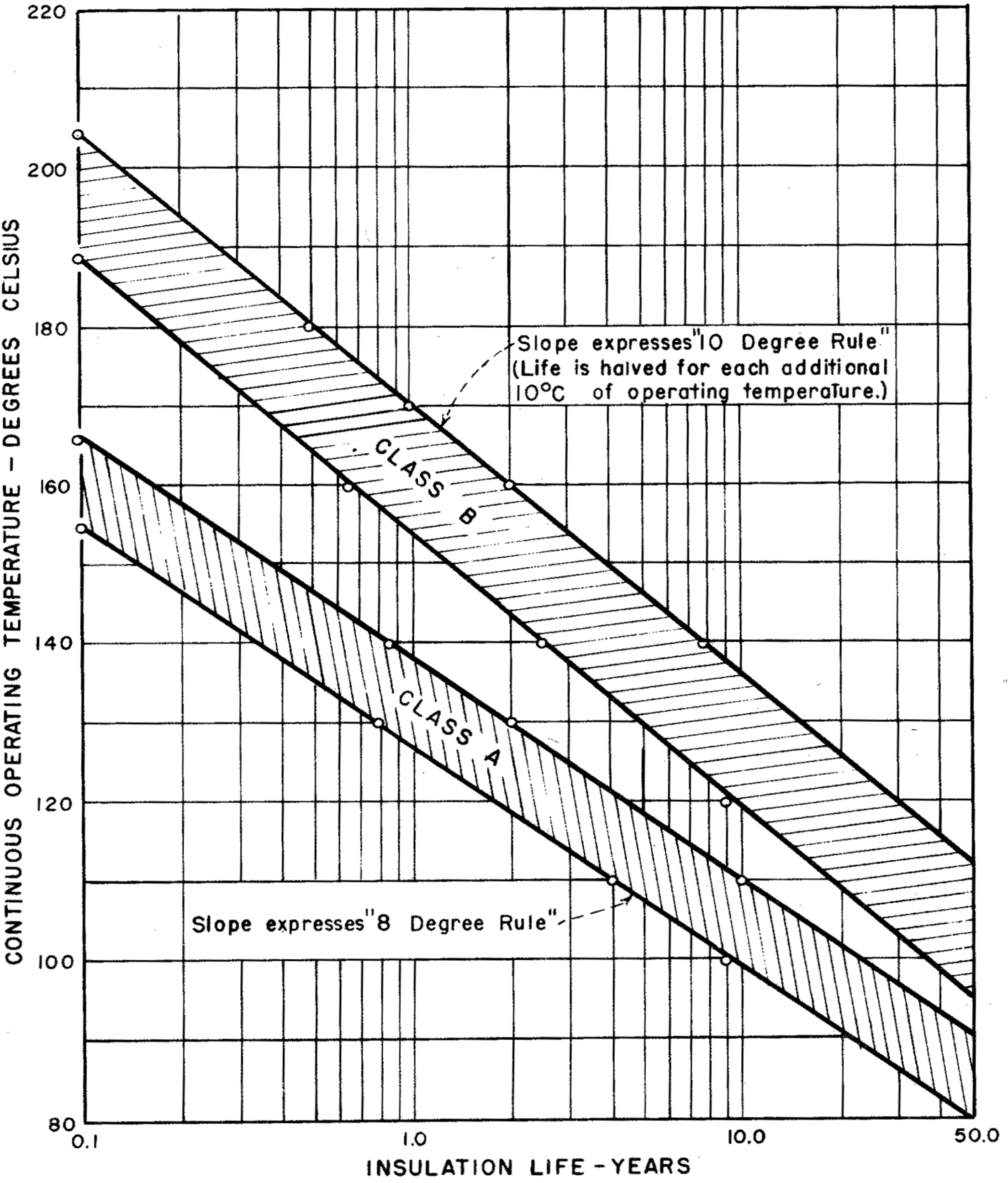


Figure 1. - Continuous operating temperature vs. insulation life.

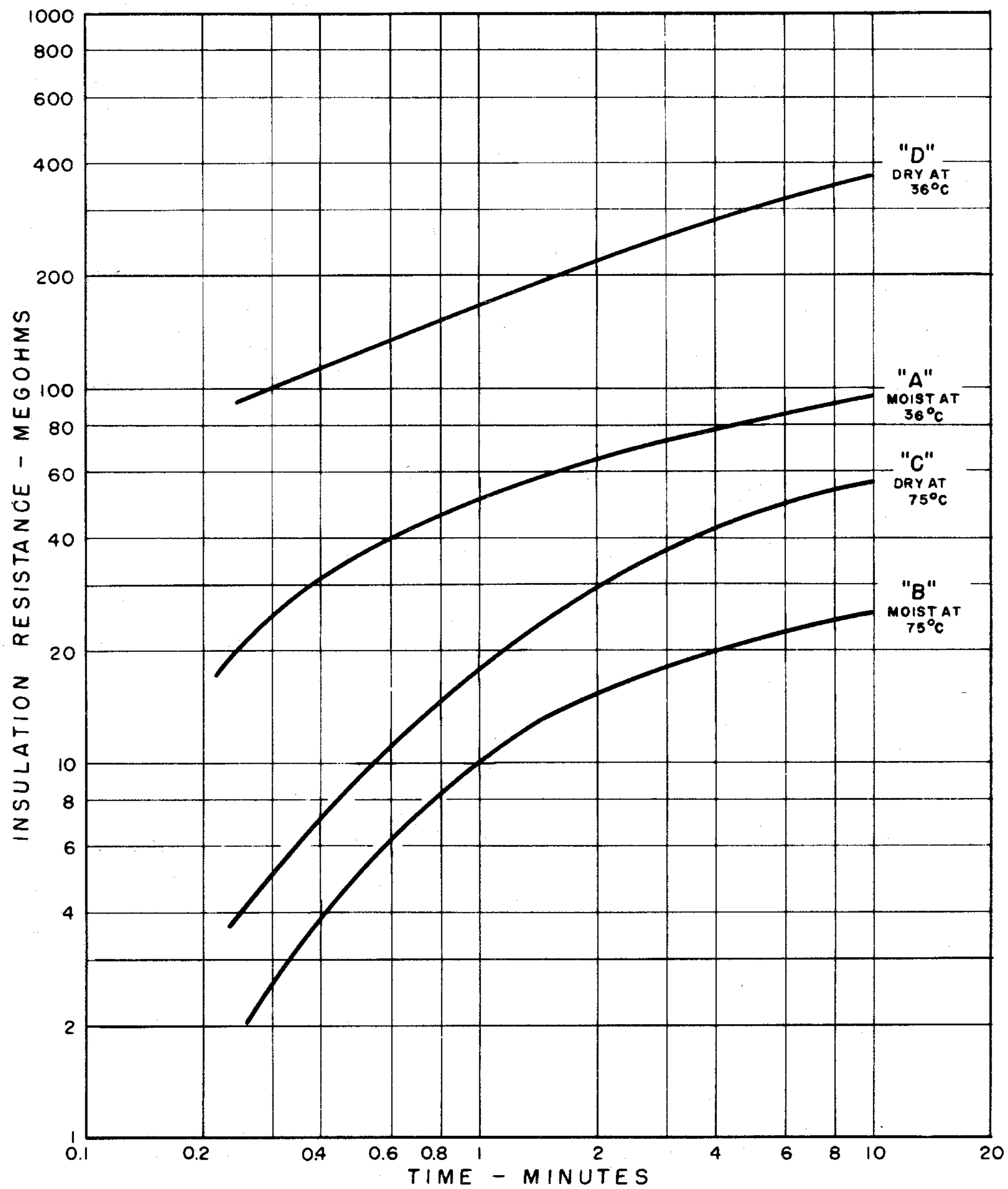


Figure 2. - Dielectric absorption curves before and after initial dryout for Grand Coulee unit L-6 108,000-kVA, 120-r/min, 13.8-kV, 60-Hz generator.

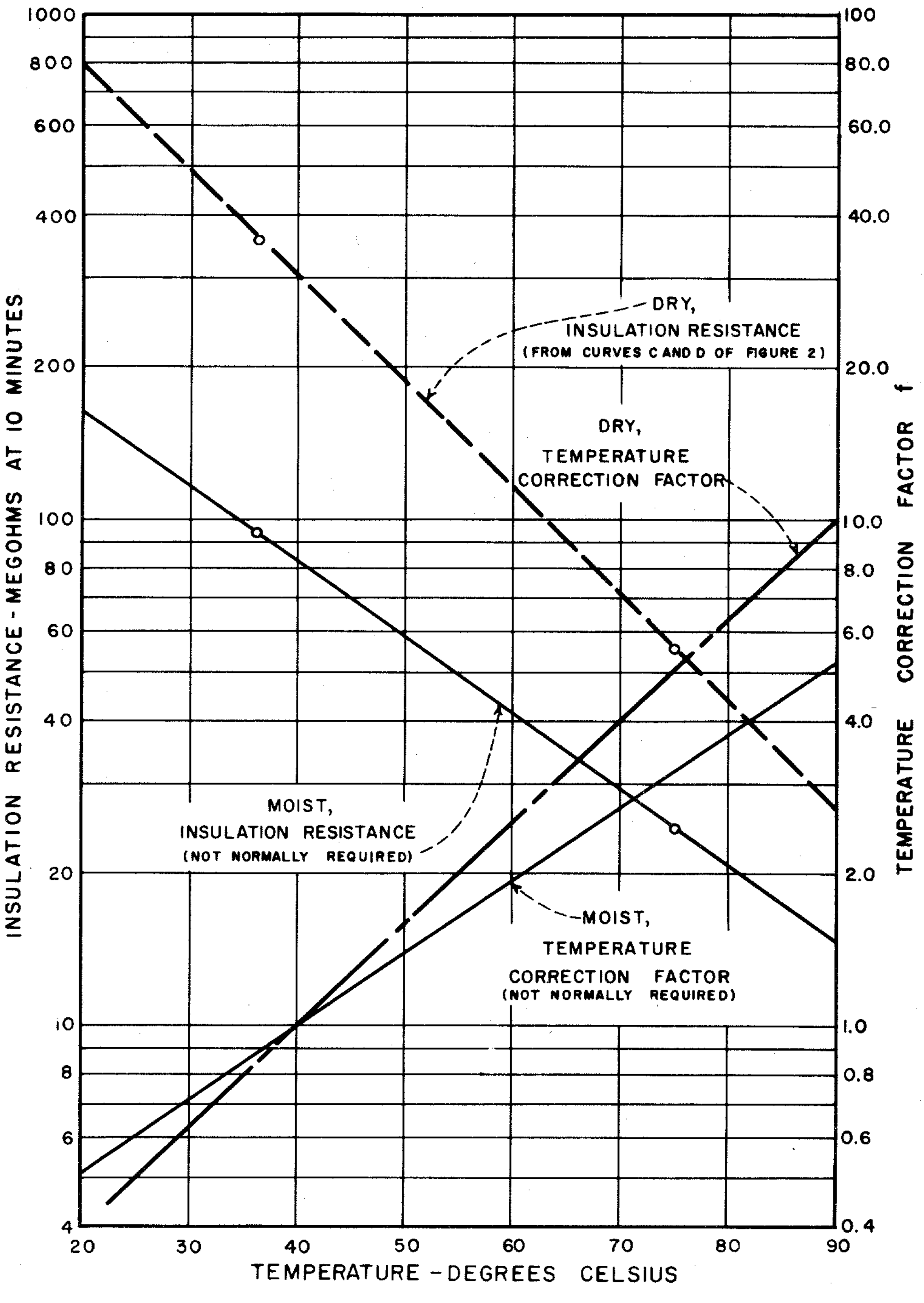


Figure 3. - Insulation resistance and temperature correction factor vs. temperature for figure 2.

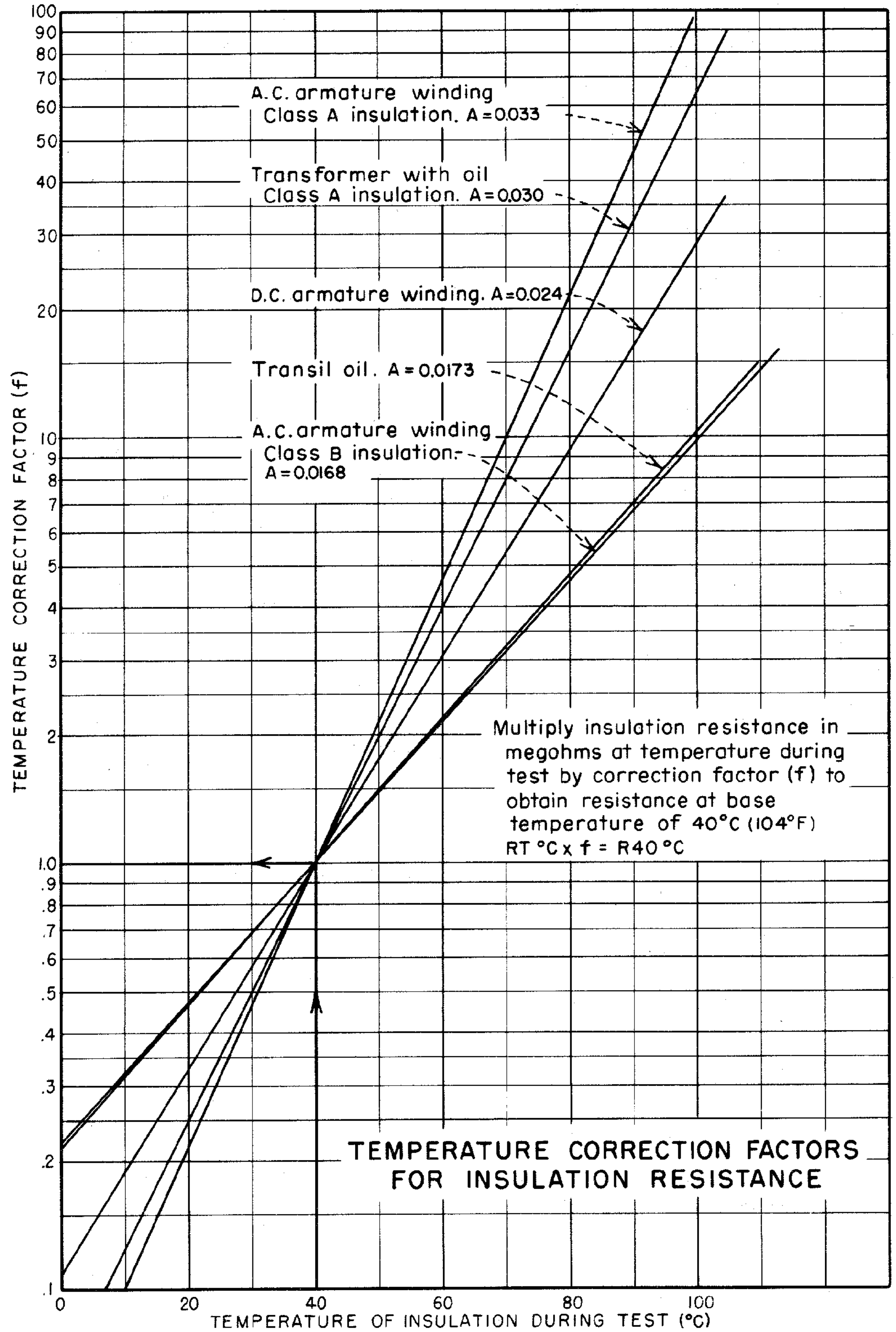


Figure 4. - Temperature correction factors for insulation resistance.

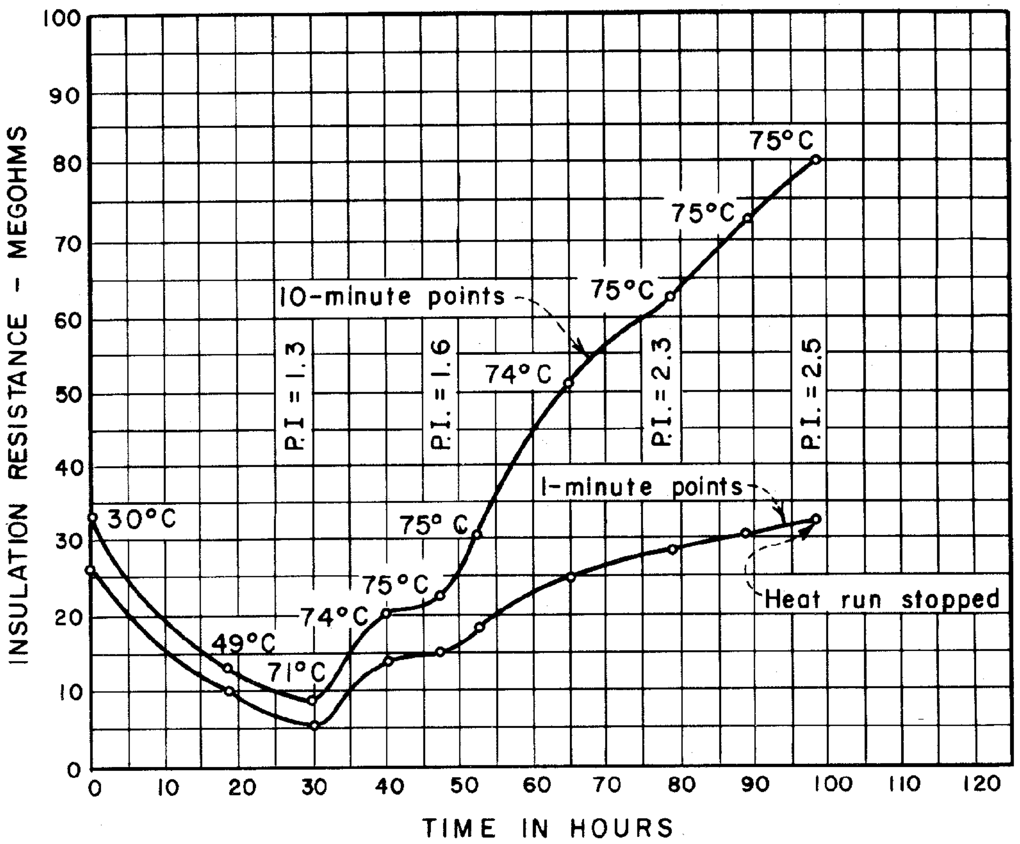


Figure 5. - One- and ten-minute resistance values during dry out of 37 500-kVCA, 13.8-kV hydrogenerator.

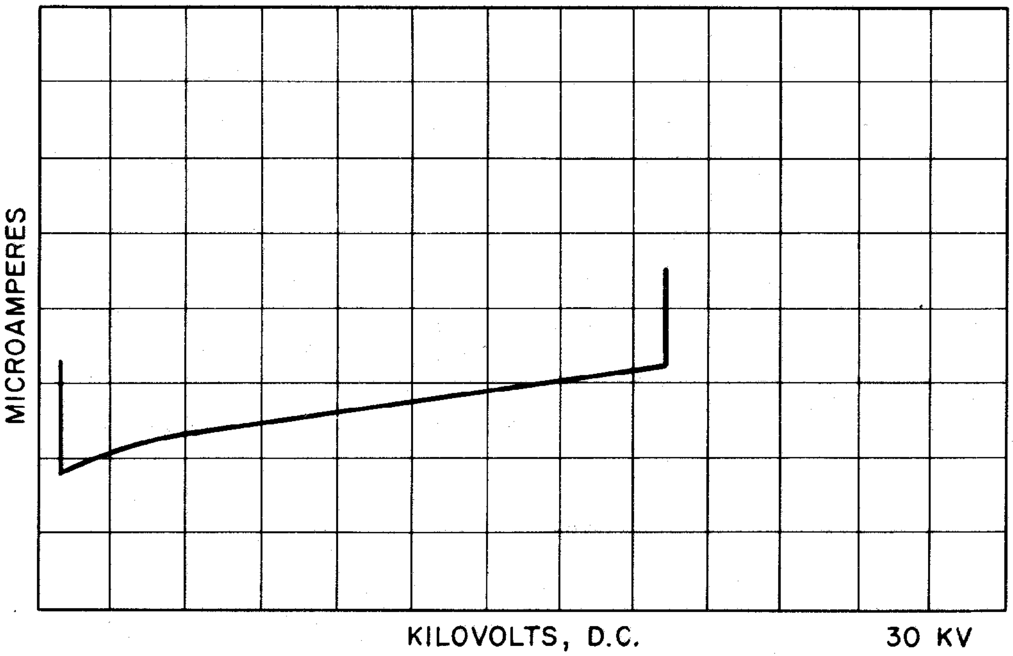


Figure 6. - D-c ramped-voltage test with unit buswork connected-Yellowtail unit 2, k A, February 26, 1979.

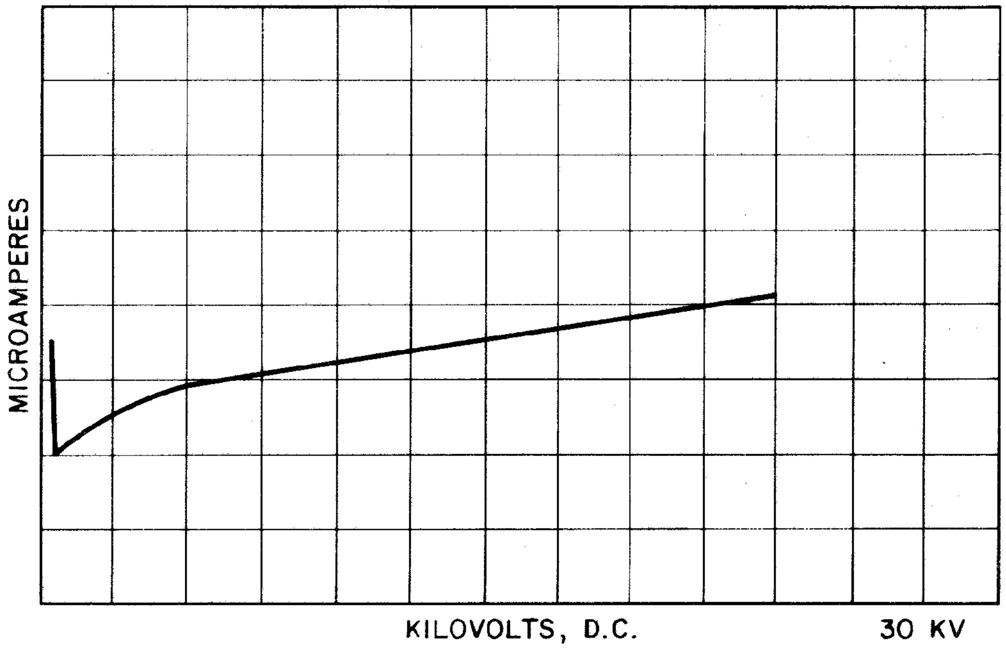


Figure 7. - D-c ramped-voltage test with unit buswork not connected-Yellowtail unit 2, k A, March 13, 1979.

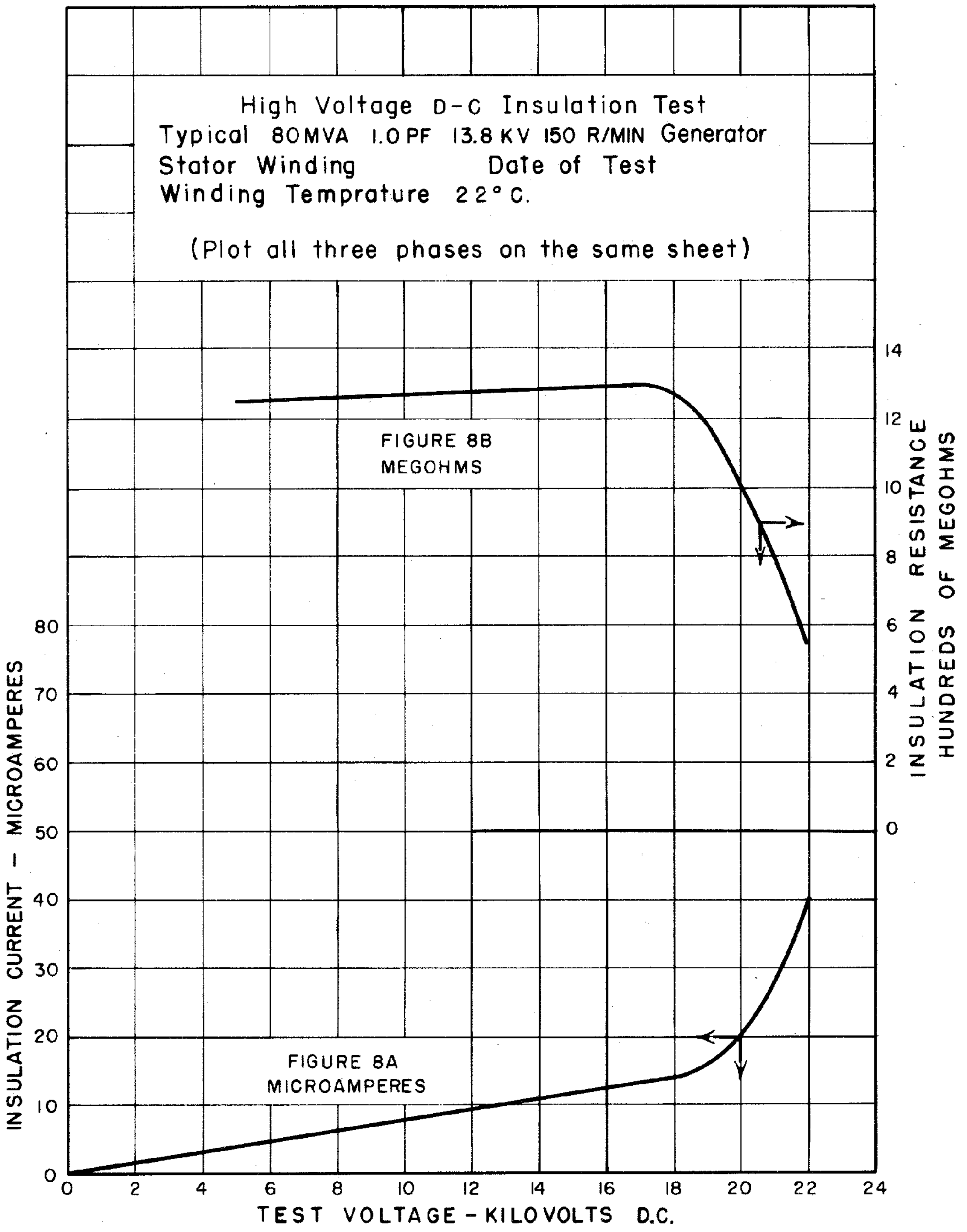


Figure 8. - Arrangement for plotting insulation test data.

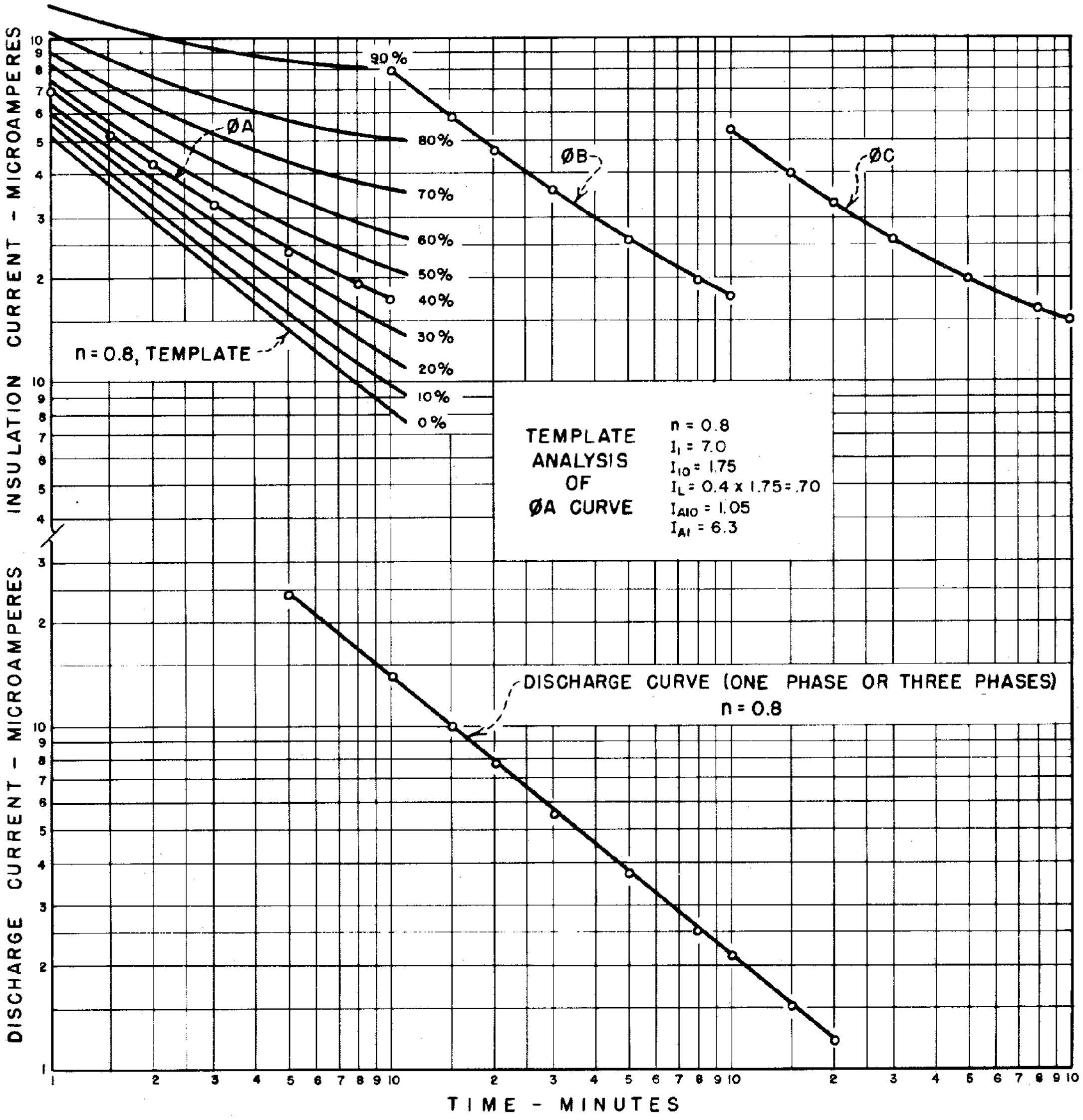
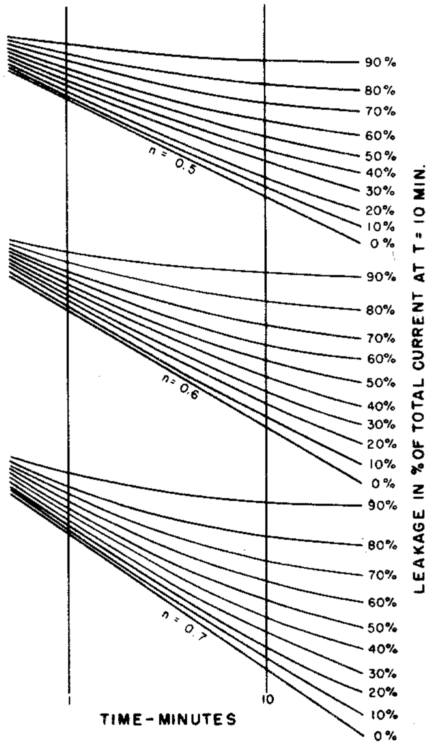
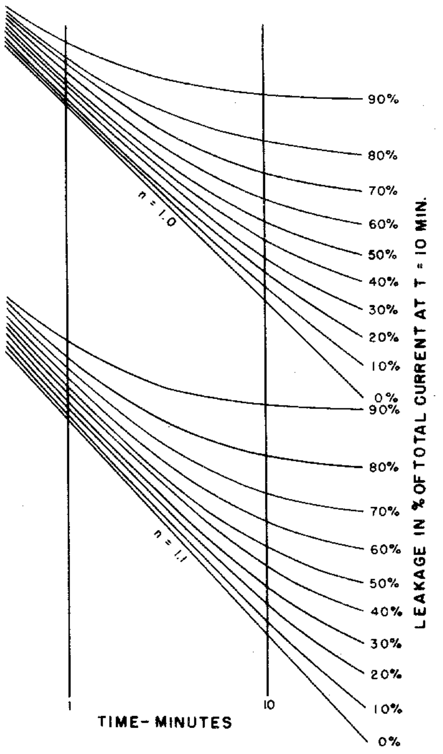
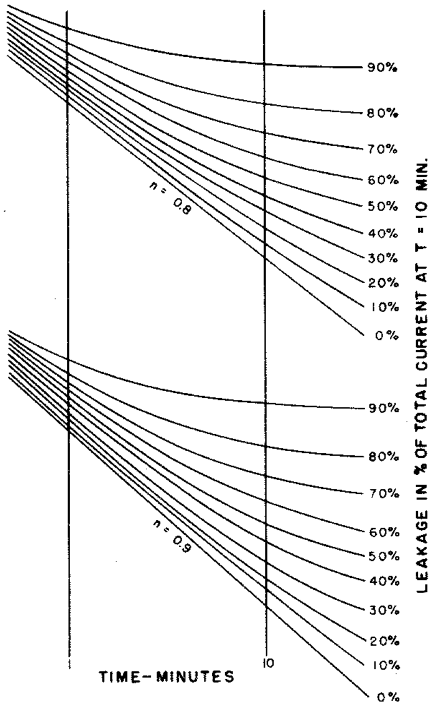


Figure 9. - Log-log plots of dielectric absorption curves and discharge curves.







DESCRIPTION OF TEMPLATE ANALYSIS

TEMPLATES FOR SEPARATION OF LEAKAGE AND ABSORPTION COMPONENTS

(Set of transparent templates, reduced for illustration must be of same scale as log-log plots to be analyzed.)

Procedure:

1. Determine absorption exponent by selecting a 0% line that has same slope as discharge curve.
2. Superimpose template curves of corresponding exponent, with vertical time lines of template and plot matched, select curve that best matches plotted points.
3. Multiply ten-minute insulation current by percentage for curve to determine leakage component.
4. Subtract leakage component from total insulation current to determine absorption component.

Figure 10. - Template analysis.

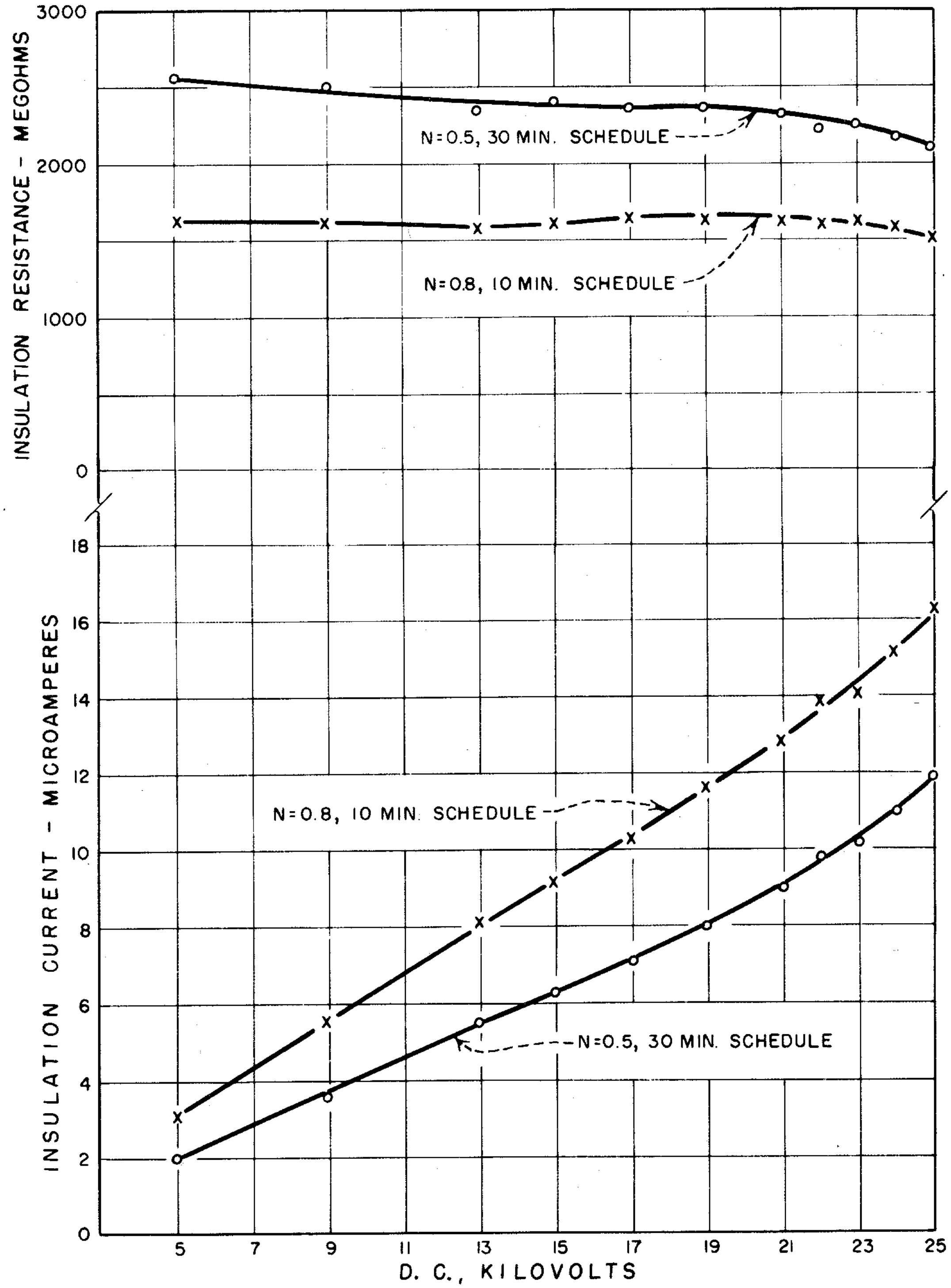


Figure 11. - Comparison of text curves between 30- and 10-minute schedules, kB, Grand Coulee, L-8 June 28, 1960.

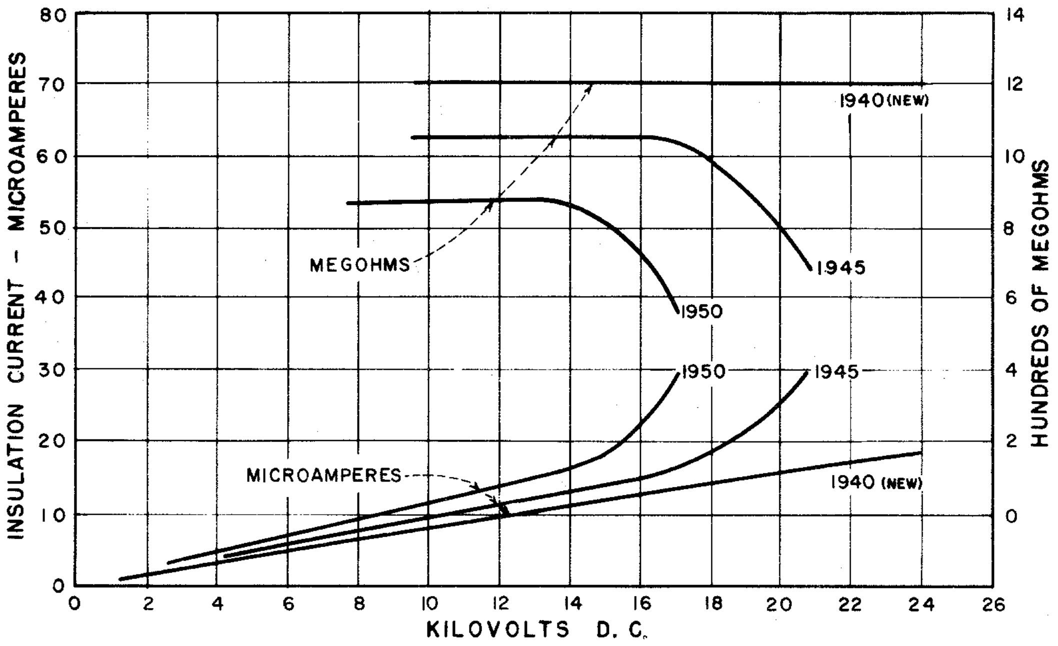


Figure 12. - Comparison of test to show progress of deterioration of wining insulation.

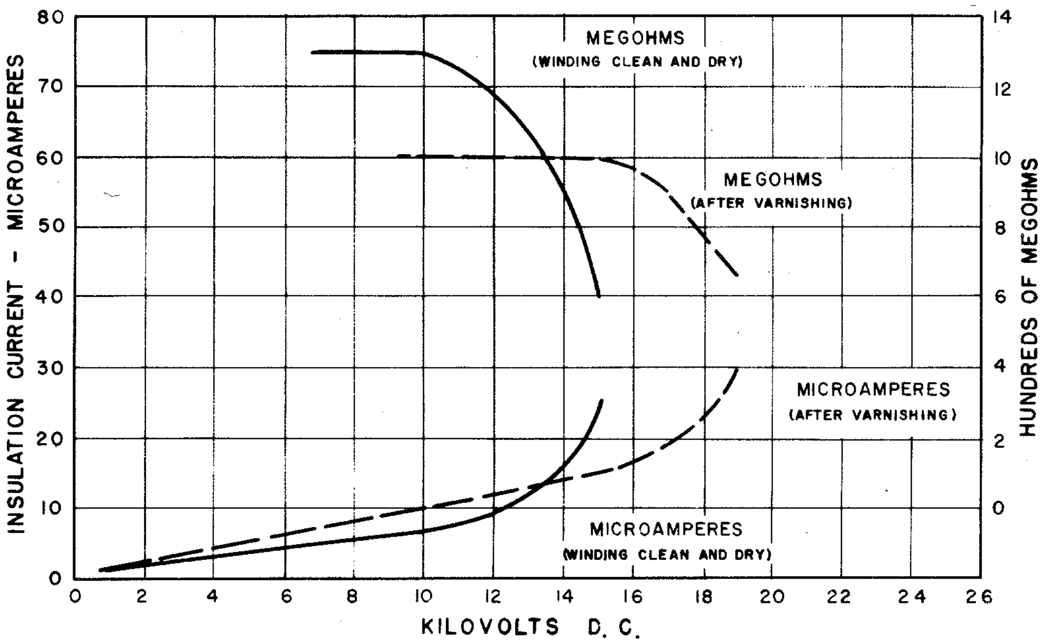


Figure 13. - Characteristics of very dry winding before and after varnishing. (Note that the insulation resistance meter reading may be lower but indicated puncture strength higher after varnishing.)

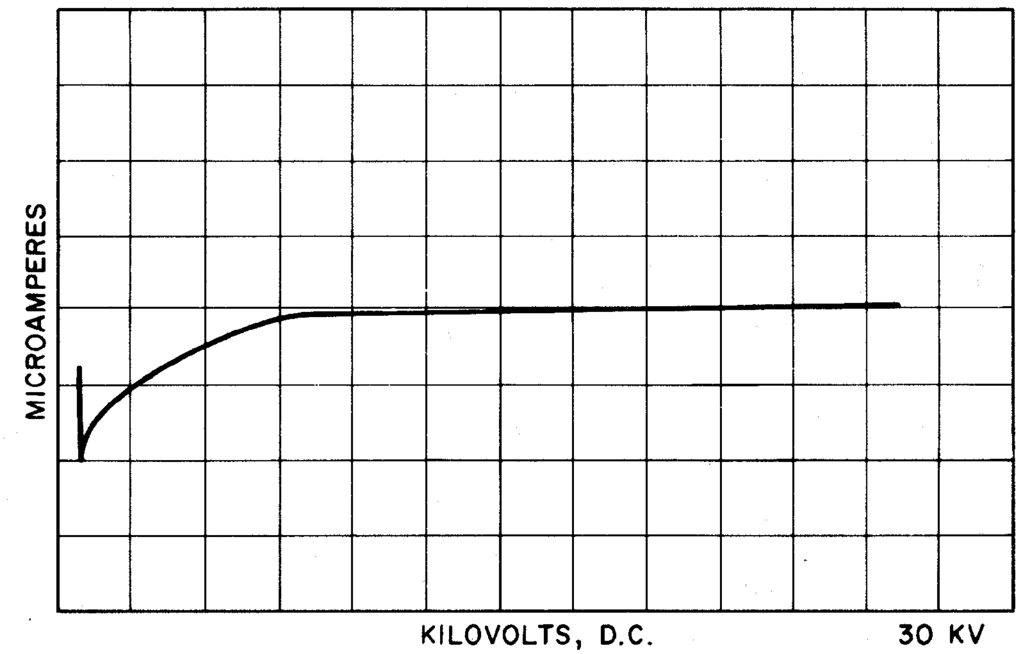


Figure 14. - Typical stator insulation ramped-voltage test results-new epoxy-mica insulation.

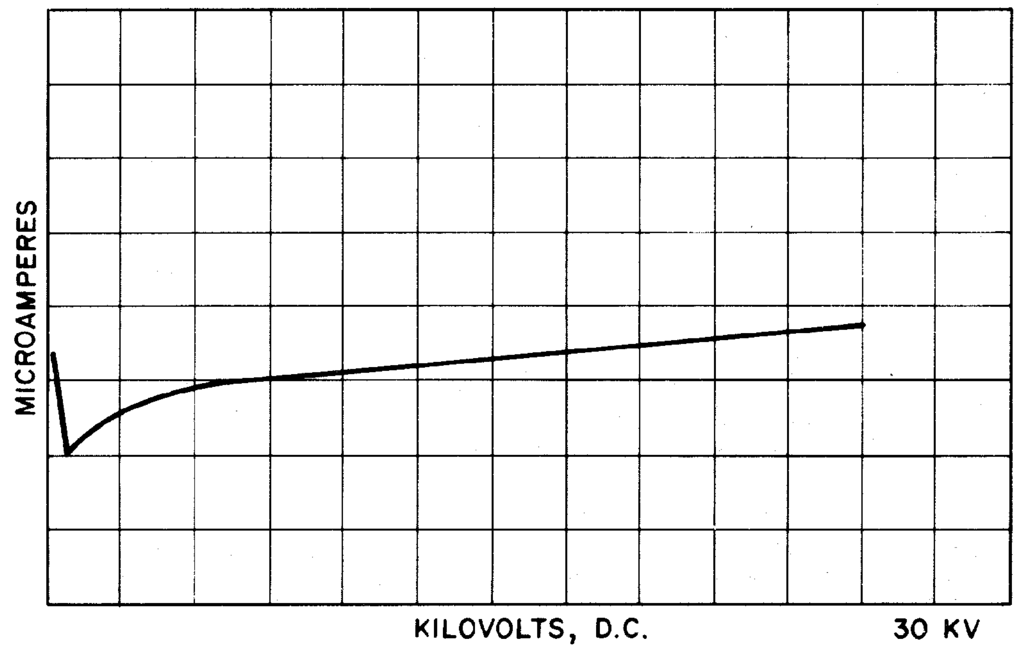


Figure 15. - Typical stator insulation ramped-voltage test results-new asphalt-mica insulation.

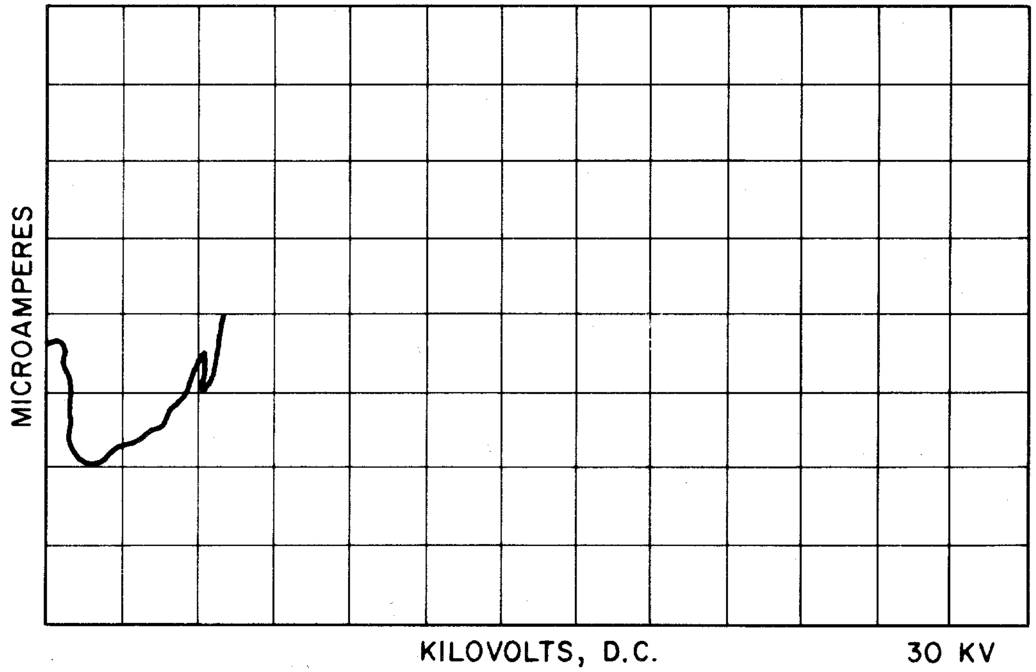


Figure 16. - Typical stator insulation ramped-voltage test results-asphalt-mica insulation with a localized weak spot.

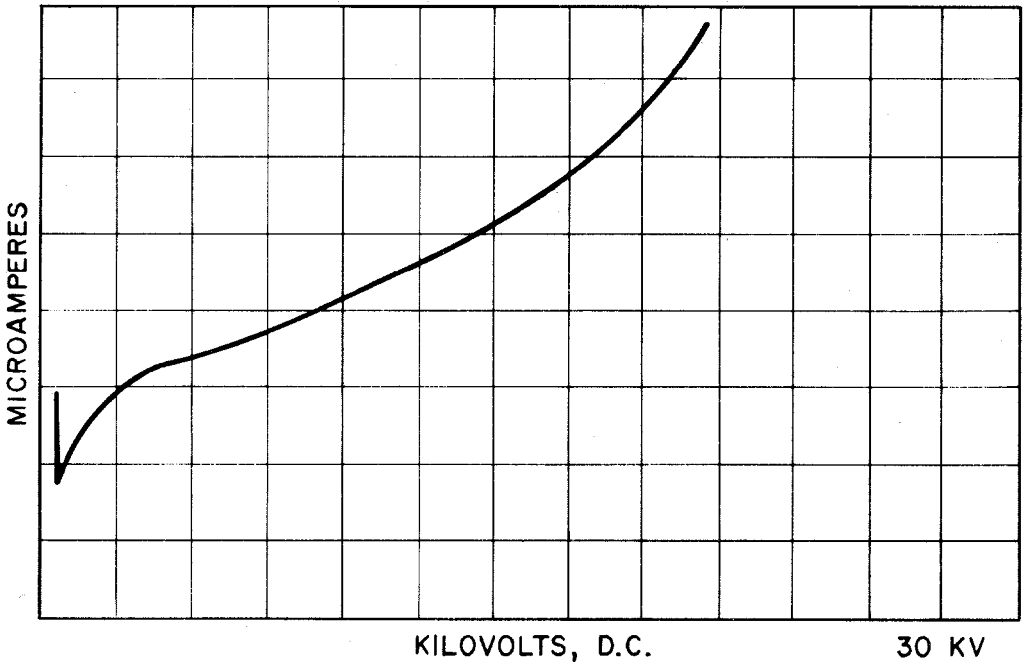


Figure 17. - Typical stator insulation ramped-voltage test results-very old asphalt-mica insulation.

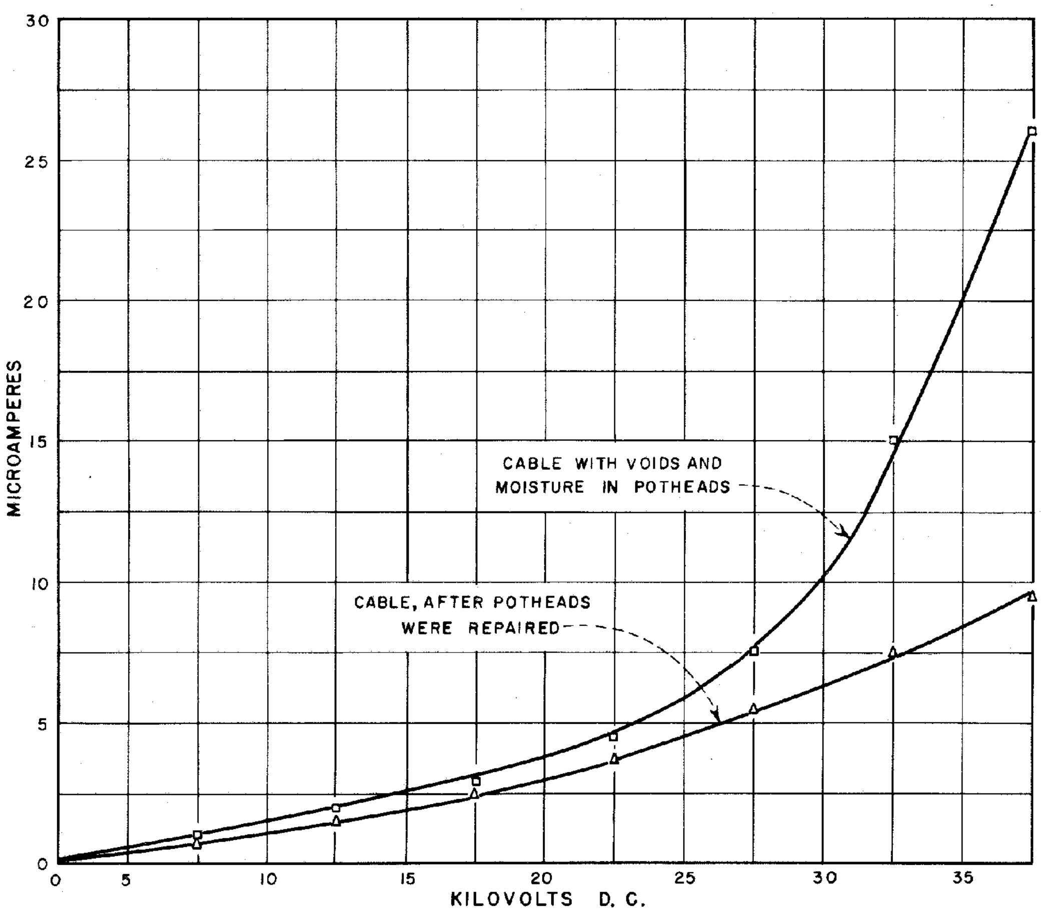


Figure 18. - High-voltage, d-c test on a 1500-kcmil varnished cambric, 250-mil (6.34-mm), lead-sheathed cable.

Data is for testing one phase winding of generator stators rated 100 and 300 r/min, 2.3, 6.9, and 13.8 kV with class B insulation when high-potential test voltage is IEEE standard 2 x normal + 1000 volts at 25 °C. The charging power varies as the square of the applied test voltage.

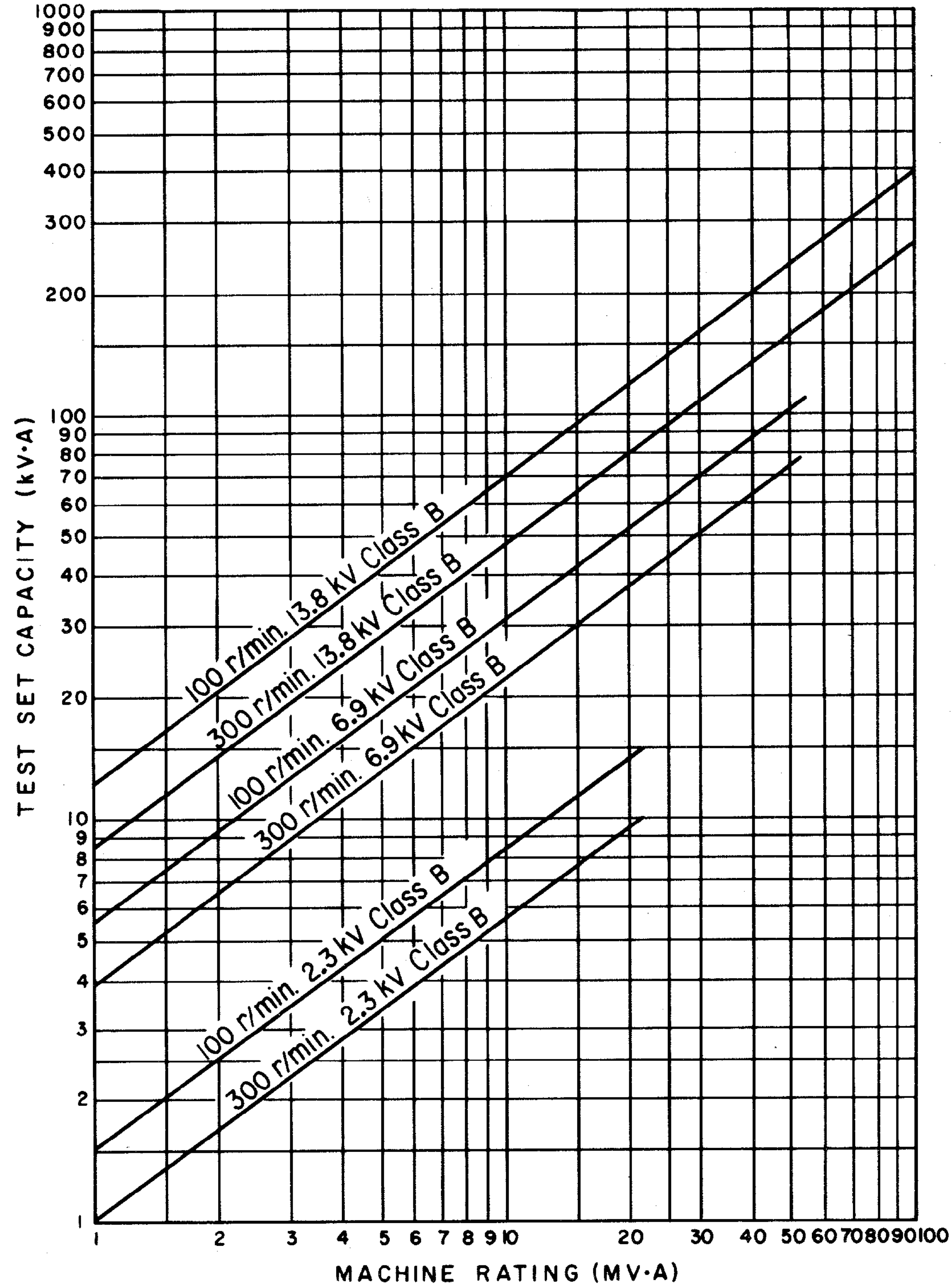


Figure 19. - Approximate charging kilovolt amperes of generator stators for determining capacity of a-c high-potential set required.

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