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Recommended Guide
for
**MAKING DIELECTRIC MEASUREMENTS
IN THE FIELD**

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In the development of this Guide full credit is extended to the Dielectric Measurements in the Field Subcommittee of the AIEE Committee on Instruments and Measurements, the membership of this Subcommittee being presently as follows.

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Recommended Guide for

MAKING DIELECTRIC MEASUREMENTS IN THE FIELD

Section 1.00

PURPOSE

- 1.01 The primary purpose of this Guide is to present and discuss the applicability and limitations of the various measurement methods now in use, or available, for testing the electrical insulation of power apparatus in the field.

Although factory tests assure the initial quality and condition, electric apparatus is subject, during shipment and installation and in operation, to influences which may affect the insulation and shorten its useful life. As a result the practice has grown of testing the insulation in the field from time to time to determine its suitability for service and to detect deterioration which can often be checked or prevented by suitable maintenance procedures.

Various electrical characteristics of the dielectric have been suggested, and used, as criteria for judging the quality and condition of insulation. In this Guide the instruments and measurement techniques for determining these electrical characteristics are presented. The Guide is a summary of the present state of the art and is intended to serve as an aid in obtaining reliable and accurate data. The interpretation of data as it relates to the quality or serviceability of insulation is beyond the scope of this publication.

- 1.02 The purpose of this Guide is also to consider the special conditions encountered in field testing, and their effect on instruments, methods and procedures for making tests on the electrical insulation of power apparatus.

"In the field" refers to the location of apparatus in operating position or where environmental conditions cannot readily be controlled.

To make tests on electrical insulation in the field requires special instruments and measurement techniques. Equipment must be suitable for transporting to the site, connecting to the apparatus in position and operating on location. Since environmental conditions cannot be controlled, their effect on the measurements must be eliminated or evaluated. Test procedure must be safe for personnel working with high voltage and in proximity to energized apparatus.

Section 2.00

SCOPE

- 2.01 The following general methods of test are either discussed or referred to in this publication:

- (1) **Low-frequency, low- and high-voltage loss-characteristic measurements.**

The measurement at power frequencies of power factor, dissipation factor or watts loss and capacitance or charging current; or equivalent quantities which define the electric circuit constants of the test specimen in the voltage range of approximately 80 volts to 50 kilovolts or higher.

- (2) **Alternating-voltage corona measurements.**

The determination of the presence of corona discharge in the test specimen, usually related to the magnitude of the applied power-frequency voltage. The presence and the severity of corona are usually determined by indirect means; for example, by the resultant increase in dielectric loss or by the measurement of high-frequency components in the current.

- (3) **Alternating-voltage distribution measurements.**

The measurement of the potential of the terminal electrodes and of one or more defined points between the high- and low-voltage electrodes of the test specimen, usually with applied voltage of power frequency.

- (4) **Direct low- and high-voltage insulation resistance measurements.**

The measurement of the current-voltage relationship of the test specimen with the application, for a specified time, of direct voltage in the range of approximately 500 volts to 75 kilovolts or higher.

- (5) **Direct low- and high-voltage absorption or resistance-time measurements.**

The measurement of the insulation resistance, or total current, as a function of time of application of a fixed voltage. Alternatively a measurement of absorption current as a function of time on discharge may be made.

- (6) **60-cps breakdown tests (liquid samples only).**

The determination of the dielectric strength of samples of insulating fluid from or for use in power apparatus.

- (7) **Surge-comparison tests.**

The evaluation of the insulation between turns of coil structures by a comparative impulse test.

- (8) **60-cps withstand tests.**

The demonstration of the ability of the insulation to withstand a specified 60-cps voltage for a specified time.

(9) **Direct-voltage withstand tests.**

The demonstration of the ability of the insulation to withstand a specified direct voltage for a specified time.

- 2.02 All electric power apparatus in all voltage and power ratings is considered in this Guide, as for example: rotating machinery; transformers, regulators and reactors; cables; circuit breakers; lightning arresters; capacitors; insulators; hot-line tools; insulating liquids.

Section 3.00

GENERAL CONSIDERATIONS

3.01 Temperature of Apparatus Under Test.

As a general rule the characteristics of dielectrics vary with temperature, the most variable of the quantities mentioned under 2.01 being those related to the low-frequency loss characteristics and the direct-current insulation resistance. In order to make proper comparison of results it is necessary to make all measurements at the same temperature or to apply corrections to reduce all results to a common reference temperature. In the field the temperature cannot readily be controlled so temperature corrections are usually applied. These temperature corrections are empirical and will vary according to the type and the condition of the dielectric.

For the application of temperature corrections the desired temperature is the average temperature of the dielectric. Usually this temperature cannot be measured directly but must be approximated from other temperatures obtained by available measuring means as for example oil-temperature indicators, imbedded detectors, conductor resistance, applied thermometers or thermocouples and ambient-air thermometers.

Conditions of rapidly changing dielectric temperature should be avoided for most accurate results.

The temperature of the dielectric under test should be above the freezing point of water to avoid the possibility of any moisture freezing in the dielectric and thus changing the losses due to free moisture and making difficult the detection of unwanted moisture.

3.02 Environmental Influences.

(1) **Atmospheric conditions.**

Dielectric measurements on insulation which is exposed to the air may be influenced by atmospheric conditions. For example excessive humidity may result in surface moisture and consequently increased low-frequency loss and decreased insulation resistance. The quantities which should be measured to suitably define the atmospheric conditions are wet- and dry-bulb temperatures and, for withstand tests, barometric pressure. From these measurements the relative humidity, absolute humidity, vapor pressure, dew point and relative air density can

be obtained. If the temperature of the insulation surface is below the dew point, surface moisture may have a marked effect on the dielectric measurements particularly if the surface is contaminated with airborne deposits. Best results are obtained when the insulation is slightly warmer than the ambient air and the relative humidity is below 60 percent. Tests may be made at any ambient temperature when the dielectric under stress is maintained at a temperature higher than the freezing temperature of water. Measurements made at temperatures near the reference temperature are preferred in making comparisons because of the uncertainties in applying empirical temperature corrections for large deviations.

(2) **Environmental electric and magnetic fields.**

Dielectric measurements in the field must often be made in the vicinity of live apparatus so that measurements made at line frequency may be influenced by stray fields. The influence of electric fields can be minimized by properly shielding the measuring apparatus and connecting leads. The influence of magnetic fields is principally the effect on the indicating instruments and necessitates that they be adequately shielded. The effect of stray fields from external sources can often be determined by measurements with reversed polarity of the test source. The use of low-voltage instruments which operate at power-line frequency may be impractical in some switch-yard locations because of the large influence from electric fields.

3.03 Dielectric Networks.

Since dielectrics are used to insulate electric conductors from one another, any two conductors become electrodes for the application of voltage used in testing such dielectrics. These electrodes therefore become the terminals of a basic two-terminal electric circuit where the dielectric is the circuit under consideration. The dielectric under test may have numerous conducting or capacitive paths throughout its structure, thereby forming a complex electric network, but when only two electrodes are available for the application of a test voltage it remains a two-terminal network.

In some cases the two-terminal network may be converted to a three-terminal network by applying a third conducting electrode or terminal to certain surfaces of the dielectric. A sample of a simple or basic two-terminal network would be a single suspension type porcelain insulator. Figure 1 shows such a network, C_1 indicating the capacitance involved, R_1 indicating the volume resistance, and R_2 indicating the surface resistance. The dotted connection to R_2 indicates how a third terminal may be made available by applying a metal band around the surface of the dielectric.

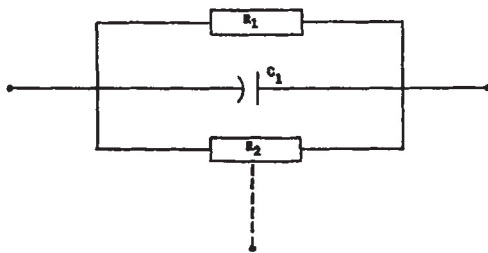


Figure 1.

Some forms of electric apparatus have several conducting elements or electrodes separated by insulation, so that numerous terminals are available in the network. Since all electric apparatus in field service requires insulation to ground, all apparatus to be tested will have ground as one of the electrodes. For example, a two-winding transformer has a grounded electrode formed by the tank and core, and two ungrounded electrodes, each formed by one of the windings and its associated bushings. If there are n ungrounded electrodes then the number of dielectric circuits to ground is n , the number of dielectric circuits between ungrounded electrodes is $\frac{1}{2} n (n-1)$, and the total number of dielectric circuits is $\frac{1}{2} n (n+1)$.

In general, dielectric measurements in the field are made during the application of either direct voltage or single-phase alternating voltage to the insulation in question. Therefore, essentially two-wire (two-terminal) devices are used to test multi-terminal networks. A third (guard) terminal may be provided in the test device to make it possible to eliminate from the measurement the insulation associated with certain terminals of the multi-terminal network under test.

The test circuit consists of three basic elements; the voltage source, the measuring element and the test specimen, connected in series as shown in Figure 2. For a two-terminal measuring device terminals I and II are provided for connection to

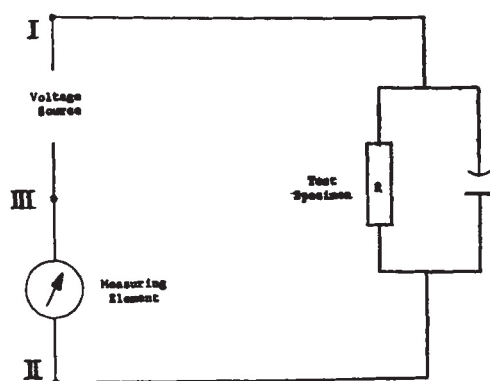


Figure 2.

the test specimen. For a three-terminal measuring device the guard terminal III is also provided. Since in field measurements one terminal of the dielectric network is always ground, it follows that one terminal of the measuring device must be connected to ground. In some devices any one of the terminals may be connected to ground, in others the choice is limited to one or possibly two. There are many variations of the basic circuit.

One of the problems in making dielectric measurements in the field is how to use most effectively a two- or three-terminal measuring device on the multi-terminal insulation network in the apparatus under test. In general, where the number of terminals available exceeds those of the measuring device, they are grouped in such a manner that some insulating paths may be measured in parallel, some may be short-circuited, and others may be isolated by holding them at guard potential.

It is usually possible to determine the impedance of each single two-terminal element of a network, either by direct measurement or by calculation from a series of measurements.

The application of these principles to dielectric measurements of electric apparatus is illustrated by the equivalent circuit of Figure 3. In this circuit the terminals 1, 2 and 3 represent the conducting elements of three windings; for example, the primary, secondary and tertiary of a three-winding transformer or the stator windings of a three-phase generator. The dielectric circuits between windings and from windings to ground are represented by six admittance elements.

The inter-winding admittances are:

$$Y_{12} = g_{12} + j b_{12} \quad (\text{where } g = \frac{1}{r} \text{ and } b = \frac{1}{x} = 2\pi f C)$$

$$Y_{13} = g_{13} + j b_{13}$$

$$Y_{23} = g_{23} + j b_{23}$$

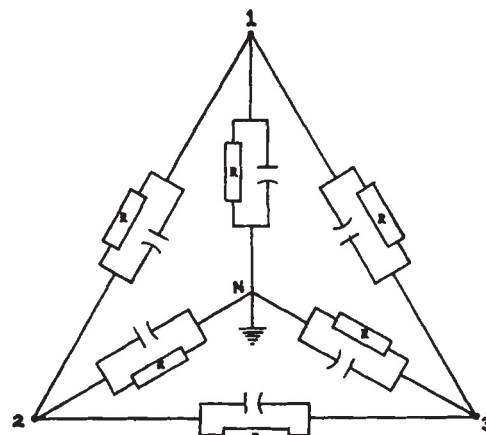


Figure 3.

The admittances to ground are:

$$\begin{aligned} Y_{2N} &= g_{2N} + j b_{2N} \\ Y_{3N} &= g_{3N} + j b_{3N} \\ Y_{1N} &= g_{1N} + j b_{1N} \end{aligned}$$

The circuit constitutes a four-terminal network in which the terminal N is grounded.

Using the three-terminal measuring device of Figure 2 the six admittance elements can be determined from six measurements in the following manner.

Measured Admittance	Terminal Connections			
	I	2	3	N
$Y_A = Y_{1N}$	I	III	III	II
$Y_B = Y_{2N}$	III	I	III	II
$Y_C = Y_{3N}$	III	III	I	II
$Y_D = Y_{13} + Y_{1N}$	I	III	II	II
$Y_E = Y_{12} + Y_{2N}$	II	I	III	II
$Y_F = Y_{23} + Y_{3N}$	III	II	I	II

From these measurements the inter-winding admittances may be calculated.

$$\begin{aligned} Y_{12} &= Y_E - Y_B \\ Y_{13} &= Y_D - Y_A \\ Y_{23} &= Y_F - Y_C \end{aligned}$$

The admittances to ground are given directly as shown in the first three measurements.

It will be noted that in the above measurements terminal II of the measuring device was the grounded terminal in all six measurements, the voltage source being not otherwise grounded. If the device is one which permits a choice in ground connections and measurements can be made with terminal III connected to ground, then it is possible to measure the inter-winding admittances directly by the following connections.

Measured Admittance	Terminal Connections			
	I	2	3	N
Y_{13}	I	III	II	III
Y_{12}	I	II	III	III
Y_{23}	III	I	II	III

In the application of a three-terminal measuring device the shunting effect of the impedances of the guard circuit, terminal III, to the specimen terminals I and II of Figure 2 must be recognized as a possible source of error. Impedance between terminals I and III imposes an additional load on the voltage source. Impedance between terminals II and III shunts the measuring element. In variations of the basic circuit this impedance may shunt the current coil of a measuring instrument or one branch of a bridge network. The shunting impedances can be measured, the error can be calculated, and if it is appreciable corrections can be applied. The mathematical expressions for correcting such errors will vary considerably, depending upon the test circuit used, and would involve more detail than can be adequately covered in this Guide.

It is recommended that such information be obtained from the manufacturer of the specific test equipment being used.

If the guard terminal III of Figure 2 is not provided, the measuring device becomes a two-terminal device. The six admittance elements of the dielectric network of Figure 3 can be determined from the following six measurements.

Measured Admittance	Terminal Connections			
	I	2	3	N
$Y_G = Y_{12} + Y_{13} + Y_{1N}$	I	II	II	II
$Y_H = Y_{12} + Y_{23} + Y_{2N}$	II	I	II	II
$Y_J = Y_{13} + Y_{23} + Y_{3N}$	II	II	I	II
$Y_K = Y_{13} + Y_{23} + Y_{2N} + Y_{1N}$	I	I	II	II
$Y_L = Y_{12} + Y_{13} + Y_{2N} + Y_{3N}$	II	I	I	II
$Y_M = Y_{12} + Y_{23} + Y_{3N} + Y_{1N}$	I	II	I	II

From these measurements the six admittances may be calculated.

$$Y_{12} = \frac{Y_G + Y_H - Y_K}{2}$$

$$Y_{13} = \frac{Y_G + Y_J - Y_M}{2}$$

$$Y_{23} = \frac{Y_H + Y_J - Y_L}{2}$$

$$Y_{2N} = \frac{Y_K + Y_L - Y_J - Y_G}{2}$$

$$Y_{3N} = \frac{Y_L + Y_M - Y_H - Y_G}{2}$$

$$Y_{1N} = \frac{Y_K + Y_M - Y_H - Y_J}{2}$$

3.04 Test Leads.

Test leads, that is the leads necessary to connect the measuring instruments to the apparatus under test, must meet special requirements for field use. They must be mechanically rugged to withstand continued moving and handling. They should be either shielded or sufficiently free of corona at maximum test voltage to avoid significant influence on the measurements.

Bare leads if properly supported and isolated for safety are sometimes sufficient for use in withstand tests.

Guard shields and ground shields may be incorporated in test leads as for example in alternating-current loss and direct-current insulation-resistance measurements. The use of a high-voltage guard shield on the test lead is illustrated in Figure 4(a). In this application the guard shield eliminates from the measuring instrument the unwanted stray currents from the conductor of the test lead to ground. Figure 4(b) shows the use of a low-voltage guard shield for the same purpose. In this application the conductor of the test lead must be insulated from the guard shield for the full test voltage. The low-voltage guard shield is advantageous from

surfaces, such as bushing terminations. The design of these surfaces is generally such that effects of relative air density present no serious problem.

- (d) The insulating parts of rotating machines are generally effectively shielded from the effects of environmental electric or magnetic fields by the frame of the machine. Also, the capacitances of the windings involved are relatively high, so that the effects of stray fields on imperfectly shielded test leads or short lengths of exposed leads are usually not appreciable. Consideration, however, must be given to the effect of stray fields on the measuring equipment used, as outlined in a later section of this guide.

4.014 Multi-Terminal Networks.

In the application of the test methods involving direct connection to machine parts and where a quantitative measurement of some insulation properties, such as insulation resistance, power factor, or dielectric loss is involved, the electrodes involved and the intervening insulation may be conveniently thought of as a circuit problem involving two or more terminals. In common usage for testing machine insulation, either a two- or three-terminal network will be involved. A measurement of the insulation to ground of a complete winding is a two-terminal test. In cases where the phases can be separated a three-terminal test can be made. For instance, the insulation between one phase and ground of a three-phase stator winding may be tested by making the terminals of the other two phases the guard terminal of a three-terminal network.

Also, see Section 3.03.

4.015 Test Leads.

(Sec. 3.04)

4.016 Safety of Personnel.

(Sec. 3.05)

4.02 Transformers, Regulators and Reactors.

This section includes distribution, power and regulating transformers; instrument transformers; step-voltage and induction-voltage regulators; reactors; specialty transformers and rectifier transformers.

4.021 General Considerations.

Dielectric measurements on transformers, regulators and reactors may be made on the insulation between windings; or between winding and core, frame and tank. Included in this insulation are terminal bushings and insulating liquids, where used.

Where insulating liquids are subjected to intense electric fields during high-voltage testing, particularly in the case of direct current, there is a possi-

bility of a migration of contaminating particles which may result in internal flashover.

4.022 Test Methods.

(1) Winding Insulation.

The winding insulation, including the terminal bushings, may be tested by the following methods:

- (a) Low-frequency, low- and high-voltage loss-characteristic measurements. (Sec. 5.00 and AIEEE No. 505)
- (b) Alternating-voltage corona measurements. (Sec. 7.00)
- (c) Direct low- and high-voltage insulation-resistance measurements. (Sec. 6.00)
- (d) Direct low- and high-voltage absorption or resistance-time measurements. (Sec. 6.00)
- (e) 60-cps withstand tests. (Sec. 5.01)
- (f) Direct-voltage withstand tests. (Sec. 6.00)

Since the capacitance of the windings is often large in comparison with that of the bushings it is desirable to make measurements to determine the condition of the bushings separate from the windings.

(2) Terminal Bushings.

The following methods are applicable to the terminal bushings in place on the apparatus.

- (a) Low-frequency, low- and high-voltage loss-characteristic measurements. (Sec. 5.00)
- (b) Direct low- and high-voltage insulation resistance measurements. (Sec. 6.00)

In order to isolate the bushing for such measurements one of the following features must be provided in the bushing or its mounting:

A conducting center tube enclosing an insulated lead to the winding with facilities for electrically disconnecting the lead from the tube.

Facilities for disconnecting the ground layer of the bushing from the mounting flange.

A potential-device tap connected to a layer of the bushing. This layer is usually near the outside of the bushing.

A bushing flange which may be electrically disconnected from the tank.

- (c) Alternating-voltage distribution measurements. (Sec. 8.00)

(3) Insulating Liquid Samples.

The liquid sample should be indicative of the worst conditions present. Since moisture will settle at the bottom of mineral oil, the sample should be taken from the bottom. Moisture will rise to the top of askarel and the sample should be taken from the top. It may be desirable to drain off a small quantity of liquid before taking the test sample in order to obtain a more representative sample. Samples

should be extracted from the apparatus and handled in such a way as to avoid contamination.

The tests generally applied to insulating liquid samples (see also Section 9.00) in the field are:

- (a) 60-cps breakdown test. (Sec. 9.00)
- (b) Low-frequency, low- and high-voltage loss-characteristic measurements. (Sec. 5.00)
- (c) Direct low- and high-voltage insulation-resistance measurements. (Sec. 6.00)

Either the measured uniform temperature or the approximated average temperature can be used for correction to a selected reference temperature.

4.023 Test Conditions.

(1) Temperature.

Tests should preferably be made with the apparatus at a uniform temperature throughout the insulation. When this is not convenient it is necessary to measure an approximately average temperature. It is generally necessary to apply temperature corrections to low frequency loss-characteristics and direct-current insulation resistance. For alternating-current measurements see AIEE No. 505. For direct-current measurements refer to manufacturer.

(2) Temperature measurements.

The following may be used in approximating an average temperature.

Oil-immersed apparatus—top-oil temperature, temperature by winding resistance.

Dry-type apparatus—temperature by winding resistance, air temperature, insulation-surface temperature.

Bushings—temperature by average or weighted average of the oil or air and the ambient temperature when the bushing is mounted and by ambient-air temperature when the bushing is not mounted.

(3) Environmental influence.

- (a) High humidity may cause moisture condensation on insulating surfaces and result in measurements which are not good indications of the permanent condition of the apparatus under test. This is particularly true if exposed insulating surfaces are not above ambient temperature. With sealed and oil-immersed apparatus this will only affect the exposed surfaces of bushings. High humidity may affect the tests on dry-type apparatus which are open to the atmosphere.
- (b) Field tests on transformers are often made in the vicinity of energized apparatus. Under these conditions special shielding may be required for accurate low-frequency measurement.
- (c) Lower relative air density is favorable to the formation of corona and its effect

should be considered in making corona-detection tests.

4.024 Multi-Terminal Networks.

The tank, core and other connected parts usually form the ground terminal of a multi-terminal network for the measurement of dielectric loss or insulation resistance. A winding, a group of connected windings or any section of a winding, may be selected as a network terminal. Combinations of the grounded and other terminals can be used to form two or three-terminal networks. (See Sec. 3.03). In cases such as potential transformers where the magnetizing current is small and both ends of the high-voltage winding are insulated from the tank, it is possible to make low-frequency loss-characteristic tests with one end of the winding connected to the high-voltage test lead and the other end to the low-voltage guard. The secondary is usually grounded but must not be short circuited and the test voltage should not exceed the rated voltage of the winding. The voltage applied to the dielectric circuit between the high voltage and the grounded case will be graded from the test potential at one end of the winding to practically ground potential at the other end.

4.025 Test Leads.

(Sec. 3.04)

4.026 Safety of Personnel

(Sec. 3.05)

4.03 Cables.

This section includes power, control and low-frequency communication cables of all types and sizes and splices in and terminations of these cables. It does not apply to high-frequency cables.

4.031 General Considerations.

Power cable may be single or multiple conductor. The insulation of single-conductor power cable may be shielded, or non-shielded. In multi-conductor power cable the insulation of the individual conductors may or may not be shielded. The assembly of non-shielded, insulated conductors in multi-conductor power cable may be covered with a belt of insulation, a metallic sheath or both. The insulation of power cable may be oil-impregnated paper, varnished cambric, natural or synthetic rubber or any of a number of the plastics. Power cable may have either a metallic or a non-metallic sheath.

Control cable may be single or multi-conductor. Low-frequency communication cable invariably has 2 or more conductors. These cables may have natural or synthetic rubber, plastic, varnished cambric or dry-paper insulation. Control and low-frequency communication cables do not have shielding over the insulation of the individual conductors. Control cable rarely has shielding over the assembly of insulated conductors. Communication cable usually has either a metallic sheath or shielding over the assembly of insulated conductors. Each of these types of cable may have either a metallic or non-metallic sheath.