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Standards
for
MEASUREMENT OF TEST VOLTAGE
IN
DIELECTRIC TESTS

(Revised January 1940)



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ACKNOWLEDGEMENT

The Institute wishes to acknowledge its indebtedness to those who have so freely given their time and knowledge and have conducted experimental work on which many of the A. I. E. E. Standards are based.

In the development of this standard full credit is extended to the A. I. E. E. Committee on Instruments and Measurements.

Development of the Standards of the American Institute of Electrical Engineers

Recognizing the importance in the development of electrical engineering, of standardization in the electrical field, the A.I.E.E. in 1898 appointed a Committee on Standardization, consisting of seven members having qualifications and experience from designing, manufacturing and operating standpoints. The report of this Committee was accepted at a meeting of the Institute in June 1899.

Experience gained in applications of the standards and further developments in electrical apparatus and methods showed the necessity of revision, and a committee was appointed which after consultation with manufacturing and operating engineers presented the first revised report on Standardization Rules of the A.I.E.E. in June 1902.

The next revision was undertaken by a committee of ten, which presented its report in May 1906.

In September 1906, a Standards Committee of eleven members was appointed for further revision, and its report was presented in June 1907.

The appreciation of the importance and value of standardization resulted in the formation of a Standing Committee, with the title of Standards Committee of the A.I.E.E. This became effective in the Constitution of June 1907. The scope and amount of work necessitated increasing the number of members from time to time until in 1922 there were 37 members divided into a number of subcommittees specializing on various subjects.

A.I.E.E. Standards published in a single volume as each revision was adopted were generally accepted as Standards of the electrical industry of the United States since the adoption of the first report in 1899. Subsequent reports on Standards were made and published, in some cases in several editions. The dates of adoption by the Board of Directors of such reports are as follows: June 20, 1902; June 21, 1907; June 27, 1912; July 10, 1914; June 30, 1915; June 28, 1916; November 8, 1918; October 8, 1920, and June 29, 1922.

On June 29, 1922, in view of the increasing complexity of the work, a reorganization of the Standards Committee was effected, and a working organization established which provided for an increase in standardization work and for the appointment on Working Committees of the Standards Committee of non-Institute members.

The present plan under which the Institute Standards are being issued involves the separation of the complete body of Standards into more than forty sections, each published as a separate pamphlet and dealing with a specific subject. Each section of the Standards has been formulated either by a Working Committee of the Standards Committee which was made as representative as possible for the work in hand, by an A.I.E.E. technical committee or subcommittee, or by a Sectional Committee organized according to the procedure of the American Standards Association. The division of the Standards into a number of separate publications simplifies the process of keeping the standards revised to conform with the latest development and enables those interested in a particular field to obtain in concise form the material relating to that field. In framing the Institute Standards the chief purpose has been to define terms and conditions which characterize the rating and behavior of electrical machinery and apparatus, with special reference to the conditions of acceptance tests.

This revision of A.I.E.E. Standard No. 4 was developed under the auspices of the Instruments and Measurements Committee of the Institute and was approved by the Board of Directors on January 23, 1940.

The A.I.E.E. Standards Committee takes this occasion to draw attention to the value of suggestions based upon experience gained in the application of the Standards to general practise. Any suggestions looking toward improvement in the Standards will be welcomed for the guidance of the Committee in preparation of future editions, and should be communicated to the Secretary of the A.I.E.E. Standards Committee, 33 West 39th Street, New York.



STANDARDS OF THE American Institute of Electrical Engineers

MEASUREMENT OF TEST VOLTAGE IN DIELECTRIC TESTS

(Adopted by the Board of Directors May 18, 1928. Revised January 23, 1940.)

SCOPE AND PURPOSE

- 4-1 In this standard are set forth methods for the measurement of test voltages and wave shapes used in dielectric tests of electrical apparatus or insulating material. These tests are in three classes: 1. Puncture tests. 2. Flashover tests. 3. Voltage proof tests. The tests may involve the use of alternating current, direct current, or surges from surge generators. Different pieces of apparatus may require different dielectric tests, some requiring power frequency or direct-current tests only; other apparatus may require surge tests in addition. The specific requirements for any particular type of apparatus will be found in the standard dealing with that type of apparatus. This standard deals with the measurements themselves.

DIELECTRIC TESTS

- 4-2 Injury, if produced by dielectric stress applied to insulation is related to the time during which the stress is applied. Stresses up to a certain limit may be applied for an indefinite period without injury to the insulation. A somewhat greater stress, however, will cause heating of the insulation and progressive deterioration eventually resulting in breakdown. Higher values may be applied for short periods of time without causing damage to the insulation. This principle is used in dielectric tests on apparatus insulation using over-potentials of power frequency maintained for a specified limited time. The breakdown of insulation when subjected to surges often results in mechanical shattering. If the surge voltage is too high, repeated applications may cause failure. For surge tests the voltage applied should always be limited to a value such that a large number of repeated applications will not injure insulation which is in normal good condition.
- 4-3 The test voltage which shall be applied to determine the suitability of insulation for commercial operation is dependent upon the nature and design of the apparatus, its operating voltage, the nature of the service in which it is to be used and the severity of the mechanical and electrical stresses to which it may be subjected. The values of voltage and other conditions of

test which are specified in each of the standards dealing with the specific types of apparatus have been adopted as reasonable and proper.

VOLTAGE MEASUREMENTS

- 4-50 Methods of voltage measurement in dielectric tests are as follows:

Alternating Voltage Tests

Standard methods for alternating voltage values
Sphere gap Par. 4- 51
Transformer-voltmeter Par. 4- 68

Standard methods for wave shapes

Magnetic oscillograph Par. 4- 70
Cathode-ray oscillograph Par. 4- 71

Approved methods for alternating voltage values

Crest voltmeter Par. 4- 80
Electrostatic voltmeter Par. 4- 81
Primary voltage measurements....Par. 4- 82
Rectified capacitor current Par. 4- 83
Rotary or Generating voltmeter...Par. 4- 84
Sparkless sphere gap Par. 4- 85
Vacuum tube voltmeter Par. 4- 86
Voltmeter coil Par. 4- 87

Other methods for alternating voltage values

Rod gap Par. 4- 90
Point gap Par. 4- 91

Direct Voltage Tests

Standard method for direct voltage values

Resistor-ammeter method Par. 4-100

Standard method for voltage variations (ripples)

Magnetic oscillograph Par. 4-110
Cathode-ray oscillograph Par. 4-111

Approved methods for direct voltage values

Alternating voltage method Par. 4-120
Electrostatic voltmeter Par. 4-121
Rotary or Generating voltmeter...Par. 4-122
Sparkless sphere gap Par. 4-123
Sphere gap Par. 4-124

Other method for direct voltage values

Point gap Par. 4-130

Surge Voltage Tests

General recommendations Par. 4-150

Standard methods for surge voltage tests

Sphere gap Par. 4-160
Cathode-ray oscillograph Par. 4-161

Approved methods for surge voltage tests	
Gas glow tubes	Par. 4-170
Triode tubes	Par. 4-171
Rod gap	Par. 4-172
Other method for surge voltage tests	
Lichtenberg figures	Par. 4-180
Note: Surge current measurements...Par. 4-167	

ALTERNATING VOLTAGE TESTS

Standard Methods for Alternating Voltage Values

4-51 Standard Sphere Spark Gap.—The standard sphere spark gap shall be between two suitably mounted metal spheres of equal diameter. No extraneous conducting body other than the supporting shanks should be nearer the gap than twice the sphere diameter. Insulating bodies, such as supporting structures, should be at least one sphere diameter from the gap. The shanks should not be greater in diameter than one-fifth the sphere diameter. Metal collars, etc., through which the shanks extend, shall be as small as practicable and shall not during any measurement, come closer to the spheres than the maximum gap length used in the measurement. The sphere curvature measurement by a spherometer should not vary more than one per cent from that of a true sphere of the required diameter.

4-52 60-Cycle, Impulse and D-c Voltages.—When proper precautions are taken the sphere spark gap is a suitable reference standard for the measurement of crest values of 60-cycle* and impulse voltages.

4-53 Positive and Negative Calibration Curves.—In Table I two sets of values of crest voltage in kilovolts are given. One is for use with 60-cycle and impulse voltages in which the ungrounded sphere is negative, and the other is for use with impulse voltages in which the ungrounded sphere is positive. It will be noted that these sets of values are practically identical when the spacing is less than about one-third the diameter of the sphere.

4-54 Time to Spark-over.—The recommended sphere spark gap calibrations (Table I) may be used for the measurement of crest voltage for waves requiring more than one or two microseconds to spark-over. For waves of less than one or two microseconds to spark-over, the sphere spark gap with these calibrations would indicate something lower than true crest voltages, by an amount which depends upon the wave shape. Superimposed oscillations may introduce measurement errors.

* Until such time as sufficient supporting data become available the calibrations given for 60-cycle can be used for other industrial frequencies and d-c voltages.

4-55 External Electric Fields.—The standard sphere gap should be set up for use in a space comparatively free from external electric fields. Care should be taken that conducting bodies forming part of the circuit, or at circuit potential, are not so located with reference to the gap that their electric fields are superimposed on that of the gap, e.g., the protective resistance should not be arranged so as to present a large surface near the gap, even at a distance of twice the sphere diameter.

4-56 Effect of Ground.—Variations in spark-over voltage due to the effect of ground, adjacent objects, walls and other field distorting influences may require consideration for gap spacings above one-half the sphere diameter. When spacings in excess of three-quarter sphere diameter are used, attention should be given to clearances and the position of the line potential lead.

4-57 Horizontally Mounted Spheres.—The sphere gap calibrations (Table I) apply for vertically mounted spheres. They may be used for horizontally mounted spheres provided the spacing does not exceed three-quarter sphere diameter.

4-58 Both Spheres Insulated.—The recommended sphere gap calibrations and requirements for one sphere grounded shall apply to the case of both spheres insulated provided the spacing is limited to one-third of the sphere diameter for 25 cm and smaller spheres, and to one-quarter the sphere diameter for 50 cm and larger spheres.

4-59 Distance to Ground.—Distance to ground of the ungrounded sphere, from the sparking point, shall be not less than 5 nor more than 10 sphere diameters for 50 cm and smaller spheres. Due to limitations of space in laboratories, it may be necessary to reduce clearances for spheres larger than 50 cm below the five-sphere diameters specified. It is permissible to reduce the spacing in graduated steps down to two and one-half-sphere diameters for 200 cm spheres.

4-60 Accuracy.—When sphere gaps are used as specified, with corrections properly applied, the accuracy of the voltage measurement should be within three per cent.

4-61 Sphere-Gap Spark-Over Voltage.—The standard values of spark-over voltage between spheres for various spacings are shown in Tables I and I-A. The former gives crest values of voltage and the latter the rms values of a sinusoidal wave having the crest values given in Table I.

4-62 Effect of Air Density on Spark-Over Voltage.—The only correction to be applied to the

tabulated values of spark-over voltage is that for air density which depends on air pressure and temperature existing at the gap. Humidity has a negligible effect unless condensation takes place on the sphere surfaces. A small effect has been observed using 12.5 cm spheres, which lies within the tolerance of this standard. The spark-over voltage, for a given gap, decreases with decreasing barometric pressure and increasing temperature. This variation may be considerable at high altitudes. When the variation from sea level is not great, the relative air density may be used as the correction factor; when the variation is great, or greater accuracy is desired, the correction factor corresponding to the relative air density should be taken from Table II in which

$$\text{Relative air density}^* = \frac{0.392 b}{273 + t}$$

b = barometric pressure in mm

t = temperature in degrees centigrade.

Corrected curves may be plotted for any given altitude, if desired. It will be noted in Table II that for values of relative air density above 0.9 the correction factor does not differ greatly from the relative air density.

4-63 Correction of Gap Spacing for Air Density.—

To determine the gap spacing for a required spark-over voltage, divide the required voltage by the correction factor obtained from Table II, and use the new voltage thus obtained to find the corresponding spacing from Table I, using the voltage values given for 25 C. For convenience, a graph of voltage (25 C values) versus gap spacing may be used.

4-64 Correction of Voltage for Air Density.—To determine the spark-over voltage for a given gap spacing, multiply the voltage (25 C value) corresponding to the gap spacing obtained from Table I by the correction factor from Table II.

4-65 Use of Sphere Gaps in Dielectric Tests.—

When using sphere gaps to check voltage in dielectric tests of electrical apparatus, precaution should be taken against overvoltage oscillations which may cause erratic spark discharge. To this end and to limit the resulting current at the time of spark-over, a non-inductive resistance of at least one ohm per volt of test voltage should be inserted in series with the sphere gap. This applies for measurements at ordinary power frequencies up to 70 cycles per second. For higher test frequencies and particularly in the case of the larger spheres where the drop in the resistance due to the charging current in

the spheres becomes appreciable, this resistance should be reduced. For surge voltage measurements no series resistance should be used with the sphere gap.

The resistance should be as near the gap as possible and excessive corona between the gap and apparatus should be avoided. There should be no resistance in series with the apparatus under test. When one sphere is grounded the resistance should be in series with the line potential sphere. For ungrounded spheres half the resistance shall be in series with each sphere. A water tube is a suitable resistor for this purpose although other resistors may be used whose resistance is not appreciably decreased at higher voltages.

The spheres should be kept clean and care should be taken that they do not become heated by successive discharges.

4-66 Use of Voltmeter with Sphere Gap Measurements.—

In measuring voltage with sphere gaps a voltmeter should always be used. The instrument should derive its voltage from the high-voltage circuit either through a potential transformer or by connections described under the approved methods for alternating-voltage tests (4-80 to 4-87). With the sphere gap set for a given voltage, 75 per cent of this voltage may be applied as rapidly as desired and the remaining 25 per cent to flashover applied at a substantially uniform rate within not less than ten seconds. A reading of the voltmeter is taken simultaneously with sphere gap breakdown. A voltmeter should be used whose damping characteristics are such that its reading is substantially correct at the instant of gap breakdown. Successive trials should be repeated at not less than 15-second intervals until at least three consecutive voltmeter readings are taken, whose maximum and minimum values are within three per cent of their average value. The average of these three readings should be considered as the required voltmeter reading to give the voltage for which the spark gap was set.

4-67 Ultra-Violet Irradiation.—

Ultra-violet irradiation is recommended for sphere gaps of 6.25 cm or less when measuring 60-cycle and impulse voltages for gap spacings one-third the sphere diameter and less. A quartz tube, mercury-vapor lamp operating on direct current is tentatively recommended as a source. A lamp operating with a voltage drop of 20-30 volts per inch of arc length and at approximately one ampere having a minimum wattage of 35 has been found satisfactory when its distance from either sphere did not greatly exceed five times the gap spacing. For lamps of higher

* Based on standard conditions of 25 degrees centigrade and 760 millimeters barometric pressure.

wattage the equivalent intensity can be approximately obtained by applying the inverse square law. A lamp conforming with these requirements is recommended. Other equivalent sources are permissible. The shortest distance from either sphere surface to the source shall not be less than five times the gap spacing.

- 4-68 Transformer-Voltmeter.** — Alternating voltages may be measured with an alternating-current voltmeter and a potential transformer. A potential transformer properly designed and built for measurement purposes when used with a normal instrument load, will have a nearly constant voltage ratio characteristic. This ratio characteristic should be known for the full voltage range, wave shape and burden in use and corrections applied when necessary. The potential transformer-voltmeter method of measurement provides an rms value of voltage. When this is to be changed to crest value, the correct crest factor should be determined by analysis of oscillograms of the voltage wave being measured.

Standard Methods for Wave Shapes

- 4-70 Magnetic Oscillograph.**—Wave shapes may be recorded with a magnetic oscillograph and a potential transformer or voltmeter coil of known ratio characteristic. The potential transformer, when operated well below magnetic saturation in connection with this type of oscillograph provides a satisfactory low-voltage reproduction of the high-voltage wave shape, particularly with reference to the value of the fundamental and harmonics which make up the wave. Oscillograms thus recorded with the test sample in the circuit at the test voltage level, or for flashover tests, within ten per cent of flashover voltage, will show the effect of the test sample on the wave shape.

- 4-71 Cathode-Ray Oscillograph.**—Wave shapes may be recorded with the cathode-ray oscillograph. Voltages too high for direct application may be connected to the oscillograph through a capacitance or resistance divider, a potential transformer or a voltmeter coil. Measurement conditions such as voltage level, available current and frequency response will determine the type of divider or transformer to be selected.

The capacitance divider is usually preferable when the available supply circuit current is low, and when it is required to detect and record short time surge voltages in addition to the fundamental wave and the harmonics. The divider capacitance should be of such value and so connected that the wave recorded at the oscillograph is an exact low-voltage duplicate of the high-voltage test wave. If the divider

affects the wave shape at the test piece, it must remain in the circuit while test voltage is applied. The capacitance across the deflection plates of the oscillograph should be adjusted in consideration of the amount of leakage resistance, both inherent and connected across the deflection plates of the oscillograph, and of the frequencies to be measured.

The resistance divider is usually preferable when precision is required, because it is less subject to interference and more readily calibrated. For accurate results the value of the resistance used shall be selected in accordance with the frequency to be measured. Corona streamers along the resistor must be avoided. If the resistance is low, distorting the test wave shape, it shall remain in the circuit while test voltage is applied. Wave shapes should be recorded at the level of test voltage, or for flashover tests within ten per cent of flashover voltage.

Approved Methods for Alternating Voltage Values

- 4-80 Crest Voltmeter.**—The crest voltmeter, which usually consists of a rectifier, capacitor, resistor and direct-current ammeter, may be used when crest voltage values are required. If effective values of voltage are desired, the wave shape should be measured by approved methods.

The most common arrangement of the crest voltmeter consists of a capacitor, charged through a rectifier from the voltage source to be measured, with a voltmeter arranged to measure the capacitor voltage. This voltmeter usually consists of a resistor in series with a d-c microammeter. From the ammeter current the crest voltage applied to the capacitor can be calculated, taking into account the decrease of this capacitor voltage during the non-charging period. The crest voltmeter should be calibrated against an rms voltmeter with a pure sine wave of the same frequency as the test frequency.

If a potential transformer of known ratio characteristics is used, the crest voltmeter is connected across the low voltage (secondary terminals) and the measured crest voltage is multiplied by the transformer ratio to give the required crest voltage.

When the crest voltmeter is used with the primary winding of the test transformer or with a voltmeter coil, it should be calibrated against the sphere gap or supplemented by oscillographic examination of wave shapes.

The crest voltmeter may be used with a capacitance divider for high-voltage measurements. This divider is usually made up of a high-voltage, low-capacitance element in series with a low-voltage, high-capacitance element