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Std 262-1973

An American National Standard

IEEE Standard Test Code for
Distribution, Power, and Regulating Transformers

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American National Standard

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Foreword

(This foreword is not part of American National Standard Test Code for Distribution, Power, and Regulating Transformers, ANSI C57.12.90-1973, IEEE Std 262-1973.)

Standards in the C57 series covering transformers, regulators, and reactors have been issued and updated with regularity since March 1940, when a trial-use volume containing C57.1, C57.2, and C57.3 was published. That document superseded standards 12, 13, 14, 100, and the Test Code for Transformers of the American Institute of Electrical Engineers (one of the predecessors of IEEE) and contained data derived from the standards of the Edison Electric Institute and the National Electrical Manufacturers Association. Two years later, an extensively revised document was published covering the same material as a full status standard. Further revisions and expansions were reflected in 1948, 1949, and 1956 editions. The 1956 edition, designated C57.12-1956, consolidated preceding standards on distribution, power, and regulating transformers, and it formed the parent document for the nearly thirty current standards and guides in the C57 series.

The present document reflects revisions carried out within the Working Group on Revision of Dielectric Tests and the Working Group on Thermal Evaluation of Power and Distribution Transformers of the Power Transformer Subcommittee of the Transformer Committee of the IEEE Power Engineering Society. Following approval by the IEEE Standards Committee, this standard was submitted to American National Standards Committee C57 and received approval for submission to ANSI. At the time it approved this standard, C57 had the following membership:

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An American National Standard

IEEE Standard Test Code for

Distribution, Power, and Regulating Transformers

1. Scope

This standard prescribes methods for performing tests specified in American National Standard General Requirements for Distribution, Power, and Regulating Transformers, C57.12.00-1973 (IEEE Std 462-1973) and in the separate transformer standards of the C57.12 Series of American National Standards.

The test methods covered herein are as follows:

- (1) Resistance measurements (see Section 2)
- (2) Dielectric insulation (see Section 3)
- (3) Losses and impedance (see Section 4)
- (4) Ratio and regulation (see Section 5)
- (5) Temperature rise (see Section 6)
- (6) Insulation power factor tests (see Section 7)
- (7) Polarity and phase relation (see Section 8)
- (8) Short-circuit calculations (see Section 9)

2. Resistance Measurements

Resistance measurements are of fundamental importance for two purposes:

- (1) For the calculation of the conductor or $I^2 R$ loss
- (2) For the calculation of winding temperatures at the end of a temperature test

2.1 Determination of Cold Temperature. The cold temperature of the winding shall be determined as accurately as possible when measuring the cold resistance. The following precautions shall be observed:

2.1.1 General. Cold resistance measurements shall not be taken on a transformer when it is located in drafts or when it is located in a room in which the temperature is fluctuating rapidly.

2.1.2 Transformer Windings Out of Oil.

The temperature of the windings shall be recorded as the average of several thermometers inserted between the coils, with extreme care used to see that their bulbs are as nearly as possible in actual contact with the copper of the windings. It should not be assumed that the windings are at the same temperature as the surrounding air.

2.1.3 Transformer Windings Immersed in Oil. The temperature of the windings shall be assumed to be the same as the temperature of the oil, provided the transformer has been under oil with no excitation and with no current in its winding from three to eight hours before the cold resistance is measured, depending upon the size of the transformer.

2.2 Drop-of-Potential Method. The drop-of-potential method is generally more convenient than the bridge method (see Section 2.3) for measurements made in the field. It should be employed only if the rated current of the transformer winding is 1 A or more.

In all cases, greater accuracy may be obtained by the use of potentiometers for the measurement of both current and potential although the setup may be rather cumbersome.

2.2.1 Measurement is made with direct-current and simultaneous readings of current and voltage are taken using the connections of Fig 1. The required resistance is calculated from the readings in accordance with Ohm's law.

If the direct current is supplied by a commutating machine, the pointer of the voltmeter may vibrate because of the commutator ripple in the voltage. In such cases, some winding of the transformer other than the winding under test should be short-circuited; this will damp the ripple and reduce or eliminate the vibration of the voltmeter.

The current in the winding which is being measured should have become practically constant before short-circuiting the other

winding; otherwise, erroneous values of resistance may be obtained. It has been found by experience that the relative time constants under these two conditions are such that steady direct current is reached more quickly under the open-circuit conditions than under the short-circuit conditions.

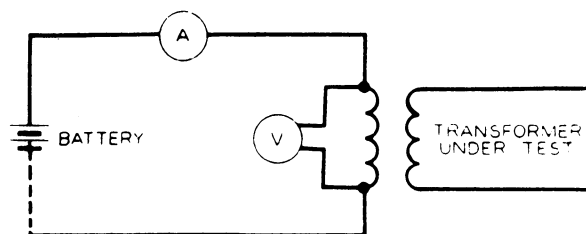


Fig 1
Connections for the Drop-of-Potential Method of Resistance Measurement

2.2.2 In order to minimize errors of observation, the measuring instruments shall have such ranges as will give reasonably large deflections.

2.2.3 The voltmeter leads shall be independent of the current leads and shall be connected as closely as possible to the terminals of the winding to be measured. This is to avoid including in the reading the resistances of current-carrying leads and their contacts and of extra lengths of leads.

To protect the voltmeter from injury by off-scale deflections, the voltmeter should be disconnected from the circuit before switching the current on or off.

If the drop of potential is less than 1 V, a potentiometer or millivoltmeter shall be used.

2.2.4 Readings shall not be taken until after the current and voltage have reached steady-state values.

When measuring the cold resistance, preparatory to making a heat run, the time required for the readings to become constant should be noted. The period thereby determined should be allowed to elapse before taking the first reading at the termination of the heat run.

If the winding under test has an appreciable time constant, the current can be made to attain its steady-state value more rapidly by first raising the voltage to a value greater than

that required under steady-state conditions, to maintain the desired current value, and then decreasing the voltage as the current approaches the desired value.

2.2.5 Readings shall be taken with not less than four values of current when deflecting instruments are used. The average of the resistances calculated from these measurements shall be considered to be the resistance of the circuit.

The current used shall not exceed 15 percent of the rated current of the winding whose resistance is to be measured. Larger values may cause inaccuracy by heating the winding and thereby changing its temperature and resistance.

If the current is too low to be read on an available ammeter, a shunt and a potentiometer shall be used.

2.3 Bridge Methods. The bridge methods are generally preferred because of their accuracy and convenience, since they may be employed for the measurement of resistances up to 10 000 ohms. They should be used in cases where the rated current of the transformer winding to be measured is less than 1 A.

Bridge methods are especially recommended for all measurements which are to be used in connection with temperature-rise determinations.

2.4 Conversion of Resistance Measurements. Cold winding resistance measurements are normally converted to a standard reference temperature of rated temperature rise plus 20°C. In addition, it may be necessary to convert the resistance measurements to the temperature at which the impedance loss measurements were made. The conversions are accomplished by the following formula:

$$R_s = R_m \frac{T_s + T_k}{T_m + T_k} \quad (\text{Eq 1})$$

where

R_s = resistance at desired temperature T_s

R_m = measured resistance

T_s = desired reference temperature

T_m = temperature at which resistance was measured

T_k = 234.5 for copper, 225 for aluminum

3. Dielectric Tests

3.1 General

3.1.1 Test Procedure. Unless otherwise specified, dielectric tests shall be made in accordance with American National Standard Measurement of Voltage in Dielectric Tests, C68.1-1968 (IEEE Std 4-1968).

Exception: A protective resistance may be used in series with sphere gaps, either on the live or grounded sphere. Where unnecessary to protect the spheres from arc damage, it may be omitted.

Exception: The bushing-type potential divider method (see American National Standard C68.1-1968 [IEEE Std 4-1968]) shall be considered a standard method for transformer tests.

Exception: The rectified capacitor-current method (see American National Standard C68.1-1968 [IEEE Std 4-1968]) shall be considered a standard method for transformer tests.

3.1.2 Insulation Resistance. The insulation resistance of electrical apparatus is of doubtful significance as compared with the dielectric strength. It is subject to wide variation with temperature, humidity, and cleanliness of the parts. When the insulation resistance falls below prescribed values, it can, in most cases of good design and where no defect exists, be brought up to the required standard by cleaning and drying the apparatus. The insulation resistance, therefore, may afford a useful indication as to whether the apparatus is in suitable condition for application of the dielectric test.

The insulation-resistance test shall be made with all circuits of equal voltage above ground connected together. Circuits or groups of circuits of different voltage above ground shall be tested separately.

3.1.3 Tests on Bushings. When tests are required on bushings separately from the transformers, the tests shall be made in accordance with American National Standard Requirements and Test Code for Outdoor Apparatus Bushings, C76.1-1964 (R1970) (IEEE Std 21-1964).

3.1.4 Dielectric Tests in the Field. Field dielectric tests may be warranted on the basis of detection of combustible gas or other cir-

cumstances. However, periodic dielectric tests are not recommended because of the severe stress imposed on the insulation.

Where field dielectric tests are required, low-frequency applied potential and induced potential tests shall be used and the phase-to-ground or phase-to-phase voltage stress imposed shall not exceed 150 percent of normal operating stress or 85 percent of full test voltage, whichever is lower. The duration of the tests shall be the same as that specified in Sections 3.2.4 and 3.3.2 for applied- and induced-potential tests, respectively.

3.1.5 Factory Dielectric Tests. The purpose of dielectric tests in the factory is to check the insulation and workmanship and, when required, to demonstrate that the transformer has been designed to withstand the specified insulation tests.

Dielectric tests should preferably be made at the temperature assumed under normal operation or at the temperature attained under the conditions of routine test.

Impulse tests, when required, shall precede the low-frequency tests. Switching-surge tests, when required, shall also precede the low-frequency tests.

During low-frequency tests, either applied or induced, careful attention should be maintained for evidence of possible failure. Evidence of failure could include items such as an indication of smoke and bubbles, an audible sound such as a "thump," a sudden increase in test circuit current, an increase in corona level, etc. Any such indication should be carefully investigated either by observation, or by repeating the test or by other tests, to determine if a failure has occurred.

The insulation class of the neutral end of the winding may differ from the insulation class of the highest voltage neutral bushing for which provision is made in the transformer tank. In this case the dielectric tests on the neutral shall be determined by whichever is lower; the insulation class of the neutral end of the winding or the insulation class of the neutral bushing.

When transformers covered by this standard are to be assembled in a common tank and interconnected, the complete assembly shall be tested as a unit at 100 percent of the lowest test voltage required by any of the components.

3.2 Applied-Potential Tests

3.2.1 Connections. The terminal ends and taps brought out of the case of the winding under test should all be joined together and to the line terminal of the testing transformer.

All other terminals and parts (including core and tank) should be connected to ground and to the other terminal of the testing transformer.

The ground connections between the transformer being tested and the testing transformer should be a substantial metallic circuit.

Small bare wire may be used in connecting the respective taps and line terminal together, but care shall be taken to keep the wire on the high-voltage side well away from the ground.

The high-voltage lead from the testing transformer should preferably be at least $\frac{1}{8}$ inch in overall diameter.

3.2.2 Resistance. No appreciable resistance should be placed between the testing transformer and the one under test. It is permissible, however, to use reactive coils at or near the terminals of the testing transformer.

3.2.3 Relief Gap. A relief gap set at a voltage 10 percent or more in excess of the specified test voltage may be connected during the applied-potential test.

3.2.4 Duration and Frequency. A normal power frequency such as 60 Hz shall be used and the duration of the test shall be one minute.

3.2.5 Procedure for Application of Test Voltage. The test voltage should be started at one-quarter or less of the full test voltage and increased to full test voltage without delay other than that required for selective measurements below 85 percent of full test voltage. After being held for the duration of time specified in Section 3.2.4, the voltage should be reduced linearly to one-quarter or less of the full test voltage without delay other than that required for selective measurements below 85 percent of full test voltage, and the source circuit opened, unless a longer time is required by customer specifications.

3.2.6 Exceptions in Methods of Measuring Dielectric Test Voltage. For transformers of 100 kVA and less to be tested at 50 kV or less, it is permissible to depend on the ratio of the testing transformer to indicate the proper test voltage.

3.3 Induced-Potential Tests

3.3.1 As this test applies greater than rated volts per turn to the transformer, the frequency of the applied voltage must be high enough to limit the flux density in the core to that permitted by Section 2.4 (2) of American National Standard C57.12.00-1973. The minimum test frequency to meet this condition is:

$$\text{Test Frequency} = \frac{E_t}{1.1 \times E_r} \times \text{Rated Frequency} \quad (\text{Eq 2})$$

where

E_t = induced test voltage across winding

E_r = rated voltage across winding

3.3.2 When frequencies higher than 120 Hz are used, the severity of the test may be abnormally increased and for this reason the duration of the test shall be 7200 cycles. Representative times for different frequencies are given below:

Frequency (Hz)	Duration (Seconds)
120 and less	60
180	40
240	30
360	20
400	18

3.3.3 The test voltage should be started at one-quarter or less of the full test voltage and increased to full test voltage without delay other than that required for selective measurements below 85 percent of full test voltage. After being held for the duration of time specified in Section 3.3.2, the voltage should be reduced linearly to one-quarter or less of the full test voltage without delay other than that required for selective measurements below 85 percent of full test voltage, and the source circuit opened, unless a longer time is required by customer specifications.

3.3.4 In the case of transformers having one end of the high-voltage winding grounded, the other windings should be grounded during the induced-potential test. This ground on each winding may be made at a selected point of the winding itself or of the winding of a step-up transformer which is used to supply the voltage or which is merely connected for the purpose of furnishing the ground.

3.3.5 Three-phase transformers may be tested with single-phase voltage. The specified test voltage is induced, successively, from each line terminal to ground and to adjacent line terminals. The neutrals of the windings may or may not be held at ground potential during these tests. A separate single-phase test or three-phase test may be required when the required test voltage between adjacent line terminals is higher than the required test voltage from the line terminals to ground.

3.3.6 When the induced test on a winding results in a voltage between terminals of other windings in excess of the low-frequency test voltage specified in this standard, the other windings may be sectionalized and grounded. Additional induced tests shall then be made to give the required test voltage between terminals of windings that were sectionalized. Autotransformers with grounded neutrals cannot always be tested at the assigned low-frequency test levels because the insulation levels may not be in proportion to the ratio of the windings. In that case, the winding with the lowest ratio of low-frequency test voltage to minimum turns will determine the induced voltages on all windings. The other winding will be tested at maximum turns unless maximum turns will produce a voltage in the other winding in excess of the required test level. This situation is possible on autotransformers with a wide tap-changer range in one winding.

3.4 Impulse Tests

NOTE: See Guide for Transformer Impulse Tests, C57.98 (IEEE Std 93-1968) (Appendix to American National Standard C57.12.90-1973), for a complete report on impulse testing techniques, interpretation of oscillograms, and failure detection criteria.

When impulse tests on line terminals are specified, they shall consist of and be applied in the following order: one reduced full-wave, two chopped-waves, and one full-wave. When front-of-wave tests are also specified, impulse tests are generally applied in the following order: one reduced full-wave, two front-of-waves, two chopped-waves, and one full-wave.

The order of the chopped-wave and front-of-wave tests is not mandatory but a reduced full wave must precede all the impulse tests, and the full-wave must be the last wave applied to the terminal under test. Another reduced full-wave may be applied following the two front-of-waves.

Impulse tests shall be made without excitation.

3.4.1 Reduced Full-Wave Test. For this test the applied voltage wave shall have a crest value of between 50 and 70 percent of the full-wave value given in Tables 4 or 5 of American National Standard C57.12.00-1973 (IEEE Std 462-1973).

3.4.2 Chopped-Wave Test. For this test the applied voltage wave shall be chopped by a suitable air gap. It shall have a crest value and time to flashover in accordance with Tables 4 or 5 of American National Standard C57.12.00-1973 (IEEE Std 462-1973). This gap shall be located as close as possible to the terminals, and the impedance shall be limited to that of the necessary leads to the gap.

3.4.3 Front-of-Wave Test. For this test the voltage shall be chopped on the rising front before the normal crest of the wave by a suitable air gap. It shall have a crest value and time to flashover in accordance with Table 10 of American National Standard C57.12.00-1973 (IEEE Std 462-1973).

Two applications of the front-of-wave tests shall be used. In general, front-of-wave tests shall be applied only to line terminals, and not to neutral or other terminals.

The voltage shall be measured by a separate connection to the terminal being tested. The gap used to chop the wave on the front shall be directly connected to the terminal being tested and may be mounted directly on the terminals. The impedance shall be limited to that of the necessary leads to the gap.

In order to provide some tolerance in practical testing, a negative tolerance of 0.1 microsecond to the tabulated times in Table 10 of American National Standard C57.12.00-1973 (IEEE Std 462-1973) shall be permitted. Since the test is more severe with duration, a permissible limit shall be a positive tolerance of 0.3 microsecond. If in making any front-of-wave test, the negative tolerance of minus 0.1 microsecond is exceeded, the test may be considered as having been met provided the crest voltage attained in such test shall have equalled or exceeded the voltage determined by the following equation:

$$\text{Voltage} = \text{Crest Voltage} \left(1 + \frac{(T - 0.1) - T_1}{AT_1} \right) \quad (\text{Eq 3})$$

where

T = specified time to sparkover in micro-seconds

T_1 = actual time measured in microseconds

A = 4 for 69 kV insulation class and above
3 for 46 kV insulation class and below

NOTE: For minimum crest voltages see Column 3 of Table 10 of American National Standard C57.12.00-1973 (IEEE Std 462-1973).

When testing windings that have large capacitance such as high kVA and low voltage, it may not be practical to obtain times-to-flashover down to 0.5 microsecond. Because of the large chopping currents associated with the large capacitance, errors are introduced into the measuring circuit. In order to avoid these difficulties, the voltages and times specified shall be considered met provided the tests are made with the gap settings listed in Table 1 and with the minimum and maximum times to flashover given.

Table 1
Test Values, Gap Settings, and Minimum and Maximum Times to Flashover

Full-Wave Test Value* (kV)	Front-of- Wave Test Value (kV)	Gap Length† (Inches)	Time to Flashover	
			Min (Micro- seconds)	Max (Micro- seconds)
45	75	1¼	0.5	1
60	100	1½	0.5	1
75	125	2	0.5	1
95	165	2¾	0.5	1
110	195	3-3/8	0.5	1
150	260	4½	0.5	1

*1.2 x 50 microsecond full-wave test voltage.

†The gap shall consist of the space between two ½-inch square cut square rods. The rods shall be mounted one from the top of the terminal tested and the other either from the flange of the same terminal or other adjacent grounded parts. The gap should preferably be centered on the bushing and adjacent to it. However a separate gap resting on the transformer may be used.

NOTE: The application of steep front tests on windings directly connected to generators or other circuits not exposed to lightning is unnecessary.

3.4.4 Full-Wave Test. For this test the voltage wave shall have a crest value in accordance with Tables 4 or 5 of American National Standard C57.12.00-1973 (IEEE Std 462-1973) and no flashover of the bushing or test gap shall occur.

To avoid flashover of the bushing during adverse conditions of humidity and air density, the bushing flashover may be increased by appropriate means.

The time interval between application of the last chopped wave and the final full wave shall be minimized to avoid recovery of insulation strength if a failure has occurred prior to the final full wave.

3.5 Connections for Impulse Tests. In general, the tests shall be applied to each terminal, one at a time.

3.5.1 Terminals Not Being Tested. Neutral terminals shall be solidly grounded except in the case of low impedance windings (see Section 3.5.6). Line terminals, including those of autotransformers and regulating transformers, shall be either solidly grounded or else grounded through a resistor with an ohmic value not in excess of the following values:¹

Nominal System Voltage (kV)	Resistance (Ohms)
345 & below	500
500	400
700	300

The following factors shall be considered in the actual choice of grounding for each terminal:

(1) The voltage-to-ground on any terminal that is not being tested should not exceed 80 percent of the full wave impulse voltage level for that terminal

(2) If a terminal has been specified to be directly grounded in service, then that terminal shall be solidly grounded

(3) If a terminal is to be connected to a low impedance cable connection in service, then that terminal shall either be directly grounded or else grounded through a resistor with an ohmic value not in excess of the surge impedance of the cable

(4) Grounding through a low impedance shunt for cathode-ray oscillograph current measurements may be considered the equivalent of a solid ground

3.5.2 Windings for Series or Multiple Connection. Windings for series or multiple connection, if either connection is in the 25 kV insulation class or above, shall be tested on both series and multiple connections. The test voltage for the two conditions shall be that

¹These values are representative of typical transmission line surge impedances.

corresponding to the insulation class of the winding for that connection. For insulation class 15 kV and below, only the series connections shall be tested unless tests on both connections are specified.

3.5.3 Windings for Δ or Y Connections. Three-phase transformers having a winding for Δ or Y shall be tested on both Δ and Y connections. If either connection is in the 25 kV insulation class, or above, the test voltage for each connection shall be that corresponding to the insulation class of the winding for that connection. For insulation class 15 kV and below, only the Y connection shall be tested unless tests on both connections are specified.

3.5.4 Tap Connections. Tap connections shall be made with minimum effective turns in the winding under test. The choice of tap connections of windings not being tested shall be made by the manufacturer. (Regulating transformers shall be set at maximum buck position.)

3.5.5 Protective Devices. Transformers and regulators which have as an integral part of the equipment nonlinear protective devices connected across the series winding or portions of any winding, in an accessible place, and where the terminals are of the same voltage class, shall be tested by connecting these terminals together and applying the usual tests. If the terminals cited are not accessible, it will be necessary to include the nonlinear protective devices in place during the test. The operation of these devices usually will cause differences between the reduced-full-wave and the full-wave oscillograms. That these differences are caused by the operation of the protective devices may be demonstrated by making two or more reduced-full-wave tests at different voltage values to show the trend in their operation. Where the nature of the protective devices and the design of the transformer permit, the impedance of such devices may be varied for the full-wave and reduced-wave tests as an optional refinement in the technique of failure detection. (See Section 3.7.)

3.5.6 Windings of Very Low Impedance. The impedance of some windings may be so low that the desired time to the 50 percent voltage point on the tail of the wave cannot be obtained with available equipment. In such cases, shorter waves may be used. In order to

assure that an adequate test is obtained, the capacitance of the generator with the connection used should exceed 0.011 microfarad. At the manufacturer's preference he may test low impedance windings by tying the terminals of windings with the same insulation level together. The manufacturer may also elect to test low impedance winding by inserting a resistor of not more than 500 ohms in the grounded end of the winding.

3.6 Impulse Tests on Transformer Neutrals. Impulse tests on the neutral of a transformer or a separate regulator connected in the neutral of a transformer may be applied by one of the methods given below.

3.6.1 Method 1. The test on the neutral, or neutral and regulating winding, is induced by the application of an impulse to any line terminal with the neutral open-circuited or grounded through a suitable impedance so that the required full-wave test voltage is obtained from the neutral terminal to ground. One reduced and two full waves shall be applied to the end of a winding with a crest voltage equal to or less than the full wave level of the line end. The other windings may be short-circuited for this test. The winding being tested shall be either on the minimum voltage connection or on the maximum voltage connection. The voltage oscillograms shall be taken at the neutral.

When this method of test is used, the test on the neutral shall precede the test on the line terminal.

3.6.2 Method 2. One reduced and two full waves are applied directly to the neutral or regulator winding with an amplitude equal to the insulation level of the neutral. The winding being tested shall be either on the minimum voltage connection or on the maximum voltage connection. A wave having a front of not more than 10 microseconds and a tail of 50 microseconds to half-crest shall be used except that, if the inductance of the winding is so low that the desired voltage magnitude and duration to the 50 percent point on the tail of the wave cannot be obtained, a shorter wave-tail may be used.

3.7 Detection of Failure During Impulse Test. Because of the nature of impulse test failures, one of the most important matters is the detection of such failures. There are a number