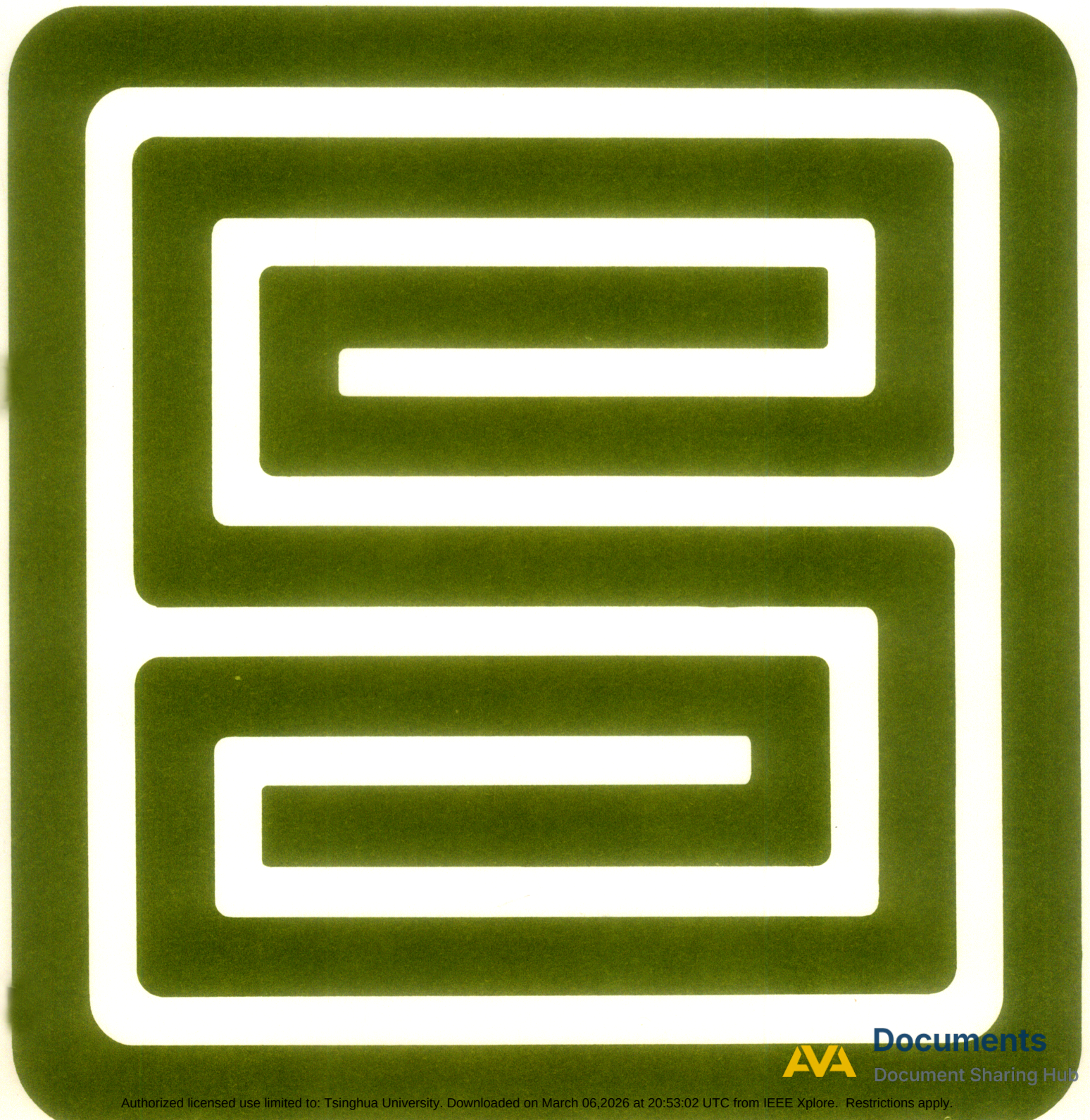
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Revision of
[redacted]

IEEE
Standard
No. 262

Institute of
Electrical and
Electronics
Engineers

USA Standard

Test Code for Distribution, Power and Regulating Transformers, and Shunt Reactors



C57.12.90-1968

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IEEE
No. 262

USAS
C57.12.90-1968
Revision of
C57.12.90-1965 &
C57.12.90a-1966

USA Standard
Test Code for
Distribution, Power, and Regulating Transformers, and Shunt Reactors

Sponsor
Electrical and Electronics Standards Board

Approved June 28, 1968
United States of America Standards Institute

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Foreword

(This Foreword is not a part of USA Standard Test Code for Distribution, Power, and Regulating Transformers, and Shunt Reactors, C57.12.90-1968.)

For a number of years prior to 1942, the Sectional Committee on Transformers, Regulators, and Reactors, C57, of the American Standards Association* was developing and correlating standards on transformers. The data used in this work was gathered from many sources, including the existing standards and publications of the Institute of Electrical and Electronics Engineers, standards of the National Electrical Manufacturers Association, reports of the Edison Electric Institute, and others. This work resulted in the publication in 1942 of the American Standard for Transformers, Regulators and Reactors.

This standard was revised and greatly expanded in 1948, 1949, and 1956. The 1956 edition was comprised of a revision and editorial consolidation of the preceding standards on distribution, power, and regulating transformers, namely American Standard Requirements for Distribution, Power, and Regulating Transformers, and Reactors Other Than Current-Limiting Reactors, C57.12-1949, American Standard Test Code for Distribution, Power, and Regulating Transformers, C57.22-1948, and American Standard Requirements for Transformers - 67,000 Volts and Below; 501 Through 10,000 kva, 3 Phase; 501 Through 5,000 kva, 1 Phase, C57.12a-1954. In addition, in order to eliminate cross-references wherever possible, the consolidation contained excerpts from other standards of the C57 family.

In 1957 two supplements to American Standard C57.12-1956 were approved and published. These were American Standard Requirements for Overhead-Type Distribution Transformers, C57.12c, Section 20, and C57.12d, which also revised certain sections of the 1956 standard.

The 1958 edition was comprised of a revision of American Standard C57.12-1956 and of the two supplements, C57.12c and C57.12d, and, in addition, incorporated, as part of the approved American Standard, Section 30 on three-phase load-tap-changing transformers, which had been published in 1956 as a Proposed American Standard recommended for use by the sectional committee on transformers.

Recognizing that some sections of the standard would require revision sooner than other sections, it was decided to issue each section as a separate standard.

The material in this standard dealing with methods of demonstrating performance and characteristics, making dielectric and other tests, and making engineering computations, has been supplied largely by the IEEE Transformers Committee. This revision has been approved by the Transformers Committee and by the IEEE Standards Committee for the IEEE, and therefore carries the IEEE designation 262 in addition to its Standards Institute designation.

The 1968 revision of this standard updates and improves the presentation of the standard. The work of consolidating and editing this standard was performed by the Subcommittee on Power Transformers, C57.12.1, and USA Standards Committee C57.

Suggestions for improvement gained in the use of this standard will be welcome. They should be sent to the USA Standards Institute.

*In 1966, the American Standards Association was reconstituted as the United States of America Standards Institute, and all American Standards current at that time are now known as USA Standards.

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The organizations which participated in this work and the names of their representatives, as listed at the time this standard was submitted to the USA Standards Committee on Transformers, Regulators, and Reactors, C57, for approval, are as follows:

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USA Standard
Test Code for
Distribution, Power, and Regulating Transformers, and Shunt Reactors

1. Scope

1.1 This standard prescribes methods for performing tests specified in USA Standard General Requirements for Distribution, Power, and Regulating Transformers, and Shunt Reactors, C57.12.00-1968, and in the separate apparatus standards of the C57.12 Series of USA Standards.

The test methods covered herein are as follows:
Resistance measurements (see Section 2)
Dielectric insulation (see Section 3)
Losses and impedance (see Section 4)
Ratio and regulation (see Section 5)
Temperature rise (see Section 6)
Insulation power factor tests (see Section 7)
Polarity and phase relation (see Section 8)
Short-circuit calculations (see Section 9)

1.2 In this standard an effort is made to use a uniform set of symbols, without, however, sacrificing simplicity or clarity. The main symbols shall be as follows:

Symbol	Quantity
E	Voltage
I	Current
P	Active power (in-phase component)
Q	Reactive power (quadrature component)
M	Impedance, mutual
Z	Impedance, self
R	Resistance
X	Reactance
θ	Temperature, as indicated, in degrees C
θ	Phase angle, as indicated, degrees
t	Time
ϕ	Impedance angle, degrees
F	Factor, as indicated
K, k	Ratio, as indicated

Subscripts and other symbols used shall be as locally identified.

2. Resistance Measurements

Resistance measurements are of fundamental importance for two purposes:

(1) For the calculation of the conductor or I^2R 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 2.3) for measurements made in the field. It should be employed only if the rated current of the transformer winding is one ampere 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-

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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.

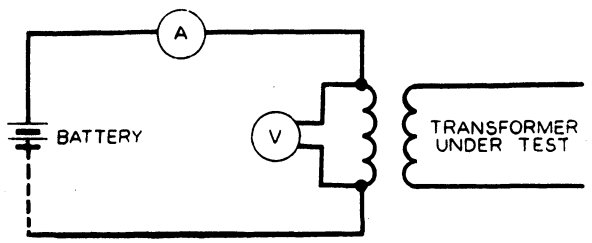


Fig. 1
Connections for the Drop-of-Potential Method of Resistance Measurement

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 one volt, 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 one ampere.

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

3. Dielectric Tests

3.1 General

3.1.1 ***Test Procedure.*** Unless otherwise specified, dielectric tests shall be made in accordance with USA Standard for Measurement of Voltage in Dielectric Tests, C68.1-1953 (IEEE No. 4-1953).

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 USA Standard C68.1-1953) shall be considered a standard method for transformer tests.

Exception: The rectified capacitor-current method (see USA Standard C68.1-1953) shall be considered a standard method for transformer tests.

3.1.2 ***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.

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

3.1.3 ***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.

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3.1.4 ***Periodic Dielectric Tests in the Field.*** It is recognized that dielectric tests impose a severe stress on the insulation, and if applied frequently will hasten breakdown or may cause breakdown, the stress imposed, of course, being the more severe the higher the value of the applied voltage. Hence, the advisability of periodic testing may be questionable.

It is recommended that when dielectric tests on transformers are made in the field subsequent to factory tests, they should not be in excess of the following: for old apparatus rebuilt in the field, 75 percent of the factory test voltage; periodic insulation tests, 65 percent of the factory test voltage. These recommendations relate to rated frequency dielectric tests applied between windings and ground and to induced-voltage tests.

Under some conditions transformers may be subjected to periodic insulation tests using direct voltage from kenotron sets. In such cases, the test direct voltage should not exceed the original factory test rms alternating voltage; e.g., if the factory test was 26 kV rms (kilovolts root-mean-square), then the routine test direct voltage should not exceed 26 kV.

Periodic kenotron tests should not be applied to transformers of higher than 34.5 kV rating.

3.1.5 ***Tests on Bushings.*** When tests are required on bushings separately from the transformers, the tests shall be made in accordance with USA Standard Requirements and Test Code for Outdoor Apparatus Bushings, C76.1-1964 (IEEE No. 21-1964).

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 apparatus 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 ⅛-inch in over-all 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.*** The duration of the applied-potential test shall be one minute.

3.2.5 ***Procedure for Application of Test Voltage.*** The voltage should be started at one-quarter or less of the full value and brought up gradually to full value in not more than 15 seconds. After being held for one minute duration, the voltage should be reduced slowly (in not more than five seconds) to one-quarter of the maximum value or less before the circuit is opened.

3.2.6 ***Exceptions in Methods of Measuring Dielectric Test Voltage.*** For transformers of 100 kVA (kilovoltamperes) 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 2.4(2) of USA Standard C57.12.00-1968. The required frequency to meet this condition is:

$$F = \frac{\text{Induced Test Voltage Across Winding}}{1.1 \times \text{Rated Voltage Across Winding}} \times \text{(Rated Frequency)}$$

3.3.2 When frequencies higher than 120 Hz are used, the severity of the test is abnormally increased and for this reason the duration of the test should be reduced in accordance with the table given below.

Frequency in hertz	Duration in Seconds
120 and less	60
180	40
240	30
360	20
400	18

3.3.3 The voltage should be started at one-quarter or less of the full value and be brought up gradually to full value in not more than 15 seconds.

After being held for the duration of time specified in 3.3.2, it should be reduced slowly (in not more than five seconds) to one-quarter of the maximum value or less, and the circuit opened.

During low-frequency tests, either applied or induced, careful watch should be maintained for evidence of possible failure. See 3.7 and particularly 3.7.2, 3.7.3, and 3.7.4. Any such indications should be carefully investigated to determine if a failure has occurred, by observation, or by repeating the test, first reprocessing the transformer, if necessary.

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3.3.4 When transformers have one winding grounded for operation on a grounded-neutral system, special care should be taken to avoid high electrostatic stresses between the other windings and ground.

3.3.5 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.

3.3.6 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 test voltage between adjacent line terminals is higher than the test voltage from the line terminals to ground.

3.3.7 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. In the case of autotransformers, it is not always possible to give induced tests corresponding to the insulation level of the winding.

See 4.1.2 of USA Standard C57.12.00-1968.

3.4 Impulse Tests

NOTE: See IEEE Guide for Transformer Impulse Tests, IEEE No. 93, June 1968, 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. Positive or negative waves may be used for other than front-of-wave tests which shall be negative. Waves of negative polarity for oil-immersed transformers and of positive polarity for dry-type or compound-filled transformers are recommended. If, in testing oil-immersed apparatus, the atmospheric conditions at the time of test are such that the bushings will not withstand the specified polarity wave, a wave of the opposite polarity may be used.

The order of the chopped-wave and front-of-wave tests is not mandatory, but 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 or USA Standard C57.12.00-1968.

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 USA Standard C57.12.00-1968.

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 USA Standard C57.12.00-1968.

Two applications of the front-of-wave tests shall be used. The front-of-wave tests shall be made after the reduced full-wave test and before the two chopped-wave impulse tests. Negative polarity shall be used for the front-of-wave tests.

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

In order to provide some tolerance in practical testing, a negative tolerance of 0.1 microsecond to the tabulated times in Table 10 of USA Standard C57.12.00-1968 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 formula:

$$\text{Voltage} = \text{Crest Voltage}^{*} \left(1 + \frac{(T - 0.1\mu s) - T_1}{AT_1}\right)$$

where

T = specified time to sparkover, microseconds
T_1 = actual time measured, microseconds
A = 4 for 69 kV insulation class and above
3 for 46 kV insulation class and below

*See Column 3 of Table 10 of USA Standard C57.12.00-1968.

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.

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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 Microseconds	Max Microseconds
45	75	1 ¼	0.5	1
60	100	1 ½	0.5	1
75	125	2	0.5	1
95	165	2 ¾	0.5	1
110	195	3 ⅜	0.5	1

*1.2 × 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.

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 USA Standard C57.12.00-1968, 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.*** One terminal of the winding under test shall be grounded directly or through a low resistance if current measurements are to be made. (For exceptions see below.) The terminals of the winding that are not being tested may be grounded directly or through a resistor in order to limit the voltage induced in these windings. It is desirable that the voltages on terminals that are not being tested should not exceed 80 percent of the full-wave voltage for their insulation class.

Exceptions: All grounds shall be direct, except as described above and at neutral terminals, which may be grounded through the same neutral grounding impedance as is to be used in service. If this impedance is unavailable, the neutral shall be directly grounded.

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 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 the two connections 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 and 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 3.7.)

3.5.6 ***Windings of Very Low Impedance.*** The impedance of some windings may be so low that the desired voltage during 40 microseconds to the 50 percent 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 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

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