



IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers

IEEE Power & Energy Society

Sponsored by the
Transformers Committee

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IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers

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**Transformers Committee
of the
IEEE Power & Energy Society**

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Abstract: Methods for performing tests specified in IEEE Std C57.12.00™ and other standards applicable to liquid-immersed distribution, power, and regulating transformers are described. Instrument transformers, step-voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, grounding transformers, and mine transformers are excluded. This standard covers resistance measurements, polarity and phase-relation tests, ratio tests, no-load loss and excitation current measurements, impedance and load loss measurements, dielectric tests, temperature tests, short-circuit tests, audible sound level measurements, and calculated data.

Keywords: tests, transformers, transformer tests

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Introduction

This introduction is not part of IEEE Std C57.12.90-2010, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

This document is a voluntary consensus standard. Its use may become mandatory only when required by a duly constituted legal authority or when specified in a contractual relationship. To meet specialized needs and to allow innovation, specific changes are permissible when mutually determined by the purchaser and manufacturer, provided that such changes do not violate existing laws and are considered technically adequate for the function intended.

When this standard is used on a mandatory basis, the word *shall* indicates mandatory requirements, and the words *should* and *may* refer to matters that are recommended or permissive, but not mandatory. The word *must* has been removed from this revision and replaced with *shall* to conform with the *IEEE Standards Style Manual*.

This standard is on a continuous revision cycle and is constantly being reviewed and updated. One can go to the website www.transformerscommittee.org to seek out information on select activities and participate in upcoming changes. Following is a brief summary of the noneditorial changes in this revision:

- Normative references and bibliography. Throughout this document, dated references have been changed to undated references, except in cases where a specific clause, table, figure, or equation is cited.
- Clause 5 introductory paragraph and 5.1.1 and 5.1.2. These passages have been slightly revised:
- Subclause 5.3. This subclause on resistance measurement methods has been changed to promote the voltmeter-ammeter method over the bridge method.
- Subclause 5.4. Resistance measurements connections and reporting have been added.
- New subclause 9.5.5. This new subclause provides a test method for zero-sequence impedance measurement on transformers with interconnected windings.
- Subclause 10.2.2.1. This subclause on switching impulse wave polarity has been changed to require negative polarity instead of an option between positive or negative polarity.
- Subclause 10.3.1.1. This subclause on full-wave impulse testing has been completely rewritten.
- Subclause 10.3.1.3. This subclause on chopped-wave impulse testing has been completely rewritten.
- Subclause 10.3.2.5. This subclause on nonlinear protective devices has been completely rewritten.
- Subclauses 10.5 to 10.10. These subclauses on low-frequency tests have been revised.
- Former subclause 10.10.5. This subclause on temperature correction factors of insulation power factor has been deleted.
- New Annex B. This normative annex presents frequency conversion factors for conversions from 50 Hz to 60 Hz and vice versa.

Technical revisions were prepared by various groups within the IEEE Transformers Committee and have been balloted and approved by these groups through the subcommittee level.

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1. Overview

1.1 Scope

This standard describes methods for performing tests specified in IEEE Std C57.12.00™ and other standards applicable to liquid-immersed distribution, power, and regulating transformers.¹ It is intended for use as a basis for performance and proper testing of such transformers.

This standard applies to all liquid-immersed transformers, except instrument transformers, step-voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, grounding transformers, and mine transformers.

Transformer requirements and specific test criteria are not a part of this standard, but they are contained in appropriate standards, such as IEEE Std C57.12.00, ANSI C57.12.10 [B1],² IEEE Std C57.12.20™, and IEEE Std C57.12.40™ [B10], or in user specifications.

¹ Information on references can be found in Clause 2.

² The numbers in brackets correspond to the numbers in the bibliography in Annex C.

1.2 Purpose

The purpose of this standard is to provide test procedure information for tests specified in IEEE Std C57.12.00 and other standards applicable to liquid-immersed distribution, power, and regulating transformers. It is intended for use as a basis for performance and proper testing of such transformers.

1.3 Word usage

When this standard is used on a mandatory basis, the word *shall* indicates mandatory requirements. The words *should* or *may* refer to matters that are recommended or permitted but not mandatory.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI C57.12.25, American National Standard for Transformers—Pad-Mounted, Compartmental-Type, Self-Cooled, Single-Phase Distribution Transformers with Separable Insulated High-Voltage Connectors; High-Voltage, 34 500 GrdY/19 920 Volts and Below; Low-Voltage, 240/120 Volts; 167 kVA and Smaller—Requirements.³

ANSI C84.1, American National Standard for Electric Power Systems and Equipment—Voltage Ratings (60 Hertz).

ANSI S1.4, American National Standard for Sound Level Meters.

ANSI S1.11, American National Standard for Octave Band and Fractional-Octave-Band Analog and Digital Filters.

IEEE Std 4TM, IEEE Standard Techniques for High-Voltage Testing.^{4, 5}

IEEE Std C57.12.00TM, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.00TM-2010, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers (specifically, Clause 7 and Clause 10; 4.1.2, 4.1.6.1, 5.9, 5.10, 5.11.2, 7.1.4.1, 9.1, 9.4; Table 5, Table 4, Table 13, and Table 18).

IEEE Std C57.12.20TM, IEEE Standard for Overhead-Type Distribution Transformers, 500 kVA and Smaller: High Voltage, 34 500 V and Below; Low Voltage, 7970/13 800Y V and Below.

IEEE Std C57.12.22TM, American National Standard for Transformers—Pad-Mounted, Compartmental-Type, Self-Cooled Three-Phase Distribution Transformers With High-Voltage Bushings, 2500 kVA and Smaller: High Voltage, 34 500 Grd Y/19 920 Volts and Below; Low Voltage, 480 Volts and Below.

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IEEE Std C57.12.23TM, IEEE Standard for Submersible Single-Phase Transformers: High Voltage 25 000 V and Below; Low Voltage 600 V and below.

IEEE Std C57.12.24TM, IEEE Standard for Submersible, Three-Phase Transformers, 3750 kVA and Smaller: High Voltage, 34 500 GrdY/19 920 Volts and Below; Low Voltage, 600 Volts and Below.

IEEE Std C57.12.26TM, IEEE Standard for Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers for Use With Separable Insulated High-Voltage Connectors (34 500 Grd Y/19 920 V and Below; 2500 kVA and Smaller).

IEEE Std C57.12.36TM, IEEE Standard Requirements for Liquid-Immersed Distribution Substation Transformers.

IEEE Std C57.12.80TM, IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.19.00TM, IEEE Standard General Requirements and Test Procedures for Power Apparatus Bushings.

IEEE Std C57.19.01TM, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.

IEEE Std C57.91TM-1995, IEEE Guide for Loading Mineral-Oil-Immersed Transformers.

IEEE Std C57.98TM, IEEE Guide for Transformer Impulse Tests.

IEEE Std C57.113TM, IEEE Recommended Practice for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.

3. Definitions

For the purposes of this document, the following terms and definitions apply. IEEE Std C57.12.80 and *The IEEE Standards Dictionary: Glossary of Terms & Definitions* should be referenced for terms not defined in this clause.⁶

actual time to crest: The time interval from the start of the transient to the time when the maximum amplitude is reached.

ambient sound pressure level: The sound pressure level measured at the test facility or at the substation without the transformer energized.

A-weighted sound level: Loudness that is measured with a sound level meter using the A-weighted response filter that is built into the meter circuitry. The A-weighting filter is commonly used to measure community noise, and it simulates the frequency response of the human ear.

C-weighted sound level: Loudness that is measured with a sound level meter using the C-weighted filter that is built into the sound level meter. The C-weighting has only little dependence on frequency over the greater part of the audible frequency range.

efficiency (of a transformer): The ratio of the useful power output of a transformer to the total power input.

guard: One or more conducting elements arranged and connected on an electrical instrument or measuring circuit to divert unwanted currents from the measuring means.

⁶ The *IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at <http://shop.ieee.org/>.

semi-reverberant facility: A room with a solid floor and an undetermined amount of sound-absorbing materials on the walls and ceiling.

sound pressure level L_p in decibels: Twenty times the logarithm to the base ten of the ratio of the measured sound pressure (P) to a reference pressure (P_o) of 20 μPa or

$$L_p = 20 \log_{10} \left(\frac{P}{P_o} \right)$$

sound power level L_w in decibels: Ten times the logarithm to the base ten of the emitted sound power (w) to a reference power (w_o) of 10^{-12} W or

$$L_w = 10 \log_{10} \left(\frac{w}{w_o} \right)$$

time to first voltage zero on the tail of the wave: The time interval from the start of the transient to the time when the first voltage zero occurs on the tail of the wave.

total losses: The sum of the no-load losses and the load losses.

4. General

4.1 Types of tests

Various types of tests (routine, design, conformance, and other) are defined in IEEE Std C57.12.80.

4.2 Test requirements

A general summary of test requirements is included in Table 18 of IEEE Std C57.12.00-2010 and indicates which tests are normally considered routine, design, or other, by size and class.

4.3 Test sequence

See 10.1.5.1 for the sequence of dielectric tests when lightning impulse or switching impulse tests are specified.

NOTE—To minimize potential damage to the transformer during testing, the resistance, polarity, phase relation, ratio, no-load loss and excitation current, impedance, and load loss tests (and temperature-rise tests, when applicable) should precede dielectric tests. Using this sequence, the beginning tests involve voltages and currents, which are usually reduced as compared with rated values, thus tending to minimize damaging effects to the transformer.⁷

4.4 Instrumentation

Although the figures in this standard show conventional meters, adequate digital readout measuring devices and digital sampling techniques with computer calculations are considered to be satisfactory alternatives.

⁷ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

5. Resistance measurements

Resistance measurements are of fundamental importance for the following purposes:

- a) Calculation of the I^2R component of conductor losses
- b) Calculation of winding temperatures at the end of a temperature test
- c) As a quality control test of the manufacturing process
- d) As a base for assessing possible damage in the field

5.1 Determination of cold temperature

The cold temperature of the winding shall be determined as accurately as possible when measuring the cold resistance. The precautions in 5.1.1, 5.1.2, and 5.1.3 shall be observed.

5.1.1 General

Cold-resistance measurements shall be made on a transformer only when the liquid or winding temperature is stable. The temperature is considered stable if the top liquid temperature does not vary more than 2 °C in a 1 h period.

5.1.2 Transformer windings immersed in insulating liquid

The temperature of the windings shall be assumed to be the same as the average temperature of the insulating liquid, provided

- a) The windings have been under insulating liquid with no excitation and with no current in the windings for a minimum of 3 h for a transformer without pumps and for 1 h for transformer with pumps running before the cold resistance is measured.
- b) The temperature of the insulating liquid has stabilized, and the difference between top and bottom temperature does not exceed 5 °C.

5.1.3 Transformer windings out of insulating liquid

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

5.2 Conversion of resistance measurements

Cold winding resistance measurements are normally converted to a standard reference temperature (T_s) equal to the rated average winding 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 Equation (1):

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

where

- R_s is the resistance at desired temperature T_s (Ω)
- R_m is the measured resistance (Ω)
- T_s is the desired reference temperature ($^{\circ}\text{C}$)
- T_m is the temperature at which resistance was measured ($^{\circ}\text{C}$)
- T_k is 234.5 $^{\circ}\text{C}$ (copper) or 225 $^{\circ}\text{C}$ (aluminum)

NOTE—The value of T_k may be as high as 230 $^{\circ}\text{C}$ for alloyed aluminum.

5.3 Resistance measurement methods

5.3.1 Voltmeter–ammeter method

The voltmeter-ammeter method is the most common method used for transformer winding resistance measurement. Resistance-measuring systems employing computer-controlled digital voltmeters, current-measuring shunts, and/or digital ammeters of appropriate accuracy are commonly used for cold-resistance measurements and in connection with temperature-rise determinations.

To use this method, the following steps should be taken:

- a) Measurement is made with direct current, and simultaneous readings of current and voltage are taken using the connections in Figure 1. The required resistance is calculated from the readings in accordance with Ohm's Law. Electronic switching power supplies may be used as voltage sources; however, batteries or filtered rectifiers may also be used, especially in instances where less ripple is desired in the measurement. Automatic recording of the resistance data is recommended so that the time to saturation and the variability of the resistance readings after stabilization can be documented.

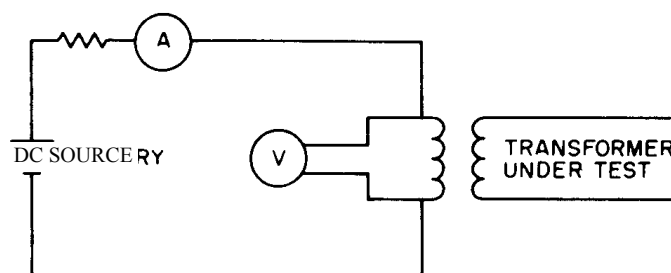


Figure 1—Connections for voltmeter-ammeter method of resistance measurement

- b) 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 step is to avoid including in the reading the resistances of current-carrying leads and their contacts and of extra lengths of leads.
- c) When making manual resistance measurements:
 - 1) The measuring instruments shall have ranges that are close to full scale to minimize errors of observation.
 - 2) The voltmeter may be disconnected from the circuit before switching the current on or off to protect the voltmeter from injury by off-scale deflections. To protect test personnel from inductive kick, the current may be switched off by a suitably insulated switch with a protective circuit to discharge the energy.

- 3) Due to inaccuracy of deflecting ammeters and voltmeters, current shunts and digital voltmeters or high-accuracy digital ammeters or other high accuracy instrumentation should be used that meets the requirement of IEEE Std C57.12.00.
- d) Resistance is recommended to be measured at intervals of 5 s to 10 s, and the readings used shall be after the current and voltage have reached steady-state values.

When measuring the cold resistance, preparatory to making a heat run, note the time required for the readings to become constant. That period of time should be allowed to elapse before taking the first reading when final winding hot-resistance measurements are being made. The residual flux in the core should be made the same for both the cold-resistance and hot-resistance measurements by saturating the core with direct current prior to the measurement.

In general, the winding will exhibit a long time constant. To reduce the time required for the current to reach its steady-state value, a noninductive external resistor may be added in series with the dc source. It may then be necessary to increase the source voltage to compensate for the voltage drop in the series resistor. The time will also be reduced by passing a direct current through other windings in either the same polarity as the winding being tested for windings on the same phase or opposite polarity for other phases during these tests. For delta-connected windings, the time can also be reduced by opening the delta connection.

- e) It is recommended that ten or more readings, but a minimum of four readings, should be used for each cold-resistance measurement, and 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% 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.

5.3.2 Bridge method

Bridge methods may be used.

NOTE—For resistance values of 1 Ω or more, a Wheatstone Bridge (or equivalent) is commonly used; for values less than 1 Ω , a Kelvin Bridge (or equivalent) is commonly used.

5.4 Resistance measurement connections and reporting

The individual phase- or terminal-to-terminal resistance readings shall be reported along with the sum total winding resistance.

5.4.1 Wye windings

For wye windings, the reported resistance measurement may be from terminal to terminal or from terminal to neutral. For the reported total winding resistance, the resistance of the lead from the neutral connection to the neutral bushing may be excluded. For terminal-to-terminal measurements, the total resistance reported is the sum of the three measurements divided by two.

5.4.2 Delta windings

For delta windings, the reported resistance measurement may be from terminal to terminal with the delta closed or from terminal to terminal with the delta open to obtain the individual phase readings. The reported total winding resistance is the sum of the three phase readings if the delta is open. If the delta is closed, the reported total winding resistance is the sum of the three phase-to-phase readings times 1.5.

5.4.3 Autotransformer windings

For autotransformer winding resistance measurements, the following method or an equivalent method shall be used. For the series winding resistance, the current shall be circulated between the high-voltage and neutral terminals, and the voltage shall be measured between the high-voltage terminal and the low-voltage terminal. For the common winding resistance, the current shall be circulated between the high-voltage and neutral terminals, and the voltage shall be measured between the low-voltage and neutral terminals. If needed, for the resistance of the lead and in-line windings (if any) between the low-voltage terminal and the neutral connection, the current shall be applied between the high-voltage terminal and the low-voltage terminal, and the voltage shall be measured between the low-voltage terminal and the neutral terminal.

6. Polarity and phase-relation tests

Polarity and phase-relation tests are of interest primarily because of their bearing on paralleling or banking two or more transformers. Phase-relation tests are made to determine angular displacement and relative phase sequence.

6.1 Subtractive and additive polarity

Windings arranged for subtractive polarity and additive polarity are shown in Figure 2 and Figure 3.

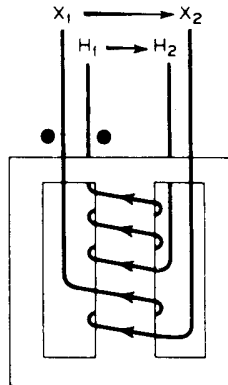


Figure 2—Windings: subtractive polarity

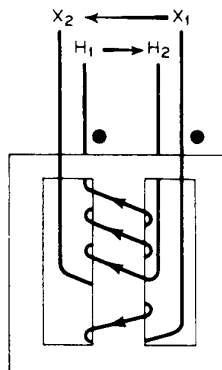


Figure 3—Windings: additive polarity

Leads and polarity marks arranged for subtractive polarity and additive polarity are shown in Figure 4 and Figure 5.

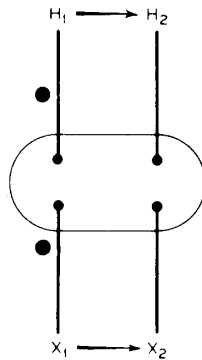


Figure 4—Leads and polarity marks: subtractive polarity

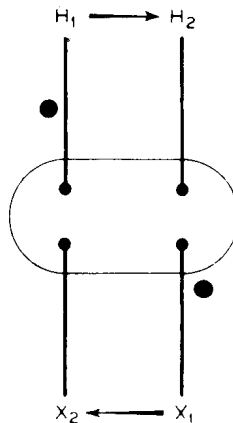


Figure 5—Leads and polarity marks: additive polarity

6.2 Polarity tests: single-phase transformers

Polarity tests on single-phase transformers shall be made in accordance with one of the following methods:

- a) Inductive kick
- b) Alternating voltage
- c) Comparison
- d) Ratio bridge

6.2.1 Polarity by inductive kick

The polarity of transformers with leads arranged as shown in Figure 2 through Figure 5 may be determined when making resistance measurements as follows:

- a) With direct current passing through the high-voltage winding, connect a high-voltage direct-current voltmeter across the high-voltage winding terminals to obtain a small deflection of the pointer.

- b) Transfer the two voltmeter leads directly across the transformer to the adjacent low-voltage leads, respectively.

NOTE—For example, in Figure 5, the voltmeter lead connected to H_1 will be transferred to X_2 as the adjacent lead, and that connected to H_2 to X_1 .

- c) Break direct-current excitation, thereby inducing a voltage in the low-voltage winding (inductive kick), which will cause deflection in the voltmeter. The deflection is interpreted in item d and item e.
- d) When the pointer swings in the opposite direction (negative), the polarity is subtractive.
- e) When the pointer swings in the same direction as before (positive), the polarity is additive.

6.2.2 Polarity by alternating-voltage test

For transformers having a ratio of transformation of 30 to 1 or less, the H_1 lead shall be connected to the adjacent low-voltage lead (X_1 in Figure 6).

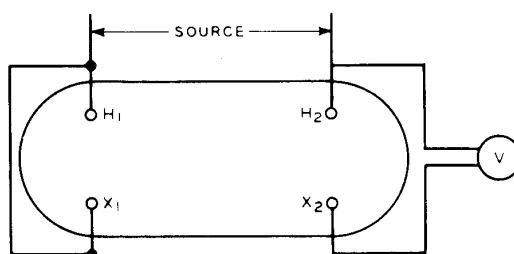


Figure 6—Polarity by alternating-voltage test

Any convenient value of alternating voltage shall be applied to the full high-voltage winding. Readings are taken of the applied voltage and the voltage between the right-hand adjacent high-voltage and low-voltage leads.

When the latter reading is greater than the former, the polarity is additive.

When the latter voltage reading is less than the former (indicating the approximate difference in voltage between the high-voltage and low-voltage windings), the polarity is subtractive.

6.2.3 Polarity by comparison

When a transformer of known polarity and of the same ratio as the unit under test is available, the polarity can be checked by comparison, as follows, similar to the comparison method used for the ratio test (see Figure 9 and Figure 10):

- a) Connect the high-voltage windings of both transformers in parallel by connecting similarly marked leads together.
- b) Connect the low-voltage leads, X_2 , of both transformers together, leaving the X_1 leads free.
- c) With these connections, apply a reduced value of voltage to the high-voltage windings and measure the voltage between the two free leads.

A zero or negligible reading of the voltmeter will indicate that the relative polarities of both transformers are identical.

An alternative method of checking the polarity is to substitute a low-rated fuse or suitable lamps for the voltmeter. This procedure is recommended as a precautionary measure before connecting the voltmeter.

6.2.4 Polarity by ratio bridge

The ratio bridge described in 7.3.3 can also be used to test polarity.

6.3 Polarity and phase-relation tests: polyphase transformers

6.3.1 Polarity of polyphase transformers

Each phase of a polyphase transformer shall have the same relative polarity when tested in accordance with one of the methods described for single-phase transformers.

6.3.2 Phase-relation tests

6.3.2.1 Test for phasor diagram for transformers with a ratio of transformation of 30 to 1 or less

The phasor diagram of any three-phase transformer that defines the angular displacement and phase sequence can be verified as follows:

- Connect the H_1 and X_1 leads together to excite the unit at a suitable, low, three-phase voltage.
- Take voltage measurements between the various pairs of leads.
- Either plot these values or compare them for their relative order of magnitude with the help of the corresponding diagram in Figure 7 or Figure 8.

Typical check measurements are to be taken, and their relative magnitudes are also to be indicated.

6.3.2.2 Zigzag windings

Equal zig and zag windings are usually necessary for zigzag transformers although unequal windings may be used for special applications.

No required test is proposed to determine the phase relationships between the line-end and neutral-end sections of a zigzag winding. However, it is recommended that a test connection be made to the junction of the two winding sections and that tests be made during manufacture to prove the desired phase relationships.

For the purpose of designation in Figure 7, zigzag windings are arbitrarily defined as windings whose line-end section is rotated 60° counterclockwise with respect to the neutral-end section.

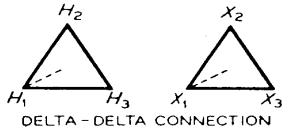
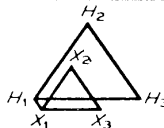
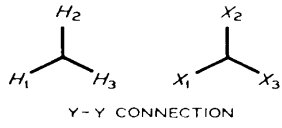
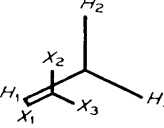
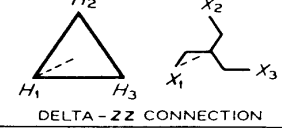
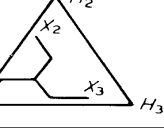
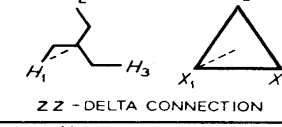
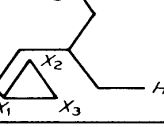
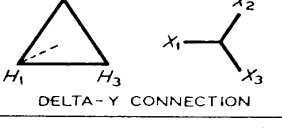
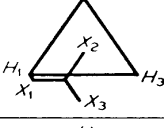
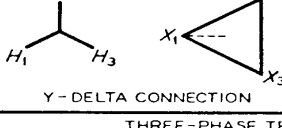
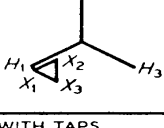
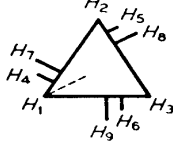
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA-DELTA CONNECTION		CONNECT H_1 TO X_1 MEASURE $H_2-X_2, H_3-X_3,$ $H_1-H_2, H_2-X_3, H_3-X_3$ VOLTAGE RELATIONS (1) $H_2-X_3 = H_3-X_2$ (2) $H_2-X_2 < H_1-H_2$ (3) $H_2-X_2 < H_2-X_3$ (4) $H_2-X_2 = H_3-X_3$
	 Y-Y CONNECTION		
	 DELTA-ZZ CONNECTION		
	 ZZ-DELTA CONNECTION		
GROUP 2 ANGULAR DISPLACEMENT 30 DEGREES	 DELTA-Y CONNECTION		CONNECT H_1 TO X_1 MEASURE $H_3-X_2, H_3-X_3,$ $H_1-H_3, H_2-X_2, H_2-X_3$ VOLTAGE RELATIONS (1) $H_3-X_2 = H_3-X_3$ (2) $H_3-X_2 < H_1-H_3$ (3) $H_2-X_2 < H_2-X_3$ (4) $H_2-X_2 < H_1-H_3$
	 Y-DELTA CONNECTION		
	THREE-PHASE TRANSFORMERS WITH TAPS 		

Figure 7—Transformer lead markings and voltage-phasor diagrams for three-phase transformer connections

6.3.2.3 Six-phase windings

Six-phase windings with no neutral connection shall be temporarily connected in delta (Δ) or wye (Y) for the test for phasor diagram.

6.3.2.4 Test of phase relation with ratio bridge

The ratio bridge described in 7.3.3 can also be used to test phase relationships.

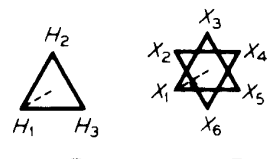
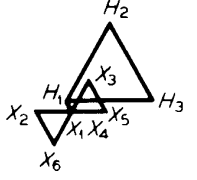
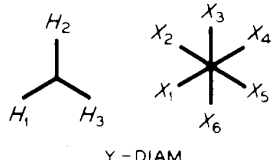
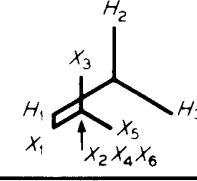
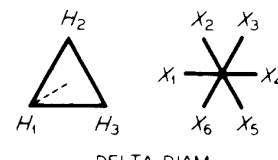
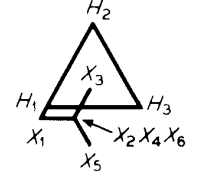
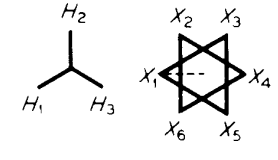
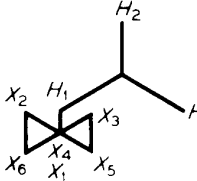
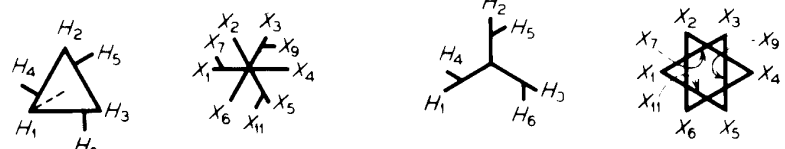
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA-DOUBLE DELTA		CONNECT H_1 TO X_1 TO X_4 MEASURE $H_2-X_3, H_1-H_2, H_2-X_5, H_2-X_6, H_3-X_2, H_2-X_2, H_3-X_3$ VOLTAGE RELATIONS (1) $H_2-X_5 = H_3-X_3$ (4) $H_2-X_6 = H_3-X_2$ (2) $H_2-X_3 < H_1-H_2$ (5) $H_2-X_6 > H_1-H_2$ (3) $H_2-X_3 < H_2-X_5$ (6) $H_2-X_2 < H_2-X_6$
	 Y-DIAM		CONNECT X_2 TO X_4 TO X_6 H_1 TO X_1 MEASURE $H_2-X_3, H_3-X_5, H_1-H_2, H_2-X_5$ VOLTAGE RELATIONS (1) $H_2-X_5 = H_3-X_3$ (2) $H_2-X_3 < H_1-H_2$ (3) $H_2-X_3 < H_2-X_5$
GROUP 2 ANGULAR DISPLACEMENT 30 DEGREES	 DELTA DIAM		CONNECT X_2 TO X_4 TO X_6 H_1 TO X_1 MEASURE $H_3-X_3, H_3-X_5, H_1-H_3, H_2-X_3, H_2-X_5$ VOLTAGE RELATIONS (1) $H_3-X_3 = H_3-X_5$ (2) $H_3-X_3 < H_1-H_3$ (3) $H_2-X_3 < H_2-X_5$
	 Y-DOUBLE DELTA		CONNECT H_1 TO X_1 TO X_4 MEASURE $H_3-X_3, H_3-X_5, H_1-H_3, H_2-X_3, H_2-X_5, H_3-X_2, H_3-X_6, H_2-X_2, H_2-X_6$ VOLTAGE RELATIONS (1) $H_3-X_3 = H_3-X_5$ (2) $H_3-X_3 < H_1-H_3$ (3) $H_2-X_3 < H_2-X_5$ (4) $H_3-X_2 = H_3-X_6$ (5) $H_3-X_2 > H_1-H_3$ (6) $H_2-X_2 < H_2-X_6$
SIX-PHASE TRANSFORMERS WITH TAPS 			

Figure 8—Transformer lead markings and voltage-phaser diagrams for six-phase transformer connections

6.3.3 Phase-sequence test

The phase-sequence indicator may incorporate either a three-phase induction motor or a split-phase circuit. It should be connected first to the higher voltage leads with the transformer excited three-phase at a low voltage suitable for the indicator and the direction of rotation or the indication of the instrument noted.

The indicator is then transferred to the low-voltage side of the transformer by connecting the lead that was connected to H_1 to X_1 , connecting the lead that was connected to H_2 to X_2 , and connecting the lead that was connected to H_3 to X_3 .

The transformer is again excited at a suitable voltage (without changing the excitation connections), and the indication is again noted.

The phase sequence of the transformer is correct when the indication is the same in both cases.

Six-phase secondaries with no neutral connection also have to be connected temporarily in delta or wye for this test. When a six-phase neutral is available, the phase-sequence indicator leads should be transferred from H_1 to X_1 , from H_2 to X_3 , and from H_3 to X_5 , respectively, and the direction of rotation should be noted. The test should then be repeated by transferring the leads from H_1 to X_2 , from H_2 to X_4 , and from H_3 to X_6 , respectively, and noting the indication, which should be the same as before.

6.3.3.1 Limitation of the phase-sequence test

The preceding method (phase-sequence test) does not disclose the angular displacement of the transformer.

6.3.3.2 Test of phase sequence with ratio bridge

The ratio bridge described in 7.3.3 can also be used to test phase sequence.

7. Ratio tests

7.1 General

The turns ratio of a transformer is the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding.

7.1.1 Taps

When a transformer has taps for changing its voltage ratio, the turns ratio is based on the number of turns corresponding to the normal rated voltage of the respective windings to which operating and performance characteristics are referred.

When the transformer has taps, the turns ratio shall be determined for all taps and for the full winding.

7.1.2 Voltage and frequency

The ratio test shall be made at rated or lower voltage and rated or higher frequency.

7.1.3 Three-phase transformers

In the case of three-phase transformers, when each phase is independent and accessible, single-phase power should be used, although, when convenient, three-phase power may be used.

7.1.4 Three-phase transformers with inaccessible neutrals

Transformers that have wye connections but do not have the neutral of the wye brought out shall be tested for ratio with three-phase power. Any inequality in the magnetizing characteristics of the three phases will result in a shift of the neutral and thereby cause unequal phase voltages. When such inequality is found, the connection should be changed, either to a delta or to a wye connection, and the line voltages should be measured. When the measured line voltages are equal to the proper value (1.73 times the phase voltages when connected in wye), the ratio is correct.

7.2 Tolerances for ratio

See 9.1 of IEEE Std C57.12.00-2010.

7.3 Ratio test methods

7.3.1 Voltmeter method

Two voltmeters shall be used (with voltage transformers when necessary): one to read the voltage of the high-voltage winding and the other, the low-voltage winding.

The two voltmeters shall be read simultaneously.

A second set of readings shall be taken with the instruments interchanged, and the average of the two sets of readings shall be taken to compensate for instrument errors.

Voltage transformer ratios should yield approximately the same readings on the two voltmeters. Compensation for instrument errors by an interchange of instruments will otherwise not be satisfactory, and it will be necessary to apply appropriate corrections to the voltmeter readings.

Tests shall be made with no less than four voltages in approximately 10% steps, and the average result shall be taken as the true value. These several values should check within 1%. Otherwise, the tests shall be repeated with other voltmeters.

When appropriate corrections are applied to the voltmeter readings, tests may be made at only one voltage.

When several transformers of duplicate rating are to be tested, work may be expedited by applying the foregoing tests to only one unit and then comparing the other units with this one as a standard, in accordance with the comparison transformer method discussed in 7.3.2.

7.3.2 Comparison method

A convenient method of measuring the ratio of a transformer is by comparison with a transformer of known ratio.

The transformer to be tested is excited in parallel with a transformer of the same nominal ratio, and the two secondaries are connected in parallel but with a voltmeter or detector in the connection between two terminals of similar polarity (see Figure 9). The voltmeter or detector indicates the difference in voltage. This method is more accurate than the following alternative method.

For an alternative method, the transformer to be tested is excited in parallel with a transformer of known ratio, and the voltmeters are arranged to measure the two secondary voltages (see Figure 10). The voltmeters shall be interchanged, and the test shall be repeated. The averages of the results are the correct voltages.

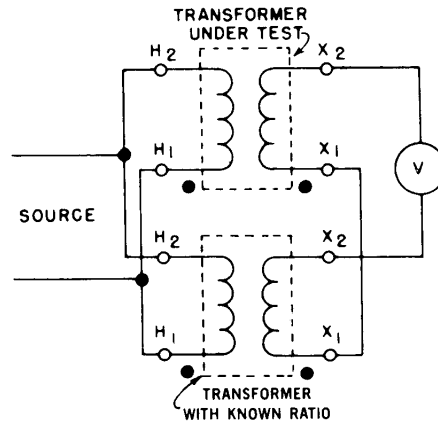


Figure 9—Voltmeter arranged to read the difference between the two secondary voltages

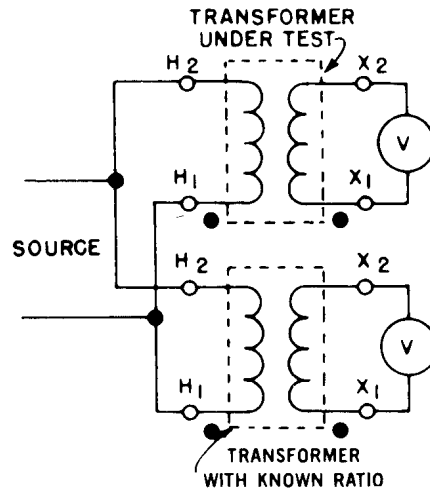


Figure 10—Voltmeters arranged to read the two secondary voltages

NOTE—Readings are repeated after interchanging voltmeters.

7.3.3 Ratio bridge

A bridge using the basic circuit of Figure 11 may be used to measure ratio. When detector DET is in balance, the transformer ratio is equal to R/R_1 .

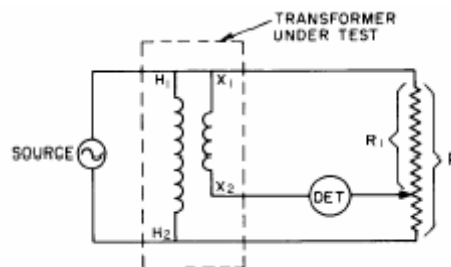


Figure 11—Basic circuit of ratio bridge

NOTE 1—Measurement of ratio using circuits of this type has also been described as ratio by resistance potentiometer.

NOTE 2—More accurate results can be obtained using a ratio bridge that provides phase-angle correction.

NOTE 3—The ratio bridge can also be used to test polarity, phase relation, and phase sequence.

8. No-load losses and excitation current

8.1 General

No-load (excitation) losses are losses that are incident to the excitation of the transformer. No-load losses include core loss, dielectric loss, conductor loss in the winding due to excitation current, and conductor loss due to circulating current in parallel windings. These losses change with the excitation voltage.

Excitation current (no-load current) is the current that flows in any winding used to excite the transformer when all other windings are open-circuited. It is generally expressed in percent of the rated current of the winding in which it is measured.

The no-load losses consist primarily of the core loss in the transformer core, which is a function of the magnitude, frequency, and waveform of the impressed voltage. No-load losses also vary with temperature and are particularly sensitive to differences in waveform; therefore, no-load loss measurements will vary markedly with the waveform of the test voltage.

In addition, several other factors affect the no-load losses and excitation current of a transformer. The design-related factors include the type and thickness of core steel, the core configuration, the geometry of core joints, and the core flux density.

Factors that cause differences in the no-load losses of transformers of the same design include variability in characteristics of the core steel, mechanical stresses induced in manufacturing, variation in gap structure, and core joints.

8.2 No-load loss test

The purpose of the no-load loss test is to measure no-load losses at a specified excitation voltage and a specified frequency. The no-load loss determination shall be based on a sine-wave voltage, unless a different waveform is inherent in the operation of the transformer. The average-voltage voltmeter method is the most accurate method for correcting the measured no-load losses to a sine-wave basis and is recommended. This method employs two parallel-connected voltmeters: one is an average-responding [but root mean square (rms) calibrated] voltmeter (V_a), and the other is a true rms-responding voltmeter (V_r). The test voltage is adjusted to the specified value as read by the average-responding voltmeter. The readings of both voltmeters are employed to correct the no-load losses to a sine-wave basis, using Equation (2) in accordance with 8.3.

8.2.1 Connection diagrams

Tests for the no-load loss determination of a single-phase transformer are carried out using the schemes depicted in Figure 12 and Figure 13. Figure 12 shows the necessary equipment and connections when instrument transformers are not required. When instrument transformers are required, as is generally the case, the equipment and connections shown in Figure 13 apply. If necessary, correction for losses in connected measurement instruments may be made by disconnecting the transformer under test and noting the wattmeter reading at the specified test circuit voltage. These losses represent the losses of the connected instruments (and voltage transformer, if used). They may be subtracted from the earlier wattmeter reading to obtain the no-load loss of the transformer under test.

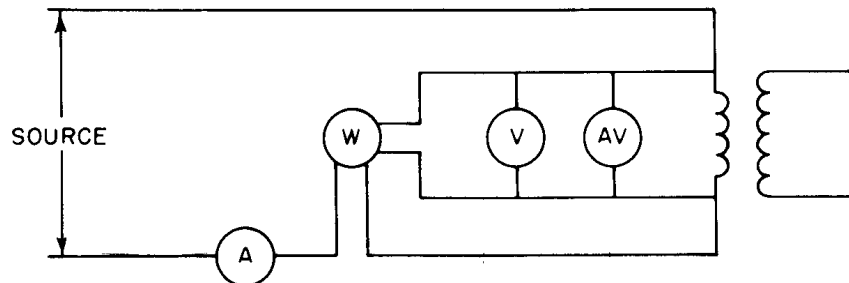


Figure 12—Connections for no-load loss test of a single-phase transformer without instrument transformers

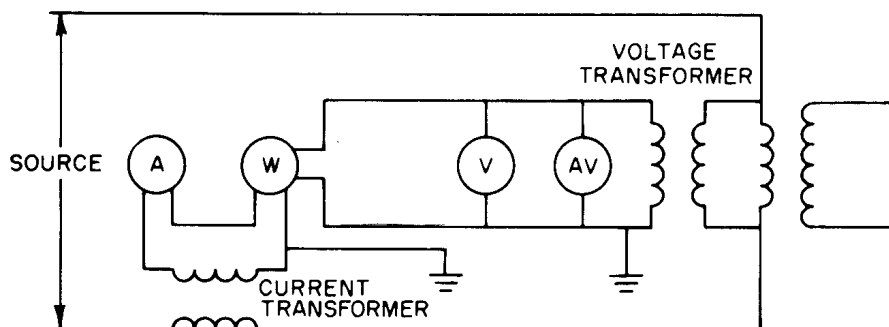


Figure 13—Connections for a no-load loss test of a single-phase transformer with instrument transformers

Tests for the no-load loss determination of a three-phase transformer shall be carried out by using the three wattmeter method. Figure 14 is a schematic representation of the equipment and connections necessary for conducting no-load loss measurements of a three-phase transformer when instrument transformers are necessary.

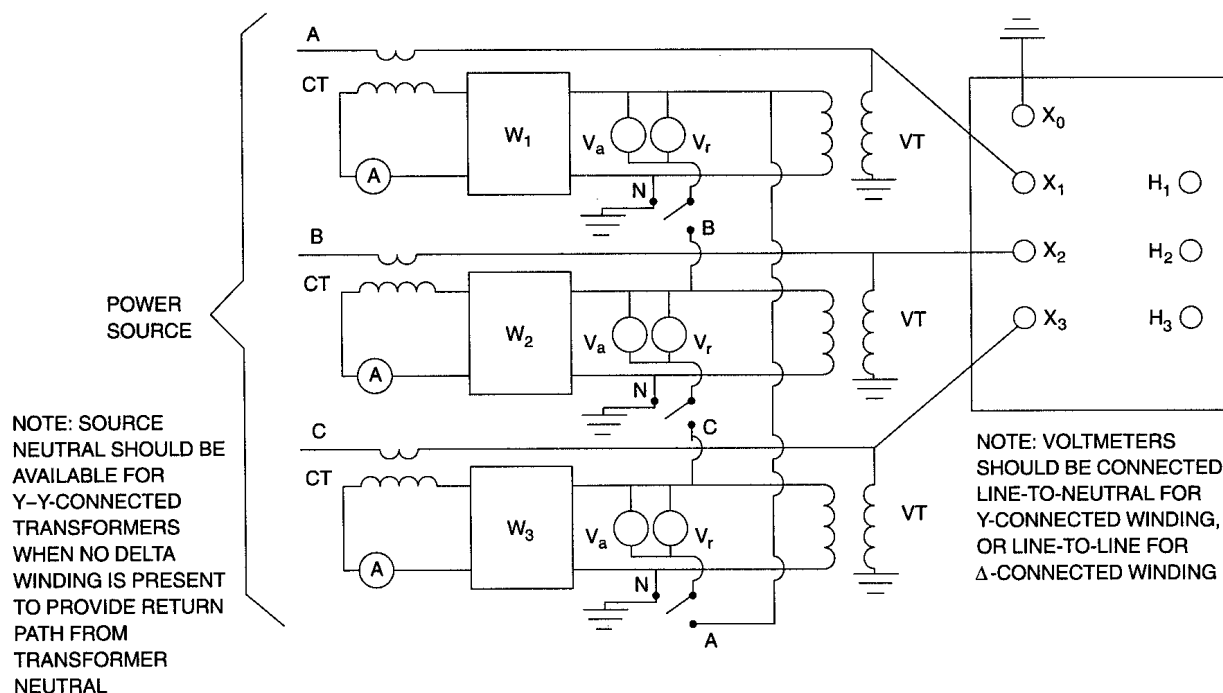


Figure 14—Three-phase transformer connections for no-load loss and excitation current tests using three-wattmeter method

8.2.2 Voltmeter connections

When correcting to a sine-wave basis using the average-voltage voltmeter method, attention shall be paid to the voltmeter connections because the line-to-line voltage waveform may differ from line-to-neutral voltage waveform. Therefore, depending on whether the transformer windings energized during the test are connected delta or wye, the voltmeter connections shall be such that the waveform applied to the voltmeters is the same as the waveform across the energized windings.