



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

IEEE Power and Energy Society

Developed by the
Transformers Committee

IEEE Std C57.12.90™-2021
(Revision of IEEE Std C57.12.90-2015)



STANDARDS

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

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Transformers Committee
of the
IEEE Power and Energy Society

Approved 9 November 2021

IEEE SA Standards Board

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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. 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 are covered in this standard.

Keywords: IEEE C57.12.90™, tests, transformer tests, transformers

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Introduction

This introduction is not part of IEEE Std C57.12.90-2021, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

This standard is one document within the IEEE C57 series of documents, applicable to transformers and associated equipment. It covers “Test Code,” which specifies the test procedure to be followed. The requirements and applicability of the tests are covered in other documents, such as IEEE Std C57.12.00™.¹

This standard is on a continuous revision cycle and is constantly being reviewed and updated. It has been revised and republished in years 2015, 2010, 2006, 1999, 1993, 1987, and earlier. For information on select activities and to participate in upcoming projects, go to <http://www.transformerscommittee.org>. The following is a brief summary of the technical changes in this revision, from 2015 to 2020:

- Implemented corrigendum IEEE C57.12.90™-2015/Cor 1-2017, to correct an editorial mistake of the constant k in the definitions for [Equation \(2\)](#) in [8.3](#), and in [10.8.2](#), the terminal voltage was changed from 115 kV to 69 kV to reflect the new definition (in 2015) of Class II transformers.
- Subclause [5.4.1](#). Added requirement for line-to-ground resistance measurement on wye windings.
- Subclause [9.3.1](#). Added text for an alternative method for measuring load loss and impedance, and a new [Figure 19](#). All figures after this in the document are renumbered accordingly.
- Subclause [10.2.4](#). Added text regarding tap connection during switching impulse test.
- Subclause [10.3.1](#) and [10.3.1.1](#). Added text regarding impulse waveshape and front-time of full wave.
- Subclause [10.3.1.3](#). Added text regarding steepness of voltage collapse for chopped-wave test.
- Subclause [10.3.2.1](#). Added text regarding connection of tertiary terminals during impulse test.
- Subclause [10.7.7](#). Inserted a new procedure for a special induced test to detect improper core grounding of wound cores, for distribution transformers and Class I power transformers. This is to coincide with a new requirement in IEEE Std C57.12.00-2021, Subclause 6.7.2.1 and Table 17.
- Subclause [10.8.1](#). Added text regarding tap connection during induced voltage test. Also, added [Annex D](#) with more information on this subject. The plan is to transfer the annex and possibly parts of the subclause text into a future guide on low-frequency testing, currently in development.
- Subclause [10.8.2](#). Added requirement that overpressure is not allowed during induced test.
- Subclause [10.8.5](#). Decreased partial discharge failure detection limits: 500 pC to 250 pC; 150 pC to 50 pC.
- Subclause [11.1.2.2e](#)). Added text to allow subsequent gradient runs of 30 min, instead of 60 min.
- Subclause [11.4.3](#). Change (editorial) from 3280 ft to 3300 ft as 1000 m equivalent. This is to coordinate with altitude corrections used here and in other IEEE documents such as IEEE Std C57.12.00 and IEEE Std C57.91™.

Technical revisions were prepared by various groups (TF, WG, SC) within the IEEE PES Transformers Committee and have been surveyed and approved by these groups up through the subcommittee level, in accordance with the procedure manual.

¹ Information on references can be found in [Clause 2](#).

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1. Overview

1.1 Scope

This standard describes methods for performing tests specified in IEEE Std C57.12.00^{TM1} 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.

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, IEEE Std C57.12.10TM [B18 B47],² IEEE Std C57.12.20TM, and IEEE Std C57.12.40TM [B19 B48], or in user specifications.

¹~~Information on references can be found in Clause 2.~~

²The numbers in brackets correspond to those of the bibliography in Annex E. ~~D~~

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

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{3, 4} The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

~~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.~~

³ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁴ The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

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 C84.1, American National Standard for Electric Power Systems and Equipment Voltage Ratings (60 Hertz).~~³

ANSI S1.4, American National Standard for Sound Level Meters.⁵

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.^{6,7 4,5}

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

IEEE Std C57.12.10TM, IEEE Standard Requirements for Liquid-Immersed Power Transformers.

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.

^{5 3} ANSI publications are available from the ~~Sales Department~~, American National Standards Institute, ~~25 West 43rd Street, 4th Floor, New York, NY 10036, USA~~ ([https](https://www.ansi.org/) ~~http~~://www.ansi.org/).

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IEEE Std C57.12.23™, IEEE Standard for Submersible Single-Phase Transformers 167 kVA and Smaller; High Voltage 25 000 V and Below; Low Voltage 600 V and Below.

IEEE Std C57.12.24™, 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 C57.12.34™, IEEE Standard for Requirements for Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers, 5 MVA and Smaller; High Voltage, 34.5 kV Nominal System Voltage and Below; Low Voltage, 15 kV Nominal System Voltage and Below.

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

IEEE Std C57.12.38™, IEEE Standard for Pad-Mounted-Type, Self-Cooled, Single-Phase Distribution Transformers; High Voltage, 34 500 GrdY/19 920 V and Below, Low Voltage, 240/120 V; 167 kVA and Smaller.

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

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

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

[IEEE Std C57.19.04™, IEEE Standard for Performance Characteristics and Dimensions for High Current Power Transformer Bushings with Rated Continuous Current in Excess of 5000 A in Bus Enclosures](#)

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

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

IEEE Std C57.113™, 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. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁸

NOTE—Although the term “liquid” is used in some places in this document for simplicity, it is synonymous with the term “insulating liquid” and includes, as appropriate, insulating liquids such as mineral oil, natural esters, synthetic esters, silicone, or high molecular weight hydrocarbons.^{2 7}

~~**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.

^{8 6} *IEEE Standards Dictionary Online* ~~subscription~~ is available at: <http://ieeexplore.ieee.org/xpls/dictionary.ieee.org.jsp>. [An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.](#)

^{2 7} Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

~~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 μ Pa or~~

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

~~(Deleted)~~

~~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~~

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

~~(Deleted)~~

~~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 17 of IEEE Std C57.12.00-[2021](#) ~~2015~~ and indicates which tests are normally considered routine, design, or other, by size and class. [Per IEEE Std C57.12.00, tests shall be made at the factory or other approved testing facility, unless otherwise specified.](#)

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 [help](#) minimize potential problems for 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 problematic effects to the transformer.

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.

5. Resistance measurements

Resistance measurements are of fundamental importance for the following purposes:

- a) Calculation of the $I^2 R$ component of conductor losses
- b) Calculation of winding temperatures at the end of a temperature-rise 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 [the following occurs](#):

- 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 $T_s(\Omega)$

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.

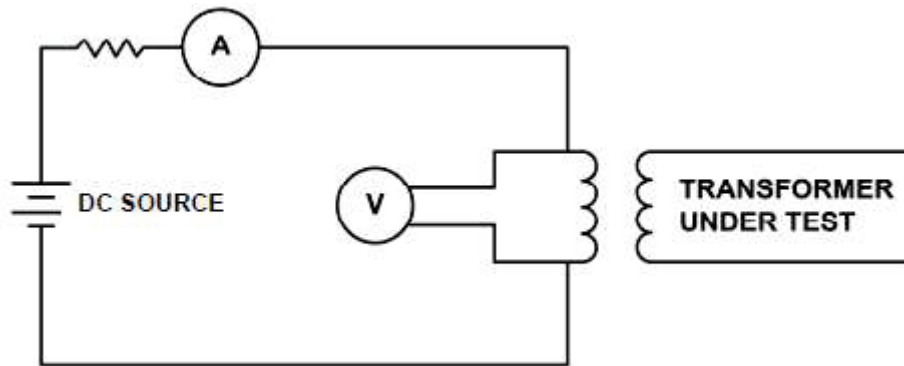


Figure 1—Connections for voltmeter-ammeter method of resistance measurement

- 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 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.

- 2) Due to inaccuracy of deflecting ammeters and voltmeters, current shunts and digital voltmeters, 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.
- e) When measuring the cold resistance, preparatory to making a temperature-rise test, 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.
- f) 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. [When there is a neutral bushing brought out, at least one terminal-to-neutral measurement at rated tap position shall be made and reported.](#) 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.

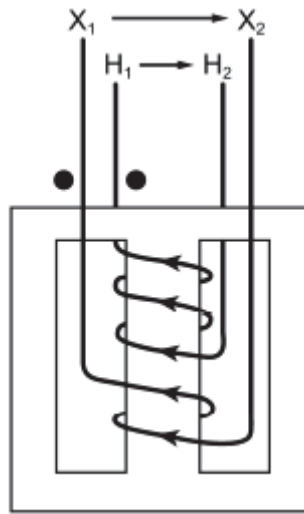


Figure 2—Windings: subtractive polarity

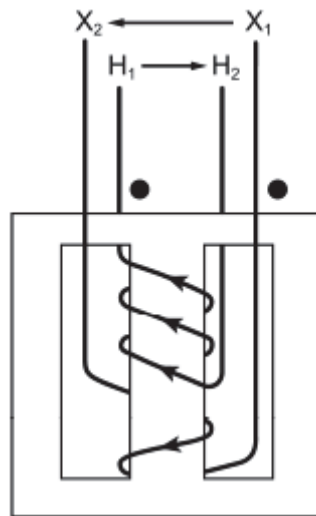


Figure 3—Windings: additive polarity

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

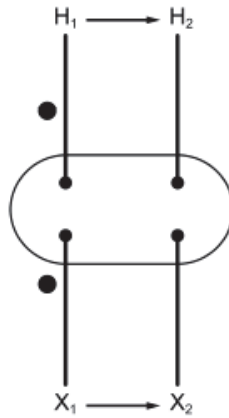


Figure 4—Leads and polarity marks: subtractive polarity

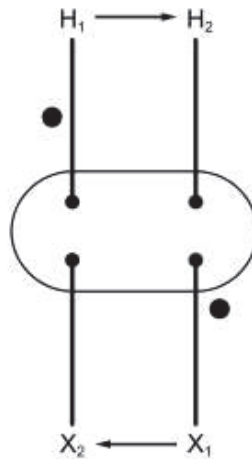


Figure 5—Leads and polarity marks: additive polarity

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) Ratio meter

- b) Inductive kick
- c) Alternating voltage

6.2.1 Polarity by ratio meter

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

6.2.2 Polarity by inductive kick

The polarity of transformers with leads arranged as shown in Figure 2 through Figure 5 may be determined with a low-voltage dc supply and analog high-voltage voltmeter 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. For example, in Figure 5, the voltmeter lead connected to H1 will be transferred to X2 as the adjacent lead, and the lead connected to H2 transferred to X1-.
- 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](#) ~~items~~ 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.

6.2.3 Polarity by alternating-voltage test

The H1 lead shall be connected to the adjacent low-voltage lead (X1 in Figure 6).

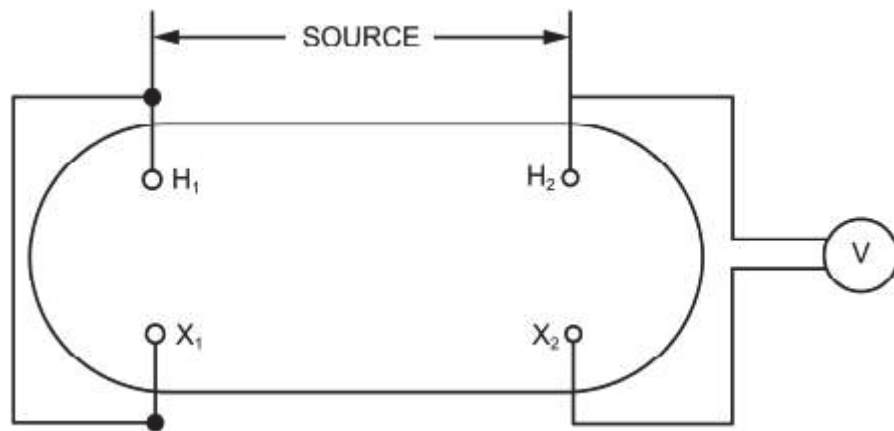


Figure 6—Polarity by alternating-voltage test

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.

6.3 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 of phase relation with ratio meter

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

6.3.2.2 Test for phasor diagram for transformers

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.

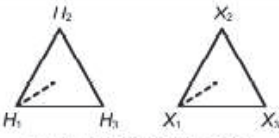
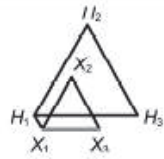
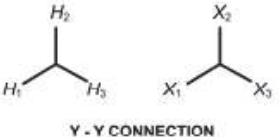
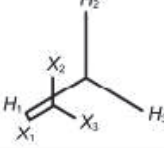
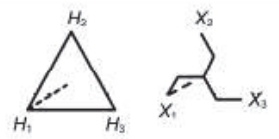
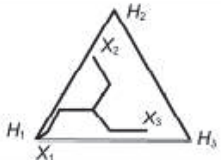
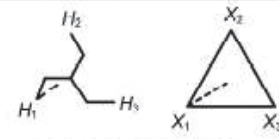
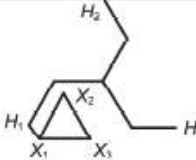
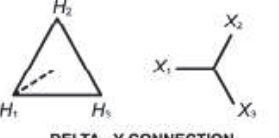
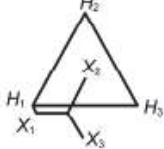
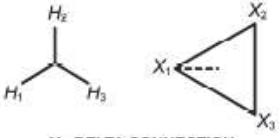
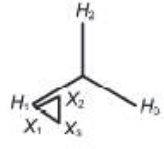
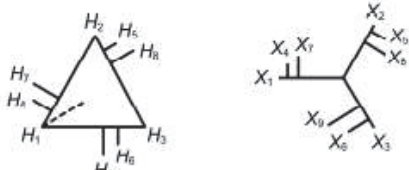
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA - DELTA CONNECTION		CONNECT H_1 TO X_1 MEASURE $H_2 - X_2, H_3 - X_3,$ $H_1 - H_2, H_2 - X_3, H_3 - X_1$ VOLTAGE RELATIONS (1) $H_2 - X_3 = H_3 - X_2$ (2) $H_2 - X_2 < H_1 - H_2$ (3) $H_2 - X_2 < H_2 - X_3$ (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 $H_1 - X_2, H_3 - X_3,$ $H_1 - H_3, H_2 - X_2, H_2 - X_3$ 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.

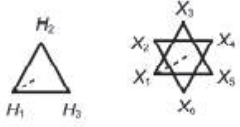
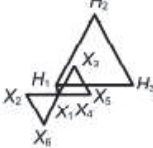
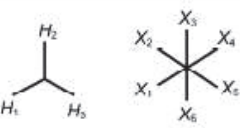
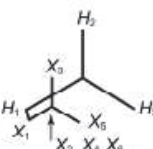
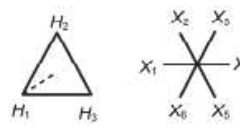
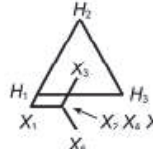
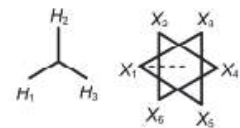
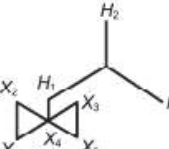
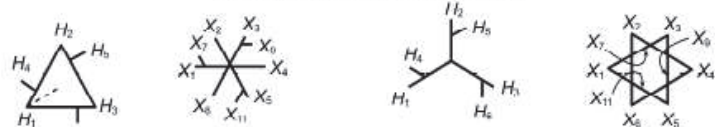
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA - DOUBLE DELTA		CONNECT H_1 TO X_1 TO X_4 MEASURE $H_2 - X_3, H_1 - H_2, H_2 - X_5, H_2 - X_6, H_3 - X_2, H_2 - X_2, H_3 - X_5$ VOLTAGE RELATIONS (1) $H_2 - X_5 = H_3 - X_3$ (4) $H_2 - X_6 = H_3 - X_2$ (2) $H_2 - X_3 < H_1 - H_2$ (5) $H_2 - X_6 > H_1 - H_2$ (3) $H_2 - X_3 < H_2 - X_6$ (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 $H_3 - X_3, H_3 - X_5, H_1 - H_3, H_2 - X_3, H_2 - X_5, H_3 - X_2, H_3 - X_6, H_2 - X_2, H_3 - X_6$ VOLTAGE RELATIONS (1) $H_3 - X_3 = H_3 - X_5$ (2) $H_3 - X_3 < H_1 - H_3$ (3) $H_3 - X_3 < H_2 - H_6$ (4) $H_1 - X_2 = H_3 - X_6$ (5) $H_3 - X_5 > H_1 - X_3$ (6) $H_2 - X_2 < H_2 - X_6$
SIX - PHASE TRANSFORMERS WITH TAPS 			

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

6.3.2.4 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.

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 may be tested for ratio and polarity with three-phase or single-phase power. For single-phase power the circuit is configured such that there is no shift in the neutral (typically this requires shorting out one phase) as shown in Figure 9. When using three-phase power, and inequality of the phase voltage is found, the connection should be changed.

Short out one phase of the winding to create a virtual neutral for testing purposes. Figure 9 shows the connections for such a transformer with a delta HV and a wye LV with inaccessible neutral.

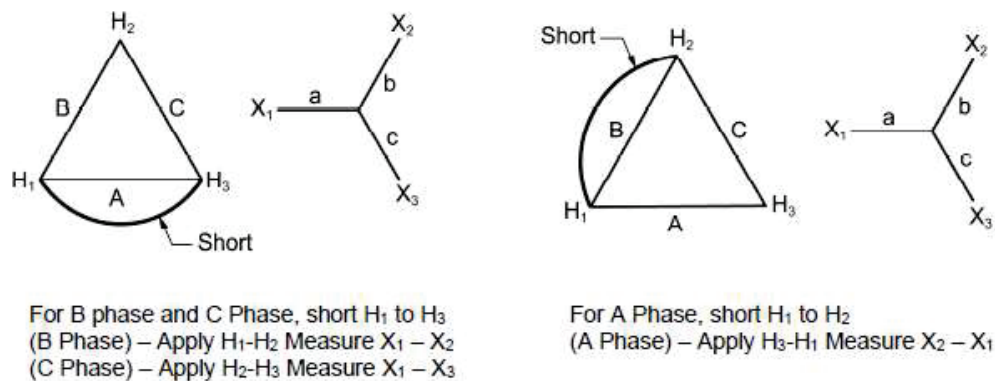


Figure 9—Connections for ratio test on a transformer with inaccessible neutral

7.2 Tolerances for ratio

See 9.1 of IEEE Std C57.12.00-[2021](#) ~~2015~~.

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 10). 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 11). The voltmeters shall be interchanged, and the test shall be repeated. The averages of the results are the correct voltages.

NOTE—Readings are repeated after interchanging voltmeters.

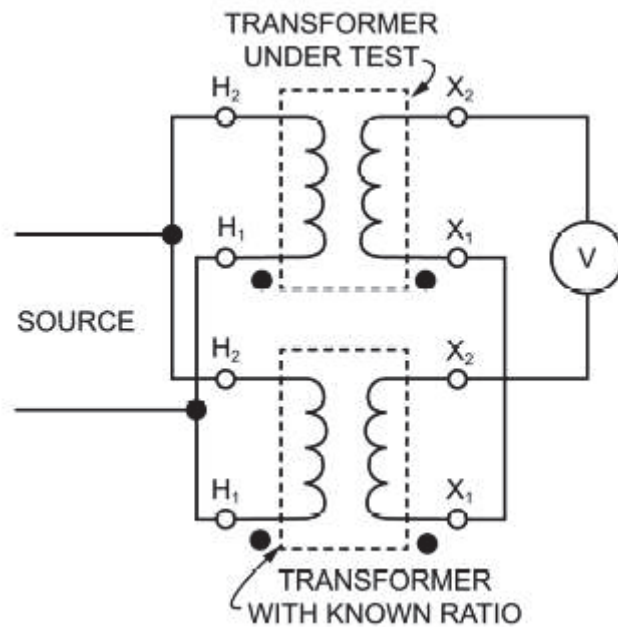


Figure 10 — Voltmeter arranged to read the difference between the two secondary voltages

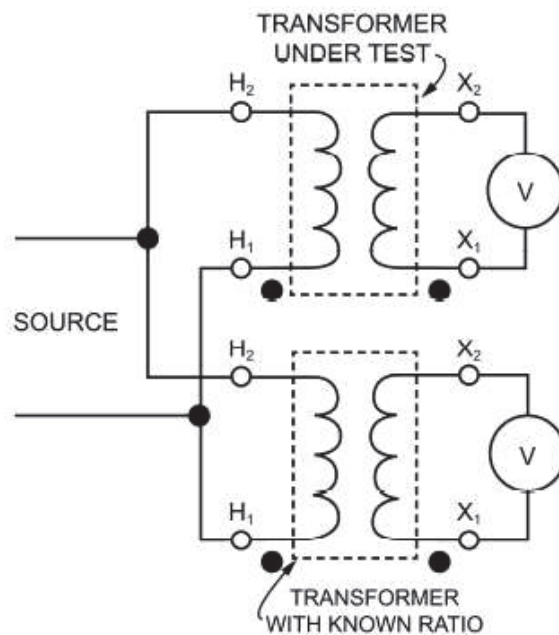


Figure 11 — Voltmeters arranged to read the two secondary voltages

7.3.3 Ratio meter

A meter using the basic circuit of Figure 12 may be used to measure ratio. When detector DET is in balance, the transformer ratio is equal to R_2/R_1 .

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 meter that provides phase-angle correction.

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

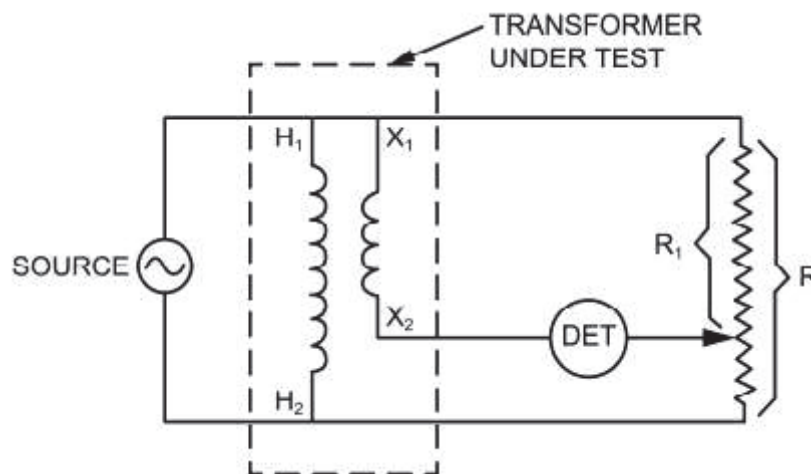


Figure 12 — Basic circuit of ratio meter

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_{av}), 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 13 and Figure 14. Figure 13 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 14 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.

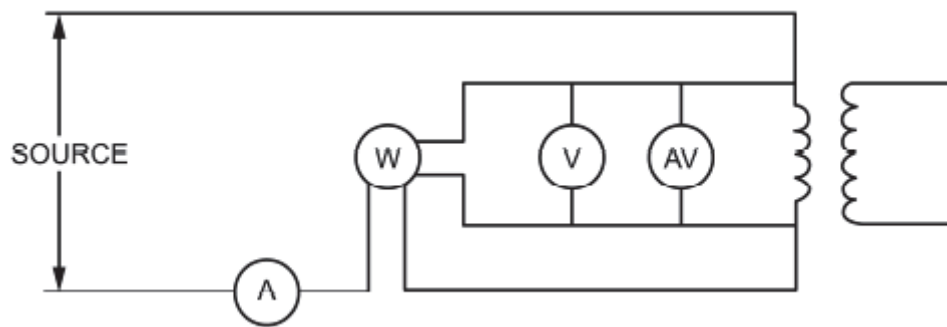


Figure 13 — Connections for no-load loss test of a single-phase transformer without instrument transformers

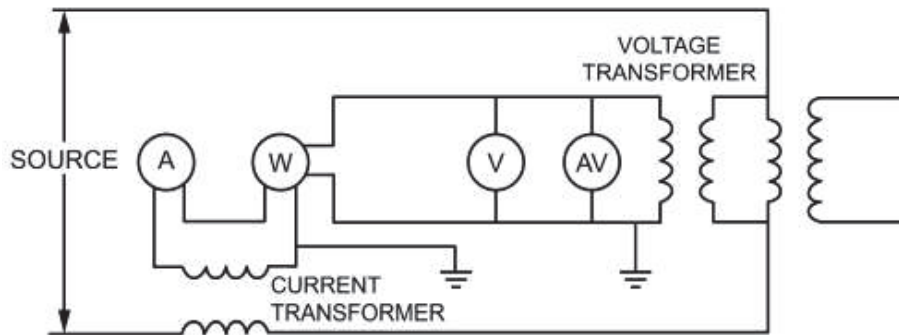


Figure 14 —Connections for a no-load loss test of a single-phase transformer with instrument transformers

Tests for the no-load loss determination of a three-phase transformer shall be carried out by using the three wattmeter method. Figure 15 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.

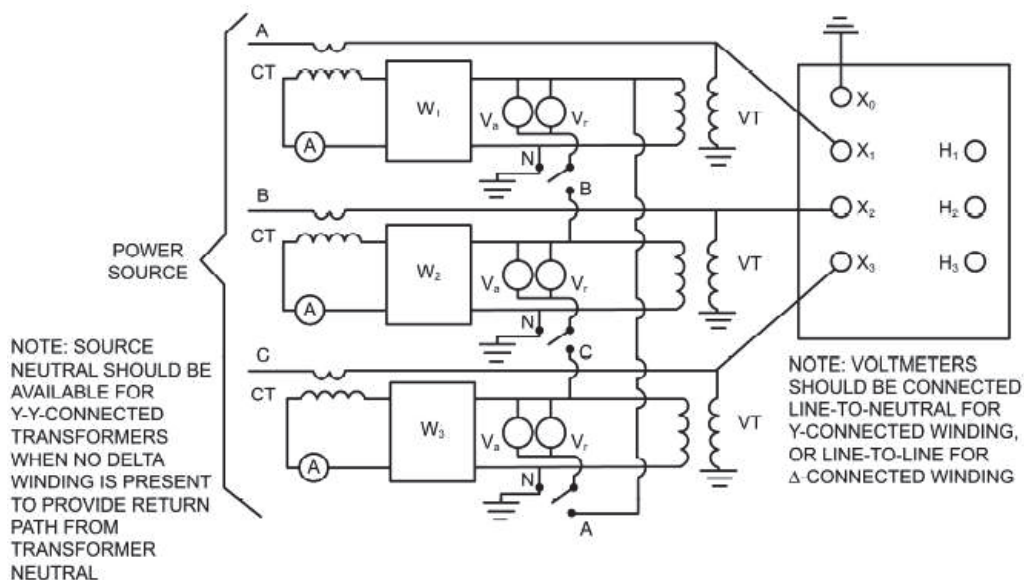


Figure 15 — Three-phase transformer connections for no-load loss and excitation current tests using three-wattmeter method

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.

8.2.3 Energized windings

Either the high- or low-voltage winding of the transformer under test may be energized, but it is generally more convenient to make this test using the low-voltage winding. In any case, the full winding (not merely a portion of the winding) should be used whenever possible. If, for some unusual reason, only a portion of a winding is excited, this portion shall not be less than 25% of the winding.

8.2.4 Voltage and frequency

The operating and performance characteristics of a transformer are based on rated voltage and rated frequency, unless otherwise specified. Therefore, the no-load loss test is conducted with rated voltage impressed across the transformer terminals, using a voltage source at a frequency equal to the rated frequency of the transformer under test, unless otherwise specified.

To determine no-load losses of a single-phase transformer or a three-phase transformer, the frequency of the test source should be within $\pm 0.5\%$ of the rated frequency of the transformer under test. The voltage shall be adjusted to the specified value as indicated by the average-voltage voltmeter. Simultaneous values of rms voltage, rms current, electrical power, and the average-voltage voltmeter readings shall be recorded. For a three-phase transformer, the average of the three voltmeter readings shall be the desired nominal value.

8.3 Waveform correction of no-load losses

The eddy-current component of the no-load loss varies with the square of the rms value of excitation voltage and is substantially independent of the voltage waveform. When the test voltage is held at the specified value as read on the average-voltage voltmeter, the actual rms value of the test voltage may not be equal to the specified value. The no-load losses of the transformer corrected to a sine-wave basis shall be determined from the measured value using Equation (2):

$$P_c(T_m) = \frac{P_m}{P_1 + kP_2} \quad (2)$$

where

T_m is the average liquid temperature at the time of test (°C)

$P_c(T_m)$ is the no-load losses, corrected for waveform, at temperature T_m

P_m is measured no-load losses at temperature T_m

P_1 is per-unit hysteresis loss

P_2 is per-unit eddy-current loss

$$k \text{ is } \left(\frac{E_r}{E_a} \right)^2$$

(New)

~~$$k \text{ is } \left(\frac{E_r}{E_a} \right)^2$$~~

(Deleted)

E_r is the test voltage measured by rms voltmeter

E_a is the test voltage measured by average-voltage voltmeter

The actual per-unit values of hysteresis and eddy-current losses should be used if available. If actual values are not available, it is suggested that the two loss components be assumed equal in value and that they each be assigned a value of 0.5 per unit. For more information, see IEEE Std C57.123.

Equation (2) is valid only for test voltages with moderate waveform distortion. If waveform distortion in the test voltage causes the magnitude of the correction to be greater than 5%, the test voltage waveform shall be improved for an adequate determination of the no-load losses and currents.

8.4 Temperature correction of no-load losses

A reference temperature is required when stating no-load losses because the no-load losses vary with core temperature. The standard reference temperature T_r for transformer no-load losses is specified in 5.9 of IEEE Std C57.12.00-[2021](#) ~~2015~~.

The observed decrease in no-load losses for an increase in temperature results from several mechanisms acting together. Changes in the core steel resistivity, changes in mechanical stress in the core structure, and variations in the temperature gradients in the core cause the no-load loss to change with temperature. Because these factors vary from design to design and between transformers of the same design, it is not practical to specify an exact formula to account for temperature variation throughout the operating temperature range of transformers.

However, ordinary variations of temperature encountered when performing the no-load loss test will not affect no-load losses materially, and no correction for temperature needs to be made, so long as the following conditions are met:

- a) The average liquid temperature is within ± 10 °C of the reference temperature T_r .
- b) The difference between the top and bottom liquid temperatures does not exceed 5 °C.

If conducting the test with temperatures outside the specified ranges is necessary, the empirical formula in Equation (3) may be used to correct the measured no-load losses to the reference temperature.÷

$$P_c(T_r) = P_c(T_m) \{1 + (T_m - T_r)K_T\} \quad (3)$$

where

$P_c(T_r)$ is the no-load losses, corrected to the standard reference temperature T_r

$P_c(T_m)$ is the no-load losses, corrected for waveform, at temperature T_m

T_r is the standard reference temperature (°C)

K_T is an empirically derived per-unit change in no-load loss per degree Celsius

If the actual value of K_T is not available, a value of 0.000 65 per-unit change per ~~degree~~ degrees Celsius should be used. This value is typical for cores constructed of grain-oriented silicon steel and is satisfactory as a correction for no-load losses when the transformer cannot be tested within the specified temperature range.

8.5 Determination of excitation (no-load) current

The excitation (no-load) current of a transformer is the current that maintains the rated magnetic flux excitation in the core of the transformer. The excitation current is usually expressed per unit or in percent of the rated line current of the winding in which it is measured. (Where the cooling class of the transformer involves more than one kilovolt ampere rating, the lowest kilovolt ampere rating is used to determine the base current.) Measurement of excitation current is usually carried out in conjunction with the tests for no-load losses. RMS current is recorded simultaneously during the test for no-load losses using the average-voltage voltmeter method. This value is used in calculating the per-unit or percent excitation current. For a three-phase transformer, the excitation current is calculated by taking the average of the magnitudes of the three line currents.

8.6 Frequency conversion of no-load losses and excitation current

In the event that the no-load loss and excitation current test cannot be done at the rated power frequency, see Annex B for 50/60 Hz frequency conversions.

9. Load losses and impedance voltage

9.1 General

The load losses of a transformer are losses incident to a specified load carried by the transformer. Load losses include I^2R loss in the windings due to load current and stray losses due to eddy currents induced by leakage flux in the windings, core clamps, magnetic shields, tank walls, and other conducting parts. Stray losses may also be caused by circulating currents in parallel windings or strands. Load losses are measured by applying a short circuit across either the high-voltage winding or the low-voltage winding and applying sufficient voltage across the other winding to cause a specified current to flow in the windings. The power loss within the transformer under these conditions equals the load losses of the transformer at the temperature of test for the specified load current.

The impedance voltage of a transformer is the voltage required to circulate rated current through one of two specified windings when the other winding is short-circuited, with the windings connected for rated voltage operation. Impedance voltage is usually expressed in per unit or in percent of the rated voltage of the winding across which the voltage is applied and measured. The impedance voltage comprises a resistive component and a reactive component. The resistive component of the impedance voltage, called the *resistance drop*, is in phase with the current and corresponds to the load losses. The reactive component of the impedance voltage, called the *reactance drop*, is in quadrature with the current and corresponds to the leakage-flux linkages of the windings. The impedance voltage is the phasor sum of the two components. The impedance voltage is measured during the load loss test by measuring the voltage required to circulate rated current in the windings. The measured voltage is the impedance voltage at the temperature of test, and the power loss dissipated within the transformer is equal to the load losses at the temperature of test and at rated load. The impedance voltage and the load losses are corrected to a reference temperature using the formulas specified in this standard (see 9.4.2).

The impedance kilovolt_ampere is the product of the impedance voltage across the energized winding in kilovolts times the winding current in amperes. The ratio of the load losses in kilowatts at the temperature of test to the impedance kilovolt_ampere at the temperature of test is the load loss power factor of the transformer during the test and is used for correction of phase-angle error as specified in this standard.

9.2 Factors affecting the values of load losses and impedance voltage

The magnitudes of the load losses and the impedance voltage will vary depending on the positions of tap-changers, if any, in various windings. These changes are due to the changes in the magnitudes of load currents and associated leakage-flux linkages as well as changes in stray flux and accompanying stray losses. In addition, several other factors affect the values of load losses and impedance voltage of a transformer. Considerations of these factors, partly, explain variations in load loss values and impedance voltage for the same transformer under different test conditions as well as variations between load loss values and impedance voltage of different transformers of the same design. These factors are discussed in 9.2.1 through 9.2.4.

9.2.1 Design

The design-related factors include conductor material, conductor dimensions, winding design, winding arrangement, shielding design, and selection of structural materials.

9.2.2 Process

The process-related factors that affect load loss values and impedance voltage are the dimensional tolerances of conductor materials, the final dimensions of completed windings, phase assemblies, metallic parts exposed to stray flux, and variations in properties of conductor material and other metallic parts.

9.2.3 Temperature

Load loss values are also a function of temperature. The I^2R component of the load losses increases with temperature, whereas the stray loss component decreases with temperature. Procedures for correcting the load losses and impedance voltage to the standard reference temperature are described in 9.4.2.

9.2.4 Measurements

At low power factors, such as those encountered while measuring load losses and impedance voltage of power transformers, judicious selection of measurement method and test system components is essential for accurate and repeatable test results. The phase-angle errors in the instrument transformers, measuring instruments, bridge networks, and accessories affect load loss test results. Procedures for correcting the load losses for metering phase-angle errors are described in 9.4.1.

9.3 Tests for measuring load losses and impedance voltage

Regardless of the test method selected, the following preparatory requirements shall be satisfied for accurate test results:

- a) To determine the temperature of the windings with sufficient accuracy, the following conditions shall be met, except as stated in the NOTE in [item 3](#) 2):
 - 1) The temperature of the insulating liquid has stabilized, and the difference between top and bottom liquid temperatures does not exceed 5 °C.
 - 2) The temperature of the windings shall be taken immediately before and after the load losses and impedance voltage test in a manner similar to that described in 5.1. The average shall be taken as the true temperature.
 - 3) The difference in winding temperature before and after the test shall not exceed 5 °C.

NOTE—For distribution and pad-mounted transformers up to 2500 kVA, where it may not be practical to wait for thermal equilibrium, the method used to determine the winding temperature should take into consideration the lack of thermal equilibrium and the effect of ohmic heating of the winding conductors by load current during the test. The method used can be verified by staging a repeated measurement of the load losses and impedance voltage at a later time when condition 1, condition 2, and condition 3 are met.

- b) The conductors used to short-circuit the low-voltage high-current winding of a transformer shall have a cross-sectional area equal to or greater than the corresponding transformer leads.
- c) The frequency of the test source used for measuring load losses and impedance voltage shall be within $\pm 0.5\%$ of the nominal value.
- d) The maximum value of correction to the measured load losses due to the test system phase-angle error is limited to $\pm 5\%$ of measured losses. If more than 5% correction is required, test methods and/or test apparatus should be improved for an adequate determination of load losses.

9.3.1 Wattmeter-voltmeter-ammeter method

The connections and apparatus needed to determine load losses and impedance voltage of a single-phase transformer are shown in Figure 16 and Figure 17. Figure 16 applies when instrument transformers are not required. If instrument transformers are required (as is generally the case), then Figure 17 applies.

NOTE—Instrument transformers to be added when necessary.

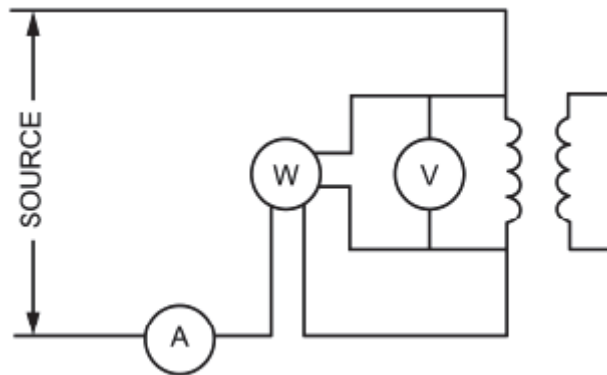


Figure 16 — Single-phase transformer connections for load loss and impedance voltage tests without instrument transformers

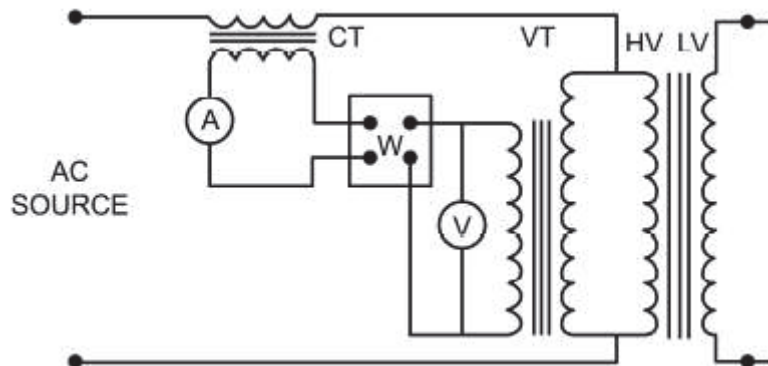


Figure 17 — Single-phase transformer connections for load loss and impedance voltage tests with instrument transformers

For three-phase transformers, a three-phase power measurement using two wattmeters is possible, but it can result in very large errors at low power factors in load loss tests of transformers. The two-wattmeter method should not be used for loss tests on three-phase transformers.

For three-phase transformers, Figure 18 shows the apparatus and connections using the three-wattmeter method.