



IEEE Standard Test Code for Dry-Type Distribution and Power Transformers

IEEE Power and Energy Society

Developed by the
Transformers Committee

IEEE Std C57.12.91™-2020
(Revision of IEEE Std C57.12.91-2011)

STANDARDS

IEEE Standard Test Code for Dry-Type Distribution and Power Transformers

Developed by the

Transformers Committee
of the
IEEE Power and Energy Society

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IEEE SA Standards Board

Abstract: To reflect current practice in the testing procedures of dry-type transformers, substantive changes to Clause 5, Clause 7, Clause 10, Clause 11, and Clause 13 of IEEE Std C57.12.91-2011 have been made in this revision. Also Annex B has been added to provide guidelines for converting test results measured at 60 Hz to the equivalent values at 50 Hz and vice versa. This revision does not address transformer requirements and specific test criteria; rather they are contained in appropriate standards such as IEEE Std C57.12.01 or in user specifications.

Keywords: dry-type transformer, IEEE C57.12.91™, power transformer

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Introduction

This introduction is not part of IEEE Std C57.12.91-2020, IEEE Standard Test Code for Dry-Type Distribution and Power Transformers.

This revision of IEEE Std C57.12.91-2011 incorporates changes to Clause 5, Clause 7, Clause 10, Clause 11, and Clause 13 and adds Annex B.

In Clause 5, 5.2.1 has been modified to clarify the location of the resistance measurements. Clause 7 has been modified to allow the use of electronic ratio meters for ratio measurement. Clause 10 has been modified to add the test method for partial discharge tests. This information was previously in IEEE Std C57.12.01.¹ Clause 11 was modified to clarify the location of the hot-resistance measurements and to clarify how an additive factor may be used in lieu of excitation temperature measurements. Clause 13 was extensively modified to bring the methods of measuring and calculating audible sound level for dry-type transformers into similarity with the methods outlined in IEEE Std C57.12.90 for liquid-immersed transformers. Finally, Annex B was added to provide guidelines for converting test results measured at 60 Hz to the equivalent values at 50 Hz and vice versa.

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

Contents

1. Overview	11
1.1 Scope	11
1.2 Purpose	11
1.3 Word usage	12
2. Normative references	12
3. Definitions	13
4. General	13
4.1 Test definitions	13
4.2 Test requirements	13
4.3 Test sequence	14
4.4 Instrumentation	14
5. Resistance measurements	14
5.1 General	14
5.2 Measurements	14
5.3 Determination of cold temperature	15
5.4 Conversion of resistance measurements	16
5.5 Resistance measurement methods	16
5.6 Resistance measurement connections and reporting	17
6. Polarity and phase-relation tests	18
6.1 General	18
6.2 Subtractive and additive polarity	18
6.3 Polarity tests—single-phase transformers	20
6.4 Polarity and phase-relation tests—polyphase transformers	21
7. Ratio test	24
7.1 General	24
7.2 Tolerances for ratio	25
7.3 Ratio test methods	25
8. Excitation losses and current	27
8.1 General	27
8.2 Excitation loss test	28
8.3 Waveform correction of excitation losses	30
8.4 Determination of excitation current	30
8.5 Frequency conversion of excitation losses and current	31
9. Load losses and impedance voltage	31
9.1 General	31
9.2 Factors affecting the values of load losses and impedance voltage	31
9.3 Tests for measuring load losses and impedance voltage	32
9.4 Calculation of load losses and impedance voltage from test data	38
9.5 Zero-phase-sequence impedance	40
10. Dielectric test	42
10.1 Factory dielectric tests	42
10.2 Dielectric tests in the field	44
10.3 Applied voltage tests	44
10.4 Induced voltage tests	45
10.5 Partial discharge tests	46
10.6 Impulse tests	47

10.7 Impulse tests on transformer neutrals	51
10.8 Detection of failure during impulse tests	51
10.9 Insulation-power-factor tests	52
10.10 Insulation-resistance tests	53
11. Temperature rise test	54
11.1 General	54
11.2 Ambient temperature measurements	55
11.3 Surface temperature measurements	55
11.4 Cold-resistance measurements	56
11.5 Hot-resistance measurements	56
11.6 Calculation of average winding temperature rise	57
11.7 Correction factors	58
11.8 Temperature rise test loading methods	59
12. Short-circuit tests	65
12.1 Scope	65
12.2 Short-circuit testing techniques	66
12.3 Test requirements	71
12.4 Test procedure	71
12.5 Failure detection techniques	75
12.6 Analysis of test results and visual inspection	76
12.7 Proof of satisfactory performance	79
12.8 Required information for transformer short-circuit test reports	80
13. Audible sound-level measurements	80
13.1 General	80
13.2 Instrumentation	81
13.3 Test conditions	82
13.4 Microphone positions	83
13.5 Sound pressure level measurements	83
13.6 Determination of audible sound level of a transformer	88
13.7 Presentation of results	88
14. Mechanical design tests	91
14.1 General	91
14.2 Components involved in lifting or moving	91
14.3 Tests of sealed dry-type transformers	91
15. Calculated data	91
15.1 Reference temperature	91
15.2 Total losses	92
15.3 Efficiency	92
15.4 Voltage regulation	92
16. Minimum information to be included in certified test data	93
16.1 General	93
16.2 Order data	93
16.3 Rating data	94
16.4 Test data	94
16.5 Calculated data	94
16.6 Certification statement and approval	94
Annex A (informative) Bibliography	95
Annex B (normative) 50/60 Hz frequency conversion of measured performance parameters	96

IEEE Standard Test Code for Dry-Type Distribution and Power Transformers

1. Overview

1.1 Scope

This standard describes methods for performing tests specified in IEEE Std C.57.12.01 and other referenced standards applicable to dry-type distribution and power transformers, with a voltage of 601 V or higher in the highest voltage winding.² It is intended for use as a basis for performance and for the proper testing of dry-type distribution and power transformers.

This standard applies to all dry-type transformers including those with solid cast and/or resin encapsulated windings, *except as follows*:

- a) Instrument transformers
- b) Step-voltage and induction voltage regulators
- c) Arc furnace transformers
- d) Rectifier transformers
- e) Specialty and General Purpose transformers
- f) Mine transformers
- g) Testing transformers
- h) Welding transformers

NOTE—Where IEEE standards do not exist for the transformers mentioned above or for other special transformers, this standard may be applicable as a whole or in parts subject to agreement between the parties responsible for the application and for the design of the transformer.³

1.2 Purpose

The purpose of this standard is to provide information regarding the procedures for the testing of dry-type transformers. Transformer requirements and specific test criteria are not a part of this standard but are contained in appropriate standards such as IEEE Std C57.12.01 or in user specifications.

² Information on normative references can be found in Clause 2.

³ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

1.3 Word usage

The word *shall* indicates mandatory requirements to be strictly followed in order to conform to the standard and from which no deviation is permitted (shall equals is required to).^{4,5}

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).

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 S1.4, American National Standard for Sound Level Meters.⁶

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

IEEE Std 4™, IEEE Standard for High-Voltage Testing Techniques.^{7,8}

IEEE Std C57.12.01™, IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers.

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

IEEE Std C57.96™, IEEE Guide for Loading Dry-Type Distribution and Power Transformers.

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

IEEE Std C57.124™, IEEE Recommended Practice for the Detection of Partial Discharge and the Measurement of Apparent Charge in Dry-Type Transformers.

⁴ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁵ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

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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.⁹ Standard transformer terminology available in IEEE Std C57.12.80 shall apply.

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 meter circuitry. C-weighting has only little dependence on frequency over the greater part of the audible frequency range.

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

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 base 10 logarithm of the ratio of the measured sound pressure (P) to a reference pressure (P_o) of 20 μ Pa or

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

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

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

4. General

4.1 Test definitions

A variety of test types including routine, design, other, and conformance tests are defined in IEEE Std C57.12.80.

4.2 Test requirements

A general summary of test requirements is included in IEEE Std C57.12.01, which indicates by size (less than 300 kVA, or 300 kVA and larger) which tests are normally considered routine, design, or other.

⁹ IEEE Standards Dictionary Online is available at <https://dictionary.ieee.org>.

4.3 Test sequence

See 10.1.2 for sequence of dielectric tests when lightning impulse tests are specified.

NOTE—If it is desired to reduce potential damage to the transformer during testing, the resistance, polarity, phase-relation, ratio, excitation loss and current, impedance and load-loss tests, and temperature rise tests (when applicable) should precede dielectric tests. When this sequence is used, the beginning tests involve voltages and currents that are usually reduced compared to rated values, thus tending to reduce damaging effects to the transformer.

4.4 Instrumentation

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

5. Resistance measurements

5.1 General

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 rise test
- c) As a quality control test of the manufacturing process
- d) As a base for assessing possible damage in the field

5.2 Measurements

5.2.1 Resistance

Resistance measurements shall be taken on all phases of each primary and secondary winding at the transformer terminals and on the rated tap connection. If a temperature rise test is to be performed, cold-resistance measurements shall also be taken on all phases of each primary and secondary winding on the combination of connections and taps to be used for the temperature rise test. The cold-resistance measurements shall be made at the coils. When that is not feasible for a sealed or nonventilated transformer, the measurements may be made at the terminals.

5.2.2 Polarity

The polarity of the core magnetization shall be kept constant during all resistance readings. A reversal in magnetization of the core can change the time constant and result in erroneous readings. The same relative polarity of the measuring leads and the transformer terminals should be maintained when transferring leads from one measurement to another.

5.2.3 Current

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

5.2.4 Making measurements

When making resistance measurements:

- a) Measurement time intervals of 5 s to 10 s are recommended. Longer intervals may be needed for the current and voltage readings to reach stable steady-state values. Readings shall not be taken before the current and voltage measurement values reach steady state.
- b) The measuring instruments shall have ranges that give a reasonably large deflection for a needle type of instrument and a high percentage of scale range for a digital instrument to reduce errors of observation.
- c) Current shunts and digital voltmeters, or high-accuracy digital ammeters, or other high-accuracy instrumentation should be used to meet the requirements of IEEE Std C57.12.01 due to inaccuracy of deflecting ammeters and voltmeters. This equipment should have a resolution of equal to or better than 0.1% of the measured value.
- d) Passing dc current of the same polarity through other windings in the same phase or current of the opposite polarity through windings in other phases during resistance measurements can help reduce charging time. Charging time can also be reduced by opening the delta connection for delta connected windings.

5.3 Determination of cold temperature

5.3.1 Cold temperature value

The cold temperature of the winding shall be determined as accurately as possible when measuring the cold resistance. The following precautions shall be observed. The temperature of the windings for ventilated units shall be recorded as the average readings of several thermometers or thermocouples inserted between the coils. Care shall be taken to see that the measuring points of the thermocouples or thermometers are as nearly as possible in actual contact with the winding conductors. The temperature of the windings for sealed units shall be recorded as the average readings of several temperature sensors in contact with the sides and cover (see 11.8.7 and Figure 31).

5.3.2 Ambient temperature

It should not be assumed that the windings are at the same temperature as the surrounding air. To help ensure that the windings are at ambient temperature, the following conditions shall be met immediately before taking cold-resistance measurements:

- a) All internal temperatures measured by the internal temperature sensors shall not differ from ambient temperature by more than 2 °C.
- b) Enclosure surface temperatures for sealed units shall not differ from ambient temperature by more than 2 °C.
- c) Ambient temperature shall not have changed by more than 3 °C for at least 3 h.
- d) The transformer has been in a draft-free area for 24 h, and neither voltage nor current has been applied to it for 24 h to 72 h, depending on transformer size.

The cold temperature shall be the average of the internal temperature sensors or, in the case of a sealed unit where the internal sensors are not available, the average of the surface temperature sensors.

5.3.3 Measurement time

When measuring the cold resistance preparatory to making a temperature rise test, the time required for the readings to become constant should be noted. The period thereby determined should be allowed to elapse before taking the first reading when final winding hot-resistance measurements are being made.

5.3.4 Residual flux

The residual flux in the core should be same for both the cold- and hot-resistance measurements by saturating the core with dc current prior to the measurement.

5.4 Conversion of resistance measurements

Cold-winding resistance measurements are normally converted to a standard reference temperature equal to 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 using Equation (1).

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

where

- R_s is resistance at desired temperature T_s
- R_m is measured resistance
- T_s is desired reference temperature
- T_k (234.5 °C for copper and 225 °C for aluminum are typical values. Other values may be used based on the alloy of the conductor in the transformer under test.)
- T_m is the temperature at which resistance was measured

5.5 Resistance measurement methods

5.5.1 Voltmeter-ammeter method

The voltmeter-ammeter method is the most common method used for transformer winding resistance measurement. Resistance measuring systems may consist of individual modules such as analog or digital voltmeters, current shunts, analog or digital ammeters, dc power sources, computerized controllers, and data-loggers. The dc power source and measuring devices may be integrated into a resistance meter. DC power sources are normally employed for current ratings of 1 A or more; integrated digital instruments may have even lower current ranges.

The following steps should be taken to use this method:

- a) Measurements are made with direct current, and simultaneous readings of current and voltage are taken using the connections of Figure 1. The required resistance is calculated from the readings by dividing the voltage measurement by the current measurement. Electronic switching power supplies are generally 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.

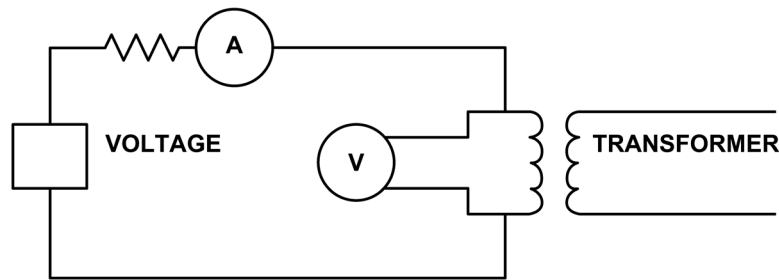


Figure 1—Connections for voltmeter-ammeter method

- b) The voltage leads shall be independent of the current leads and shall be connected to the transformer at the point of measurement as specified in 5.2.1. This is to avoid including into the readings the resistances of leads and their contact resistances.
- c) Transformer winding resistance measurements may exhibit a long dc time constant to reach stable steady-state values. 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. The external resistance should be large compared to the impedance of the winding. It is then necessary to increase the source voltage to compensate for the voltage drop in the external resistor.
- d) To protect test personnel from inductive kickback, the measuring circuit current source should be connected and disconnected by a suitably insulated switch with a protective circuit to safely discharge the energy. The voltmeter should be disconnected from the circuit before switching the current on or off to protect the voltmeter from overvoltage injury from inductive kickback.

5.5.2 Bridge method

Bridge methods or other high-accuracy digital instruments may be used in cases where the rated current of the transformer winding requires the measuring current to be less than 1 A. Wheatstone bridges (or equivalent) are commonly used for resistances greater than 1 Ω ; Kelvin bridges (or equivalent) are commonly used for resistances less than 1 Ω ; and some of the newer, digital resistance bridges have capabilities in both ranges.

5.6 Resistance measurement connections and reporting

5.6.1 Resistances to be reported

The total winding resistances, defined in 5.6.2 through 5.6.5, shall be reported. The individual terminal-to-terminal resistances should also be reported.

5.6.2 Single-phase windings

For single-phase windings, the reported resistance measurements are from terminal to terminal. The reported total winding resistance is the terminal-to-terminal measurement. For series-parallel windings, the reported total winding resistance is the sum of the series terminal-to-terminal section measurements.

5.6.3 Wye windings

For wye windings, the reported resistance measurement may be from terminal to terminal or from terminal to neutral. The reported total winding resistance is the sum of the three terminal-to-terminal measurements divided by 2. The neutral connection resistance, which is a portion of each terminal-to-neutral resistance measurement, may be excluded.

5.6.4 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 resistances. If the delta is open, the reported total winding resistance is the sum of the three terminal-to-terminal measurements. If the delta is closed, the reported total winding resistance is the sum of the three terminal-to-terminal measurements multiplied by 1.5.

5.6.5 Autotransformer windings

For autotransformer windings, the reported resistance measurements are from terminal to terminal. The reported total winding resistance is the terminal-to-terminal measurement.

For autotransformer series winding resistance, the test current shall be circulated between the high-voltage series terminal and neutral terminal, and the test voltage measured between the high-voltage series terminal and the low-voltage common terminal. For the common winding resistance, the test current shall be circulated between the high-voltage series terminal and neutral terminal, and the test voltage measured between the low-voltage common terminal and the neutral terminal. If the resistance of the common terminal connection is needed, the test current shall be applied between the high-voltage series terminal and the low-voltage common terminal, and the test voltage measured between the low-voltage common terminal and the neutral terminal.

6. Polarity and phase-relation tests

6.1 General

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.

6.2 Subtractive and additive polarity

Windings arranged for subtractive and additive polarity are shown in Figure 2 and Figure 3. Leads and polarity marks arranged for subtractive polarity and additive polarity are shown in Figure 4 and Figure 5.

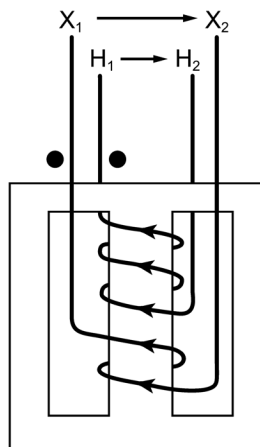


Figure 2—Windings: subtractive polarity

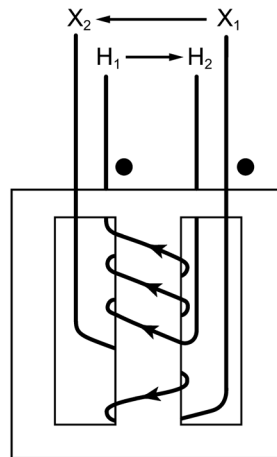


Figure 3—Windings: additive polarity

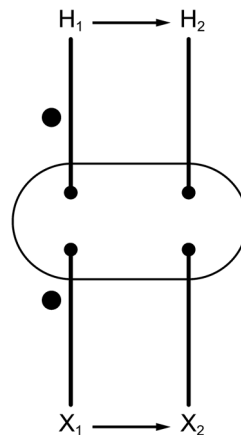


Figure 4—Leads and polarity marks: subtractive polarity

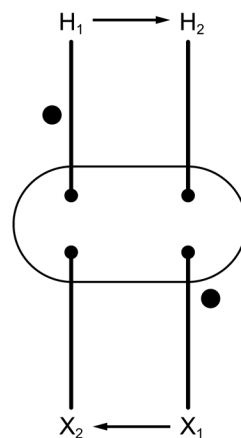


Figure 5—Leads and polarity marks: additive polarity

6.3 Polarity tests—single-phase transformers

6.3.1 General

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

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

6.3.2 Polarity by inductive kick test

The polarity of transformers with leads arranged as shown in Figure 2, Figure 3, Figure 4, and Figure 5 may be determined at the time of making the resistance measurements as follows:

- a) With direct current passing through the high-voltage winding, connect a high-voltage dc voltmeter across the high-voltage winding terminals H_1 and H_2 and adjust the sensitivity to get a small reading on the meter.
- b) Transfer the two voltmeter leads directly across the transformer with the lead on H_1 moving to X_2 and the lead on H_2 moving to X_1 .
- c) Break dc excitation, thereby inducing a voltage in the low-voltage winding (inductive kick) that causes a deflection in the voltmeter, which is interpreted in item d) and item e).
- d) If the pointer swings in the opposite direction (negative), the polarity is subtractive.
- e) If the pointer swings in the same direction as before (positive), the polarity is additive.

6.3.3 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. (In Figure 6, this is X_1 .)

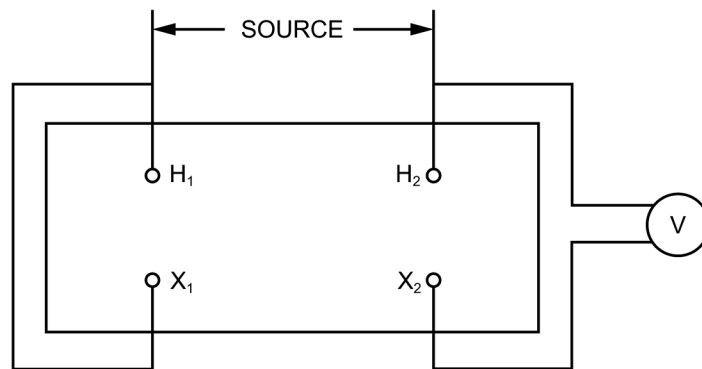


Figure 6—Polarity by alternative-voltage test

Any convenient value of alternating voltage shall be applied to the full high-voltage winding, and readings taken of the applied voltage and the voltage between the right-hand adjacent high-voltage and low-voltage leads. If the latter reading is greater than the former, the polarity is additive. If the latter voltage reading is less than the former (indicating the approximate difference in voltage between that of the high-voltage and low-voltage windings), the polarity is subtractive.

6.3.4 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) Also 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 indicates that the relative polarities of both transformers are identical.
- d) 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.

6.3.5 Polarity by ratio meter and ratio bridge

The ratio meter described in 7.3.1 and the ratio bridge described in 7.3.4 can also be used to test polarity.

6.4 Polarity and phase-relation tests—polyphase transformers

6.4.1 Polarity

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.

6.4.2 Phase-relation tests

6.4.2.1 Test to verify phasor diagram for transformers with a ratio of transformation of 60 to 1 or less

The phasor diagram of any three-phase transformer, defining both the angular displacement and phase sequence, can be verified by connecting the H_1 and X_1 leads together; exciting the unit at a suitably low, three-phase, voltage; taking voltage measurements between various pairs of leads; and then either plotting these values or comparing them for their relative order of magnitude with the help of the corresponding diagram in Figure 7 or Figure 8, in which typical check measurements to be taken and their relative magnitudes are also indicated.

6.4.2.2 Zigzag windings

Equal zig and zag windings usually are 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 the manufacturing phase to prove the desired phase relationships. 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.

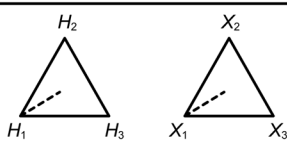
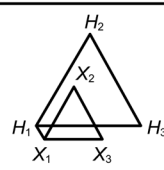
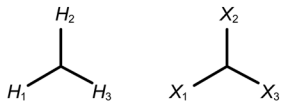
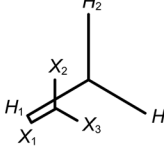
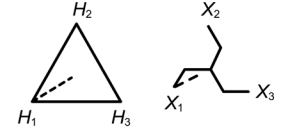
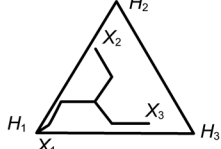
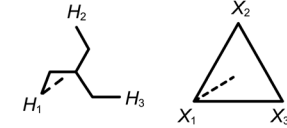
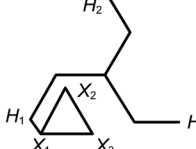
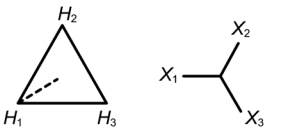
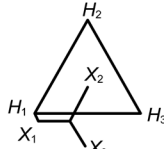
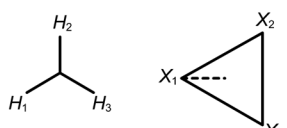
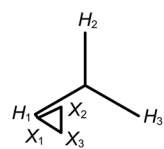
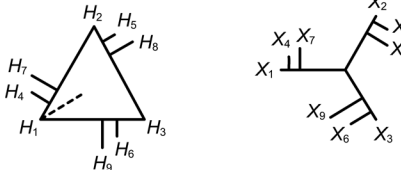
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA - DELTA CONNECTION		CONNECT H_1 TO X_1 MEASURE $H_2 - X_2, H_3 - X_3,$ $H_1 - H_2, H_2 - X_3, H_3 - X_3$ VOLTAGE RELATIONS (1) $H_2 - X_3 = H_3 - X_2$ (2) $H_2 - X_2 < H_1 - H_2$ (3) $H_2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

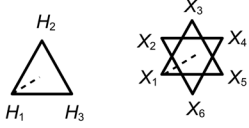
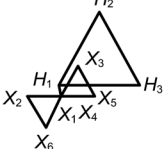
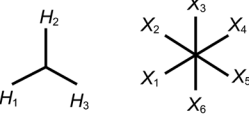
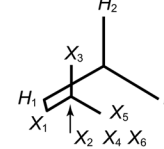
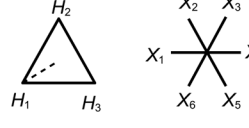
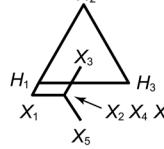
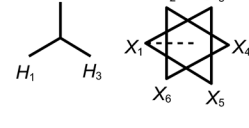
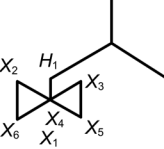
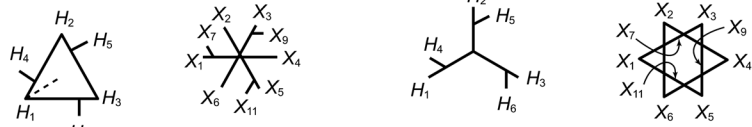
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA - DOUBLE DELTA		CONNECT H_1 TO X_1 TO X_4 MEASURE $H_2 - X_3$, $H_1 - H_2$, $H_2 - X_5$, $H_2 - X_6$, $H_3 - X_2$, $H_2 - X_2$, $H_3 - X_3$ VOLTAGE RELATIONS (1) $H_2 - X_5 = H_3 - X_3$ (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) $H_2 - X_3 < H_2 - H_5$ (4) $H_3 - X_2 = H_3 - X_6$ (5) $H_3 - X_2 > H_1 - X_3$ (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

6.4.2.3 Six-phase windings

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

6.4.2.4 Phase relation with ratio meter and ratio bridge

The ratio meter described in 7.3.1 and the ratio bridge described in 7.3.4 may also be used to test phase relationships.

6.4.3 Phase-sequence test

6.4.3.1 Test method

The following method does not measure the angular displacement of the transformer. It only indicates the phase-sequence. The phase-sequence indicator may incorporate either a three-phase induction motor or a split-phase circuit.

The indicator is first connected to the higher voltage leads; the transformer is then excited with a three-phase voltage at a level suitable for the indicator, and the direction of rotation indication of the instrument should be noted.

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

The transformer is again excited at a suitable voltage (without changing the excitation connections), and the indication again noted. The phase sequence of the transformer is correct if the indication is the same in both cases.

Six-phase secondaries, having no neutral connection, are connected temporarily in delta or wye for this test. If 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 noted. The tests should then be repeated by transferring 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.

6.4.3.2 Test of phase-sequence with ratio bridge

The ratio bridge described in 7.3.4 can also be used to test phase sequence.

7. Ratio test

7.1 General

7.1.1 Turns ratio

The turns ratio of a transformer is the ratio of the number of turns in a higher voltage winding to that in a lower voltage winding.

7.1.2 Transformers with taps

When a transformer has taps for changing its voltage ratio, the turns ratio is calculated from the number of turns corresponding to the nominal rated voltage of each winding.

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

7.1.3 Voltage and frequency requirements

The ratio test shall be made at rated or lower voltage and be such that the ratio of test voltage to test frequency is less than or equal to the ratio of rated voltage to rated frequency.

7.1.4 Three-phase transformers

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

7.1.5 Transformers with wye-diametric connections

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

7.1.6 Inaccessible neutrals

An alternative test procedure, using single-phase power, is possible resulting in negligible loss of accuracy. When only one winding has an inaccessible neutral, a connection to that neutral can be made through a coil on another phase leg. This is accomplished by shorting the energized winding on that phase leg, thereby reducing the flux in that leg to zero. With zero flux there is no voltage induced in the coil being used for the connection, and the only error is due to the added resistance of that coil. When neutrals are inaccessible on both the primary and secondary windings, the ratio can be determined using single-phase power connected line to line.

7.2 Tolerances for ratio

Ratio test tolerances are given in IEEE Std C57.12.01.

7.3 Ratio test methods

7.3.1 Electronic ratio/phase measurement meters

An electronic meter that determines the transformer turns ratio, polarity, and phase angle may be used for the measurement of these parameters.

7.3.2 Voltmeter method

Two voltmeters shall be used (with voltage transformers if necessary)—one to read the voltage of the high-voltage winding, and the other to read that of 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 be such as to yield about the same readings on the two voltmeters. Otherwise, compensation for instrument errors by an interchange of instruments is not satisfactory, and it is necessary to apply appropriate corrections to the voltmeter readings.

Tests shall be made at not 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% of each other. 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 7.3.3.

7.3.3 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). This is the more accurate method because the voltmeter or detector indicates the difference in voltage.

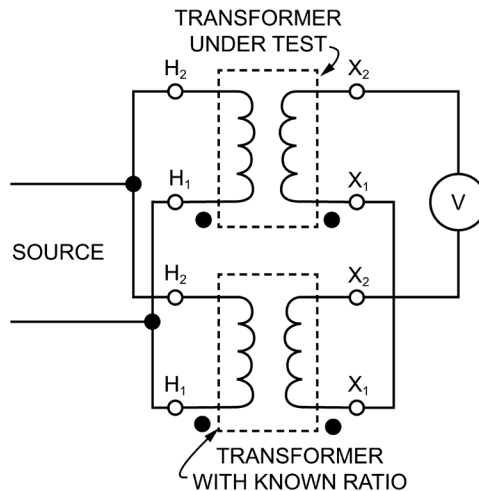


Figure 9—Voltmeter arranged to read the difference between the two secondary voltages

For an alternate 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.

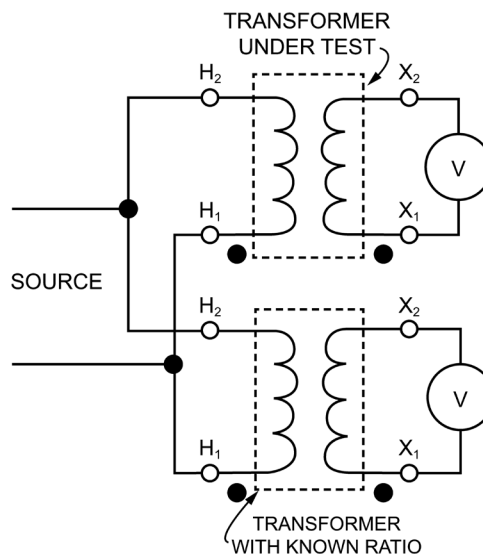


Figure 10—Voltmeters arranged to read the two secondary voltages

7.3.4 Ratio bridge

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

NOTE 1—Measurement of the ratio using circuits of this type has also (in the past) 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.

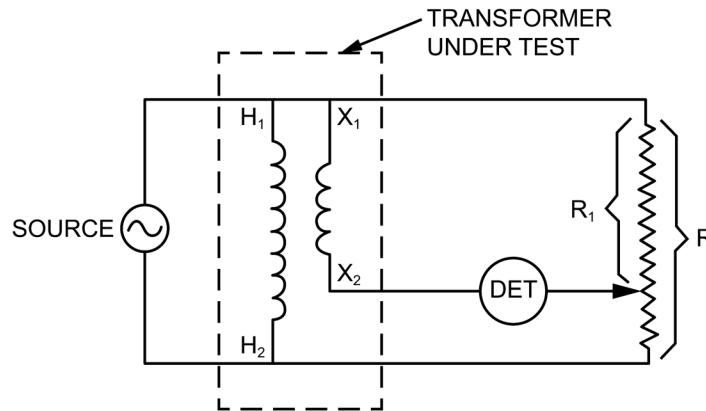


Figure 11—Basic circuit of ratio bridge

8. Excitation losses and current

8.1 General

Excitation (no-load) losses are losses that are incident to the excitation of the transformer. Excitation 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 excitation 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. Excitation losses also vary with temperature and are particularly sensitive to differences in waveform; therefore, excitation loss measurements vary markedly with the waveform of the test voltage.

In addition, several other factors affect the excitation losses and 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 excitation losses of transformers of the same design include variability in characteristics of the core steel, mechanical stresses induced in manufacturing, variation in gap structure, core joints, etc.

8.2 Excitation loss test

8.2.1 General

The purpose of the excitation loss test is to measure excitation losses at a specified excitation voltage and frequency. The excitation loss determination shall be based on sine-wave voltage excitation, 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 excitation losses to a sine-wave equivalent and is recommended. This method employs two-parallel-connected voltmeters; one is an average-responding (but root-mean-square (rms) calibrated) voltmeter; the other is a true rms-responding voltmeter. 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 excitation losses to a sine-wave basis, using Equation (2) in accordance with 8.3.

8.2.2 Connection diagrams

Tests for the excitation loss determination of a single-phase transformer are carried out using the connections depicted in Figure 12 and Figure 13. Figure 12 shows the necessary equipment and connections for the case where the exciting voltage is sufficiently low that instrument transformers are not required. For higher exciting voltages, instrument transformers are required, and 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 excitation loss of the transformer under test.

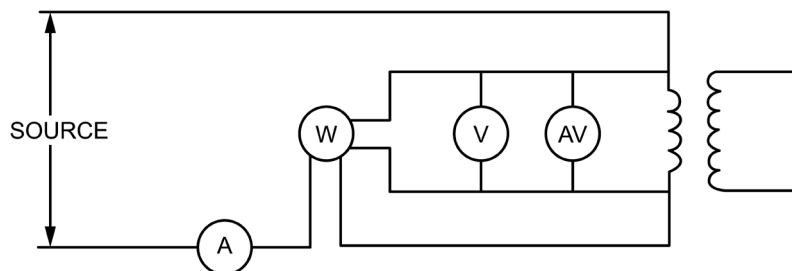


Figure 12—Connections for excitation loss test of a single-phase transformer without instrument transformers

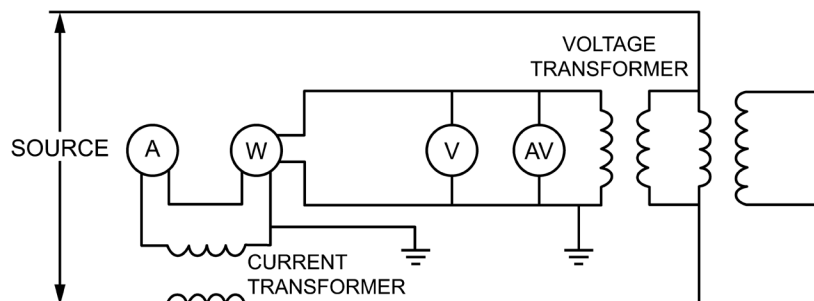


Figure 13—Connections for excitation loss test of a single-phase transformer with instrument transformers

Tests for the excitation 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 excitation loss measurements of a three-phase transformer when instrument transformers are necessary.

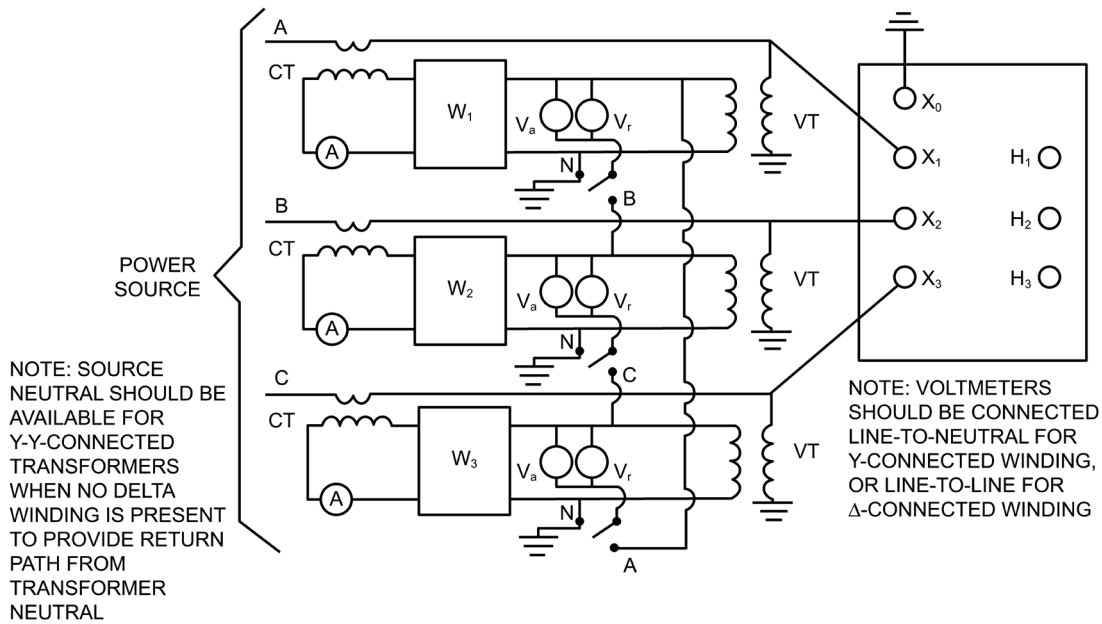


Figure 14—Three-phase transformer connections for excitation loss and current tests using three-wattmeter method

8.2.3 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 upon 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.

8.2.4 Energized windings

Either the high- or the 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. The full excited winding, rather than just a portion of the winding, should be used whenever possible. If only a portion of a winding is excited, this portion shall not be less than 25% of the winding.

8.2.5 Voltage and frequency

The operating and performance characteristics of a transformer are based upon rated voltage and rated frequency, unless otherwise specified. Therefore, the excitation 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.

For the determination of the excitation 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 excitation losses

The eddy-current component of the excitation loss varies as 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 excitation losses of the transformer corrected to a sine-wave basis shall be determined from the measured value using Equation (2) with Equation (3).

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

where

- T_m is the core temperature at the time of test (°C) of the top yoke of the core
- $P_c(T_m)$ is the excitation losses, corrected for waveform, at temperature T_m
- P_m is measured excitation losses at temperature T_m
- P_1 is per-unit hysteresis loss
- P_2 is per-unit eddy-current loss

$$k = \left(\frac{E_r}{E_a} \right)^2 \quad (3)$$

where

- 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, assigning each a value of 0.5 per unit.

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%, then the test voltage waveform shall be improved for an adequate determination of the excitation losses and currents.

8.4 Determination of excitation current

The excitation current of a transformer is the current that maintains the rated magnetic flux in the core of the transformer. The excitation current is usually expressed in 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 excitation losses. The rms current is recorded simultaneously during the test for excitation 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.