

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

Sponsor
**Transformers Committee
of the
IEEE Power Engineering Society**

Approved 26 June 1999
IEEE Standards Board

Abstract: Methods for performing tests specified in IEEE Std C57.12.00-1993 and other standards applicable to liquid-immersed distribution, power, and regulating transformers are described. Instrument transformers, step-voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, grounding transformers, and mine transformers are excluded. This standard covers resistance measurements, polarity and phase-relation tests, ratio tests, no-load-loss and excitation current measurements, impedance and load loss measurements, dielectric tests, temperature tests, short-circuit tests, audible sound level measurements, calculated data, and certified test data.

Keywords: tests, transformers, transformer tests

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Print: ISBN 0-7381-1789-7 SH94778
PDF: ISBN 0-7381-1790-0 SS94778

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Introduction

(This introduction is not a part of IEEE Std C57.12.90-1999, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.)

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

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

This revision of IEEE Std C57.12.90 separates the Test Code, Part I of Std C57.12.90-1993, from Part II of IEEE Std C57.12.90-1993, IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers. Part II of C57.12.90-1993 will become a new IEEE Transformers Committee (C57) document separate from the Test Code.

Many of the changes incorporated into this revision either are editorial, or have been made to make the documents more closely conform the *IEEE Standards Style Manual*. Some changes have been made to correct errors in previous revisions.

Periods have been deleted from the endings of some subheadings, and the words *delta* and *wye*, where possible, are now spelled out to replace symbols in text. The text in Clauses 1–4 has been rearranged, though much of the wording remains the same. Definitions listed in Clause 13 were removed since they duplicate information in Clause 3. Table 11 through Table 14 have been relabeled as Figure 31 through Figure 34.

Some of the changes that are of major importance to the revision of this standard are as follows and listed by clause numbers:

- Clause 2: References—All revisions and reaffirmations are updated.
- Clause 3: Definitions—Efficiency definition has been changed.
- Clause 8: No-load Losses and Excitation Test—Figure 14 has been corrected for accuracy.
- Clause 9: Load Losses and Impedance Voltage—Figure 17, Equation (10), Equation (12), and Table 1 have been corrected for accuracy. In 9.5.3, former Test 3 is now sequenced as Test 2, and former Test 2 is marked as Test 3.
- Clause 10: A term “cathode-ray oscillograph” is replaced by “oscilloscope.” In 10.4.2, the first paragraph has been rewritten for clarity; and in 10.4.3, the last paragraph has been changed for clarity. In 10.10.3, Table 4 for two winding transformers with guard circuit, Method II has been corrected.
- Clause 14: Several equations in 14.4.4.1 have been corrected.
- Clause 15: A word “auxiliary” has been added to c) 3) in losses. Under c) 6), the statement “when specified *” has been replaced with ** (two asterisks), and Note 6 is added for further clarification.

In this standard’s revision all primary measurements are now shown in metric units with their corresponding English equivalent measurements in parenthesis.

A new Clause 15 has been added to replace a previous informative annex.

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

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

1. Overview

1.1 Scope

This standard describes methods for performing tests specified in IEEE Std C57.12.00-1993¹ and other standards applicable to liquid-immersed distribution, power, and regulating transformers. It is intended for use as a basis for performance, safety, and the 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 are contained in appropriate standards, such as IEEE Std C57.12.00-1993, ANSI C57.12.10-1988, IEEE Std C57.12.20-1996, ANSI C57.12.40-1994, or in user specifications.

1.2 Purpose

The purpose of this standard is to provide test procedure information.

1.3 Word usage

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

¹Information on references can be found in Clause 2.

2. References

This standard shall be used in conjunction with the following publications.

ANSI C57.12.10-1988, American National Standard for Transformers 230 kV and Below, 833/958 through 8333/10 417 kVA, Single-Phase, and 750/862 through 60 000/80 000/100 000 kVA, Three-Phase without Load Tap Changing; and 3750/4687 through 60 000/80 000/100 000 kVA with Load Tap Changing—Safety Requirements.²

ANSI C57.12.20-1997, American National Standard for Overhead-Type Distribution Transformers 500 kVA and Smaller: High Voltage, 34 500 Volts and Below; Low Voltage 7970/13 800Y and Below—Requirements.

ANSI C57.12.22-1989, American National Standard for Transformers—Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers with High-Voltage Bushings, 2500 kVA and Smaller: High-Voltage, 34 500 GrdY/19 920 Volts and Below; Low Voltage, 480 Volts and Below—Requirements.

ANSI C57.12.24-1994, American National Standard for Transformers—Underground-Type Three-Phase Distribution Transformers, 2500 kVA and Smaller: High-Voltage, 34 500 GrdY/19 920 Volts and Below; Low Voltage, 480 Volts and Below—Requirements.

ANSI C57.12.25-1990, American National Standard for Transformers—Pad-Mounted, Compartmental-Type, Self-Cooled, Single-Phase Distribution Transformers with Separable Insulated High-Voltage Connectors; High-Voltage, 34 500 GrdY/19 920 Volts and Below; Low-Voltage, 240/120 Volts; 167 kVA and Smaller—Requirements.

ANSI C57.12.40-1994, American National Standard for Secondary Network Transformers—Subway and Vault Types (Liquid Immersed)—Requirements.

ANSI C57.12.70-1978 (Reaff 1993), American National Standard Terminal Markings and Connections for Distribution and Power Transformers.

ANSI C57.92-1981 (Reaff 1992), American National Standard Guide for Loading Mineral-Oil-Immersed Power Transformers.³

ANSI C63.2-1996, American National Standard for Electromagnetic Noise and Field Strength Instrumentation, 10 kHz to 40 GHz—Specifications.

ANSI C84.1-1995, American National Standard for Electric Power Systems and Equipment—Voltage Ratings (60 Hertz).⁴

ANSI S1.4-1983 (Reaff 1997), American National Standard for Sound Level Meters.

ANSI S1.11-1986 (Reaff 1998), American National Standard for Octave Band and Fractional-Octave-Band Analog and Digital Filters.

²This publication is available from both the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>), and the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

³This document was folded into IEEE Std C57.91-1995, which is available from the IEEE. ANSI C57.92-1981 is available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://www.global.ihs.com/>).

⁴This publication is available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

IEEE Std 4-1995, IEEE Standard Techniques for High Voltage Testing.⁵

IEEE Std 100-1996, The IEEE Standard Dictionary of Electrical and Electronics Terms, Sixth Edition.

IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.23-1992 (Reaff 1999), IEEE Standard for Transformers—Underground-Type, Self-Cooled, Single-Phase Distribution Transformers With Separable, Insulated, High-Voltage Connectors; High-Voltage (24 940 GrdY/14 400 V and Below) and Low-Voltage (240/120 V, 167 kVA and Smaller).

IEEE Std C57.12.26-1992, IEEE Standard for Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers for Use With Separable Insulated High-Voltage Connectors (34 500 Grd Y/19 920 V and Below; 2500 kVA and Smaller).

IEEE Std C57.12.80-1978 (Reaff 1992), IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.19.00-1991 (Reaff 1997), IEEE Standard General Requirements and Test Procedures for Outdoor Power Apparatus Bushings.

IEEE Std C57.19.01-1991 (Reaff 1997), IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.

IEEE Std C57.98-1993 (Reaff 1999), IEEE Guide for Transformer Impulse Tests.

IEEE Std C57.106-1991 (Reaff 1998), IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

IEEE Std C57.113-1991, IEEE Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.

3. Definitions

Standard transformer terminology available in IEEE Std C57.12.80-1978 shall apply. Other electrical terms are defined in IEEE Std 100-1996, The IEEE Standard Dictionary of Electrical and Electronics Terms, Sixth Edition. Terms unique to this document are defined below.

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

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

3.3 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.

⁵IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

3.4 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.

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

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

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

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

$$L_p = 20 \times \log_{10} \left(\frac{p}{p_o} \right)$$

3.9 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 of 10^{-12} W (w_o), or

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

3.10 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.

3.11 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 C57.12.80-1978.

4.2 Test requirements

A general summary of test requirements is included in Table 17 of IEEE Std C57.12.00-1993, and indicates by size which tests are normally considered routine, design, or other.

4.3 Test sequence

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

NOTE—To minimize potential damage to the transformer during testing, the resistance, polarity, phase relation, ratio, no-load loss and excitation current, impedance, and load loss tests (and temperature-rise tests, when applicable) should precede dielectric tests. Using this sequence, the beginning tests involve voltages and currents, which are usually reduced as compared to rated values, thus tending to minimize damaging 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^2R component of conductor losses
- b) Calculation of winding temperatures at the end of a temperature test
- c) 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 through 5.1.3 shall be observed.

5.1.1 General

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

5.1.2 Transformer windings immersed in insulating liquid

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

- a) The windings have been under insulating liquid with no excitation and with no current in the windings from 3 h to 8 h (depending upon the size of the transformer) 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 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 resistance at desired temperature T_s ,
- R_m is measured resistance,
- T_s is desired reference temperature ($^{\circ}\text{C}$),
- T_m is the temperature at which resistance was measured ($^{\circ}\text{C}$),
- T_k is 234.5°C (copper) or 225°C (aluminum).

NOTE—The value of T_k may be as high as 230°C for alloyed aluminum.

5.3 Resistance measurement methods

5.3.1 Bridge method

Bridge methods or high-accuracy digital instrumentation is generally preferred because of its accuracy and convenience, since it may be employed for the measurement of resistances up to $10\,000\,\Omega$. It should be used in cases where the rated current of the transformer winding to be measured is less than 1 A.

NOTE—For resistance values of $1\,\Omega$ or more, a Wheatstone Bridge (or equivalent) is commonly used; for values less than $1\,\Omega$, a Kelvin Bridge (or equivalent) is commonly used. Some modern resistance bridges have capability in both ranges.

5.3.2 Voltmeter-ammeter method

The voltmeter-ammeter method is sometimes more convenient than the bridge method. It should be employed only if the rated current of the transformer winding is 1 A or more. Digital voltmeters and digital ammeters of appropriate accuracy are commonly used 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 of Figure 1. The required resistance is calculated from the readings in accordance with Ohm's Law. A battery or filtered rectifier will generally be found to be more satisfactory as a dc source than will a commutating machine. The latter may cause the voltmeter pointer to vibrate because of voltage ripple.

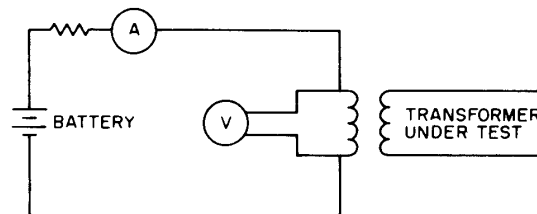


Figure 1—Connections for voltmeter-ammeter method of resistance measurement

- b) To minimize errors of observation,
 - 1) The measuring instruments shall have ranges that will give reasonably large deflection.
 - 2) The polarity of the core magnetization shall be kept constant during all resistance readings.

NOTE—A reversal in magnetization of the core can change the time constant and result in erroneous readings.

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

To protect the voltmeter from injury by off-scale deflections, the voltmeter should be disconnected from the circuit before switching the current on or off. To protect test personnel from inductive kick, the current should be switched off by a suitably insulated switch.

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

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

When measuring the cold resistance, preparatory to making a heat run, 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.

In general, the winding will exhibit a long dc time constant. To reduce the time required for the current to reach its steady-state value, a noninductive external resistor should be added in series with the dc source. The resistance should be large compared to the inductance of the winding. It will 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 operating all other transformer windings open-circuited during these tests.

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

The current used shall not exceed 15% 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.

When the current is too low to be read on a deflecting ammeter, a shunt and digital millivoltmeter or potentiometer shall be used.

6. Polarity and phase-relation tests

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

6.1 Subtractive and additive polarity

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

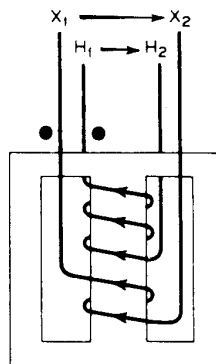


Figure 2—Windings: subtractive polarity

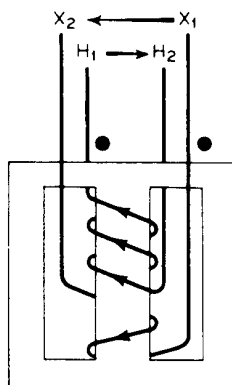


Figure 3—Windings: additive polarity

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

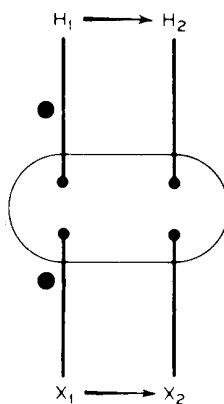


Figure 4—Leads and polarity marks: subtractive polarity

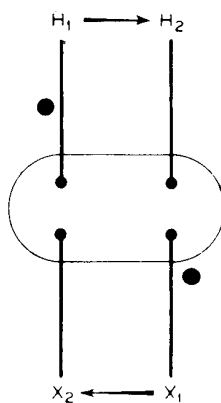


Figure 5—Leads and polarity marks: additive polarity

6.2 Polarity tests: single-phase transformers

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

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

6.2.1 Polarity by inductive kick

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

- a) With direct current passing through the high-voltage winding, connect a high-voltage direct-current voltmeter across the high-voltage winding terminals to obtain a small deflection of the pointer.
- b) Transfer the two voltmeter leads directly across the transformer to the adjacent low-voltage leads, respectively.

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

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

6.2.2 Polarity by alternating-voltage test

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

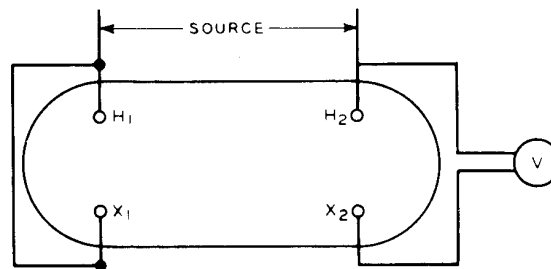


Figure 6—Polarity by alternating-voltage test

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

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

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

6.2.3 Polarity by comparison

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

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

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

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

6.2.4 Polarity by ratio bridge

The ratio bridge described in Clause 7 can also be used to test polarity.

6.3 Polarity and phase-relation tests: polyphase transformers

6.3.1 Polarity of polyphase transformers

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

6.3.2 Phase-relation tests

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

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

- Connect the H_1 and X_1 leads together to excite the unit at a suitably 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 also indicated.

6.3.2.2 Zigzag windings

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

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

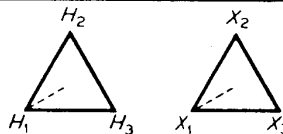
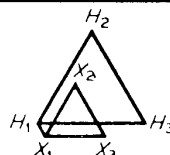
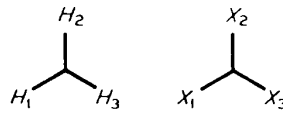
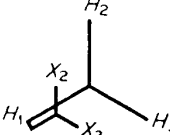
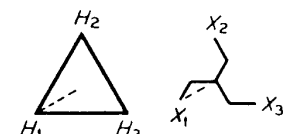
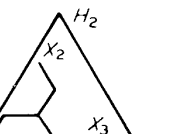
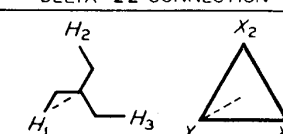
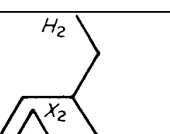
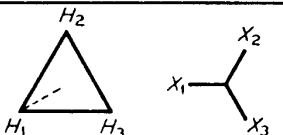
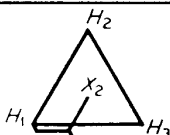
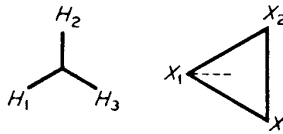
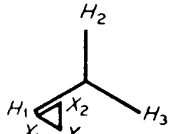
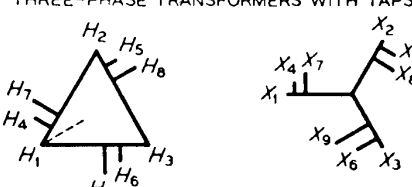
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA-DELTA CONNECTION		CONNECT H_1 TO X_1 MEASURE $H_2-X_2, H_3-X_2,$ $H_1-H_2, H_2-X_3, H_3-X_3$ VOLTAGE RELATIONS (1) $H_2-X_3 = H_3-X_2$ (2) $H_2-X_2 < H_1-H_2$ (3) $H_2-X_2 < H_2-X_3$ (4)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

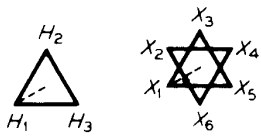
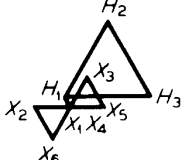
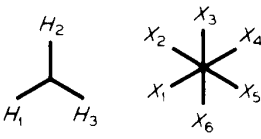
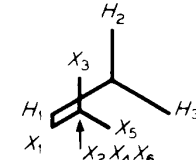
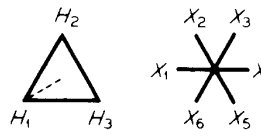
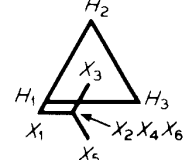
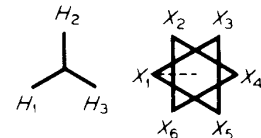
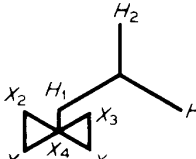
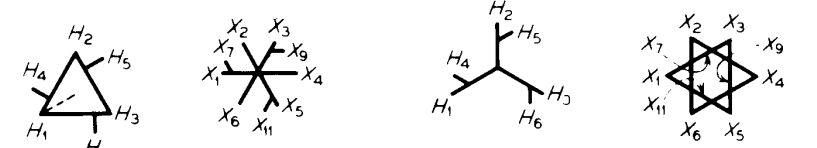
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA-DOUBLE DELTA		CONNECT H_1 TO X_1 TO X_4 MEASURE $H_2-X_3, H_1-H_2, H_2-X_5, H_2-X_6,$ $H_3-X_2, H_2-X_2, H_3-X_3$ VOLTAGE RELATIONS (1) $H_2-X_5 = H_3-X_3$ (4) $H_2-X_6 = H_3-X_2$ (2) $H_2-X_3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

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

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.

6.3.2.3 Six-phase windings

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

6.3.2.4 Test of phase relation with ratio bridge

The ratio bridge described in Clause 7 can also be used to test phase relationships.

6.3.3 Phase-sequence test

The phase-sequence indicator may incorporate either a three-phase induction motor or a split-phase circuit.

It should be connected first to the higher voltage leads, the transformer excited three-phase at a low voltage suitable for the indicator, and the direction of rotation or the indication of the instrument noted.

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

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

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

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

6.3.3.1 Limitation of the phase-sequence test

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

6.3.3.2 Test of phase sequence with ratio bridge

The ratio bridge described in Clause 7 can also be used to test phase sequence.

7. Ratio tests

7.1 General

The turn 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 turn 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 turn ratio shall be determined for all taps and for the full winding.

7.1.2 Voltage and frequency

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

7.1.3 Three-phase transformers

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

7.1.4 Three-phase transformers with inaccessible neutrals

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

7.2 Tolerances for ratio

See Clause 9 of IEEE Std C57.12.00-1993.

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 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 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%. 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 connected in parallel but with a voltmeter or detector in the connection between two terminals of similar polarity (see Figure 9). This method is more accurate than the following alternative method because the voltmeter or detector indicates the difference in voltage.

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 repeated. The averages of the results are the correct voltages.

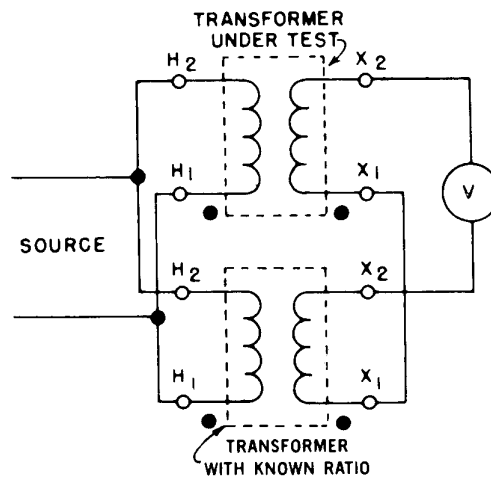
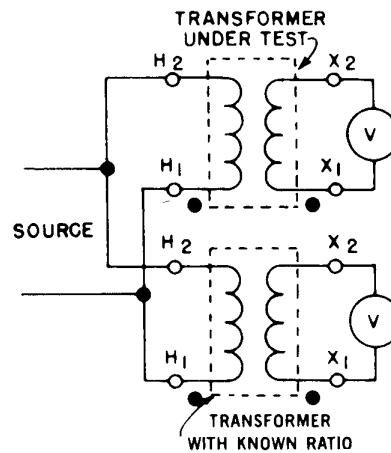


Figure 9—Voltmeter arranged to read the difference between the two secondary voltages



NOTE—Readings are repeated after interchanging voltmeters.

Figure 10—Voltmeters arranged to read the two secondary voltages

7.3.3 Ratio bridge

A bridge using the basic circuit of Figure 11 may be used to measure ratio.

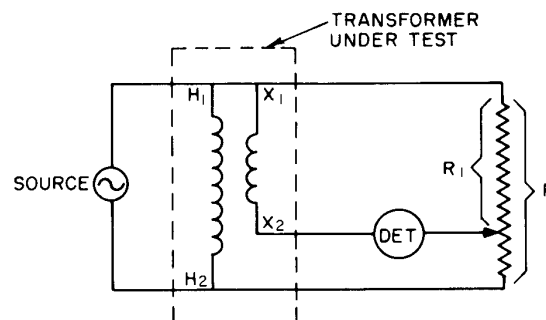


Figure 11—Basic circuit of ratio bridge

When detector DET is in balance, the transformer ratio is equal to R/R_1 .

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

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

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

8. No-load losses and excitation current

8.1 General

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

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

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

In addition, several other factors affect the no-load losses and 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; 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 no-load losses to a sine-wave basis, using Equation (2) in accordance with 8.3.

8.2.1 Connection diagrams

Tests for the no-load loss determination of a single-phase transformer are carried out using the schemes depicted in Figure 12 and Figure 13. Figure 12 shows the necessary equipment and connections when instrument transformers are not required. When instrument transformers are required, which is the general case, the equipment and connections shown in Figure 13 apply. If necessary, correction for losses in connected measurement instruments may be made by disconnecting the transformer under test and noting the

wattmeter reading at the specified test circuit voltage. These losses represent the losses of the connected instruments (and voltage transformer, if used). They may be subtracted from the earlier wattmeter reading to obtain the no-load loss of the transformer under test.

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

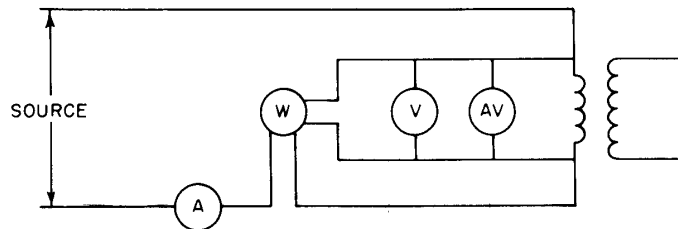


Figure 12—Connections for no-load loss test of a single-phase transformer without instrument transformers

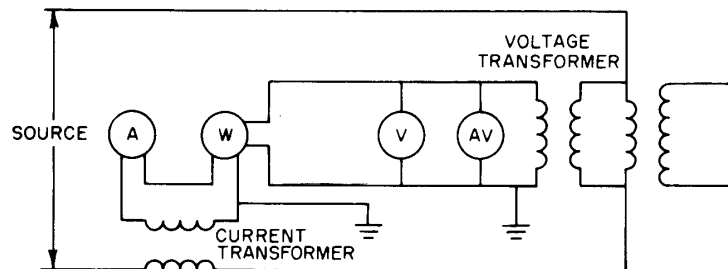


Figure 13—Connections for no-load loss test of a single-phase transformer with instrument transformers

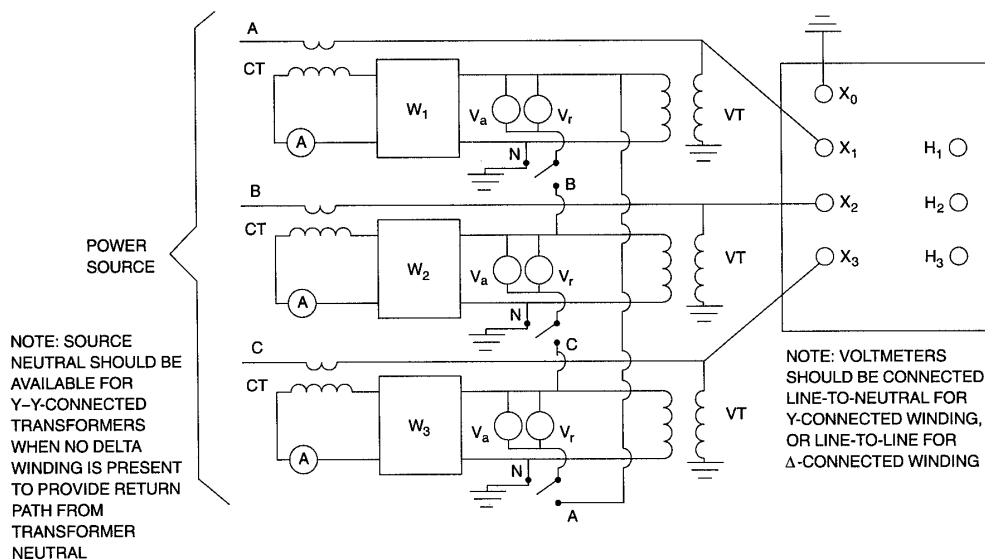


Figure 14—Three-phase transformer connections for no-load loss and excitation current tests using three-wattmeter method

8.2.2 Voltmeter connections

When correcting to a sine-wave basis using the average-voltage voltmeter method, attention shall be paid to the voltmeter connections because the line-to-line voltage waveform may differ from line-to-neutral voltage waveform. Therefore, depending 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.

8.2.3 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. 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 upon 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.

For the determination of the 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 by means of Equation (2):

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

where

- T_m is the average oil temperature at the time of test ($^{\circ}\text{C}$),
- $P_c(T_m)$ 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 is $\left(\frac{E_r}{E_a}\right)^2$,
- 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 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 C57.12.00-1993.

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 also 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 need be made, so long as the following conditions are met:

- a) The average oil temperature is within $\pm 10^\circ\text{C}$ of the reference temperature T_r .
- b) The difference between the top and bottom oil 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 ($^\circ\text{C}$),

K_T is an empirically derived per-unit change in no-load loss per $^\circ\text{C}$.

If the actual value of K_T is not available, a value of 0.000 65 per unit change per $^\circ\text{C}$ 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 shall be tested outside 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 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 kVA rating, the lowest kVA 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