

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

Sponsor

Transformers Committee
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IEEE Power Engineering Society

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IEEE-SA Standards Board

Abstract: Methods for performing tests specified in IEEE Std C57.12.01-1998 and other referenced standards applicable to dry-type distribution and power transformers are described. This standard is intended for use as a basis for performance, safety, and the proper testing of dry-type distribution and power transformers. This standard applies to all dry-type transformers except instrument transformers, step-voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, and mine transformers.

Keywords: dry-type transformer, power transformer

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Introduction

(This introduction is not a part of IEEE Std C57.12.91-2001, IEEE Standard Test Code for Dry-Type Distribution and Power Transformers.)

This revision of IEEE Std C57.12.91-1995 changes Clause 9 only to include the associated leads or bus bar during the measurement of load loss and the measurement of impedance voltage.

The working group, as promised after publication of the 1995 revision, reviewed Subclause 10.8 on insulation power-factor tests. It is the consensus of the working group that the clause should not be changed from the 1979 revision.

Hottest-spot temperature rise is a performance parameter to be met by the manufacturer to conform to IEEE Std C57.12.01-1998. It is not economically practical to measure hottest-spot temperature rise on the primary and secondary windings of all dry-type transformers. Conformance to average temperature rise limits in IEEE Std C57.12.01-1998 does not automatically assure that hottest-spot temperature rise limits are met, due to the wide range of sizes of transformers covered by IEEE Std C57.12.01-1998. A reduction of average winding temperature rise below the limits may be required to meet hottest-spot temperature rise limits. Since the publication of IEEE Std C57.12.91-1995, IEEE Std C57.134-2000, IEEE Guide for Determination of Hottest Spot Temperature in Dry Type Transformers has been developed. This guide describes methodologies for determining the steady state winding hottest spot temperature in dry-type distribution and power transformers.

This standard 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 the producer, provided such changes do not violate existing laws, and are considered technically adequate for the function intended.

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

1. Scope

This standard describes methods for performing tests specified in IEEE Std C57.12.01-1998¹ and other referenced standards applicable to dry-type distribution and power transformers. It is intended for use as a basis for performance, safety, and the proper testing of dry-type distribution and power transformers.

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

1.1 Purpose

The purpose of this standard is to provide test procedure information. Transformer requirements and specific test criteria are not a part of this standard but are contained in appropriate standards such as IEEE Std C57.12.01-1998 or in user specifications.

1.2 Word usage

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

NOTE—The introduction of this standard describes the circumstances in which the standard may be used on a mandatory basis.

2. References

Various standards and guides are listed below. References are identified throughout this standard by designation number and year.

When the standards referenced in this standard are superseded by a revision, the latest revision shall apply.

¹Information on references can be found in Clause 2.

ANSI C57.12.50-1981 (Reaff 1998), American National Standard Requirements for Ventilated Dry-Type Distribution Transformers 1 to 500 kVA, Single-Phase; and 15 to 500 kVA, Three-Phase with High-Voltage 601 to 34 500 Volts, Low Voltage 120 to 600 Volts.²

ANSI C57.12.51-1981 (Reaff 1998), American National Standard Requirements for Ventilated Dry-Type Power Transformers 501 kVA and Larger, Three-Phase, with High-Voltage 601 to 34 500 Volts, Low-Voltage 208Y/120 to 4160 Volts.

ANSI C57.12.52-1981 (Reaff 1998), American National Standard Requirements for Sealed Dry-Type Power Transformers 501 kVA and Larger, Three-Phase with High-Voltage 601 to 34 500 Volts, Low-Voltage 208Y/120 to 4160 Volts.

ANSI C57.12.55-1987 (Reaff 1998), American National Standard for Dry-Type Transformers Used in Unit Installations, Including Unit Substations—Conformance Standard.

ANSI C57.12.57-1987, American National Standard Requirements for Ventilated Dry-Type Network Transformers 2500 kVA and Below, Three-Phase, High-Voltage 34 500 Volts and Below, Low-Voltage 216Y/125 and 480Y/277 Volts.

ANSI S1.4-1983, American National Standard Specification for Sound Level Meters.

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

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.³

IEEE Std 99-1980 (Reaff 2000), IEEE Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials.

IEEE Std C57.12.01-1998, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those with Solid Cast and/or Resin-Encapsulated Windings.

IEEE Std C57.12.56-1986 (Reaff 1998), IEEE Standard Test Procedure for Thermal Evaluation of Insulation Systems for Ventilated Dry-Type Power and Distribution Transformers.

IEEE Std C57.12.58-1991 (Reaff 1996), IEEE Guide for Conducting a Transient Voltage Analysis of a Dry-Type Transformer Coil.

IEEE Std C57.12.59-1989, IEEE Guide for Dry-Type Transformer Through-Fault Current Duration.⁴

IEEE Std C57.12.60-1998, IEEE Guide for Test Procedures for Thermal Evaluation of Insulation Systems for Solid-Cast and Resin-Encapsulated Power and Distribution Transformers.

IEEE Std C57.12.70-2001, IEEE Standard Terminal Markings and Connections for Distribution and Power Transformers.

²ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

³IEEE 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/>).

⁴IEEE Std C57.12.59-1989 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

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

IEEE Std C57.96-1999, IEEE Guide for Loading Dry-Type Distribution and Power Transformers.

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

IEEE Std C57.124-1991, IEEE Recommended Practice for the Detection of Partial Discharge and the Measurement of Apparent Charge in Dry-Type Transformers.

IEEE Std C57.134-2000, IEEE Guide for Determination of Hottest Spot Temperature in Dry Type Transformers.

3. Definitions

Standard transformer terminology available in IEEE Std C57.12.80-1978 shall apply. Other electrical terms are defined in *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

4. General

4.1 Test definitions

Various types of tests such as *routine*, *design*, *other*, and *conformance* are defined in IEEE Std C57.12.80-1978.

4.2 Test requirements

A general summary of test requirements is included in Table 15 of IEEE Std C57.12.01-1998, which indicates by size (500 kVA and smaller, or 501 kVA and larger) which tests are normally considered *routine*, *design*, or *other*.

4.3 Test sequence

See 10.1.5.4 for sequence of dielectric tests when lightning impulse tests are specified.

NOTE—If it is desired 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. When this sequence is used, the beginning tests involve voltages and currents that are usually reduced 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 satisfactory alternatives.

5. Resistance measurements

5.1 General

Resistance measurements are of fundamental importance for the calculation of the I^2R component of conductor losses, for the calculation of winding temperatures at the end of a temperature rise test, and as a base for assessing possible damage in the field.

Cold-resistance measurements shall be taken on all phases of each primary and secondary winding 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. When transferring leads from one winding to another, the same relative polarity should be maintained with regard to the measuring leads and the transformer terminals.

The induction time for the measuring current to become stable should be noted during the cold-resistance measurements in order to ensure that sufficient time elapses for the induction effect to disappear before hot resistance readings are taken during the temperature rise tests. 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.

5.2 Determination of cold temperature

The cold temperature of the winding shall be determined as accurately as possible when measuring the cold resistance. The following precautions shall be observed. 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 tank and cover (see 11.8.6 and Figure 30).

It should not be assumed that the windings are at the same temperature as the surrounding air. To 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) Tank 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 24–72 h, depending on its size.

5.3 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 the following formula:

$$R_s = R_m[(T_s + T_k)/(T_m + T_k)] \quad (1)$$

where

- R_s is resistance at desired temperature, T_s ,
- R_m is measured resistance,
- T_s is desired reference temperature,
- T_k is 234.5 for copper, 225 for aluminum,
- T_m is the temperature at which resistance was measured.

NOTE—The value of T_k may be as high as 240 °C for alloyed aluminum.

5.4 Resistance measurement methods

5.4.1 Bridge method

Bridge methods (or high-accuracy digital instrumentation) are generally preferred because of their accuracy and convenience since they may be employed for the measurement of resistances up to 10 000 Ω. They 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 Ω or more, a Wheatstone bridge (or equivalent) is commonly used; for values less than 1 Ω, a Kelvin bridge (or equivalent) is commonly used. Some modern resistance bridges have capability in both ranges.

5.4.2 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.

5.4.2.1 The measuring circuit

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.

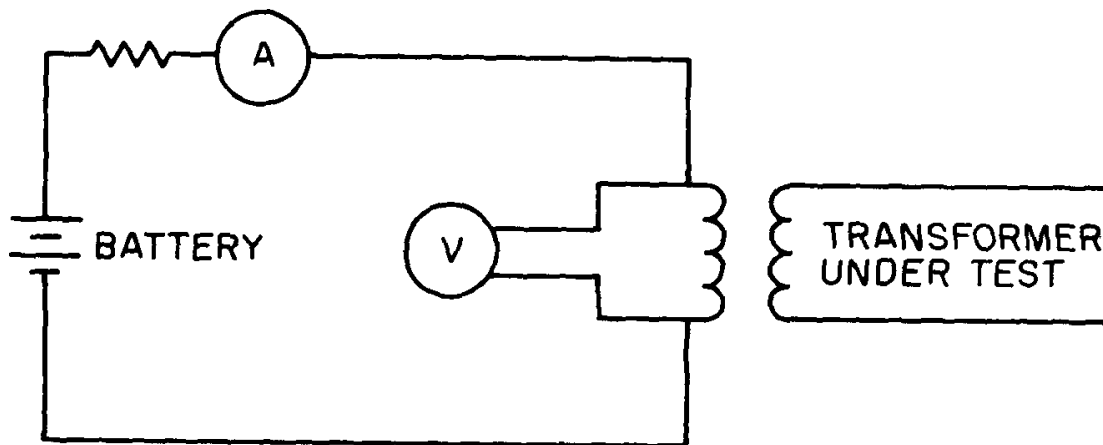


Figure 1—Connections for the voltmeter-ammeter method of resistance measurement

5.4.2.2 Minimizing errors

In order to minimize errors of observation, the following shall be implemented:

- a) The range of analog measuring instruments shall be such as to give a reasonably large deflection.
- b) 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.

5.4.2.3 Independent voltmeter and current leads

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 the current is switched 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.

5.4.2.4 The effect of winding dc time constant

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

When measuring the cold-resistance preparatory to making a heat run, the time required for the readings to become constant should be noted. The period thereby determined should be allowed to elapse before taking the first reading 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 the tests.

5.4.2.5 Maximum dc current in measuring circuit

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's resistance 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 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.

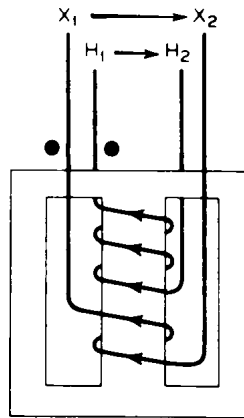


Figure 2—Windings: subtractive polarity

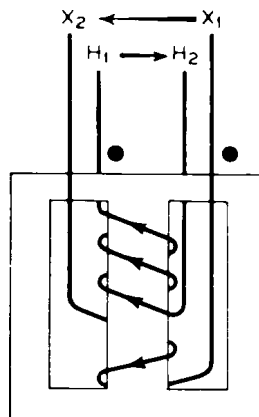


Figure 3—Windings: additive polarity

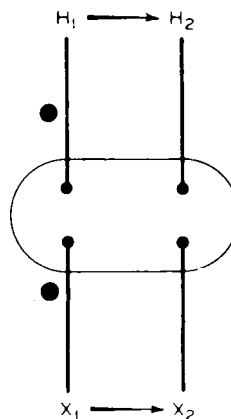


Figure 4—Leads and polarity marks: subtractive polarity

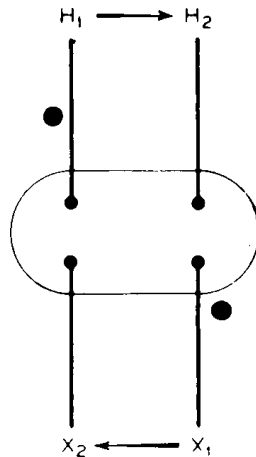


Figure 5—Leads and polarity marks: additive polarity

6.2 Polarity tests—single-phase transformers

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

6.2.1 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 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 so as to get a small deflection of the pointer.
- b) Transfer the two voltmeter leads directly across the transformer to the adjacent low-voltage leads, respectively.
- c) Break dc excitation, thereby inducing a voltage in the low-voltage winding (inductive kick) that will cause 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.

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

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. (In Figure 6, this will be X_1 .)

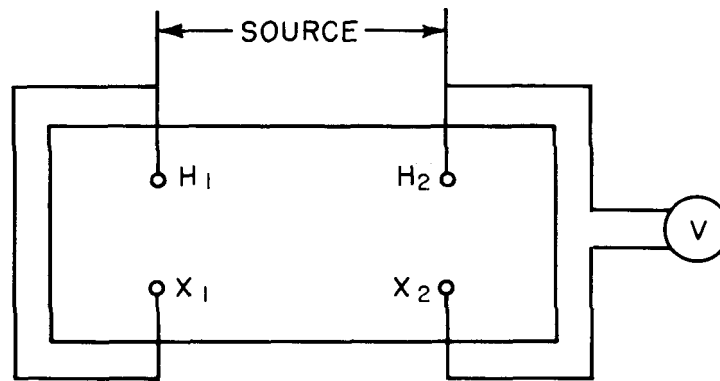


Figure 6—Polarity by alternative-voltage test

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.

6.2.3 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):

- Connect the high-voltage windings of both transformers in parallel by connecting similarly marked leads together.
- Also connect the low-voltage leads, X_2 , of both transformers together, leaving the X_1 leads free.
- 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

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 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.

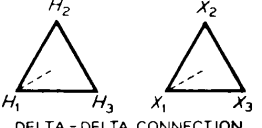
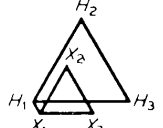
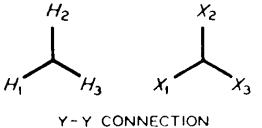
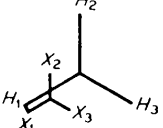
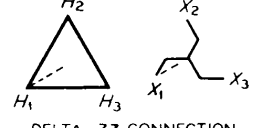
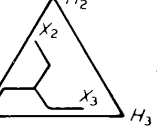
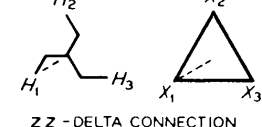
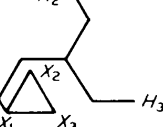
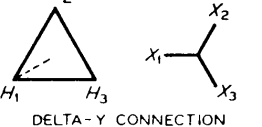
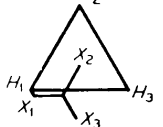
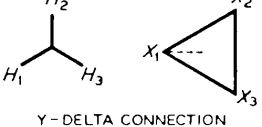
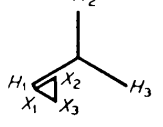
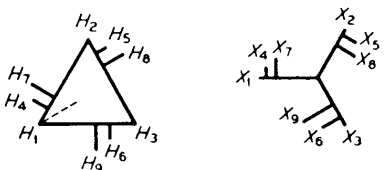
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA-DELTA CONNECTION		CONNECT H_1 TO X_1 MEASURE $H_2-X_2, H_3-X_2,$ $H_1-H_2, H_2-X_3, H_3-X_3$
	 Y-Y CONNECTION		VOLTAGE RELATIONS (1) $H_2-X_3 = H_3-X_2$ (2) $H_2-X_2 < H_1-H_2$ (3) $H_2-X_2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

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

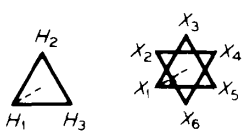
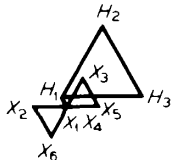
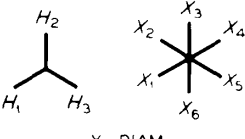
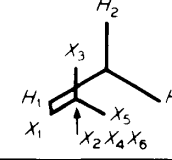
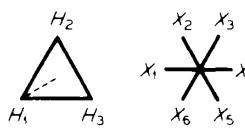
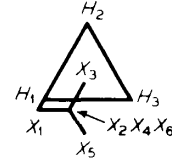
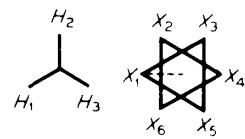
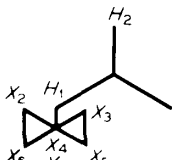
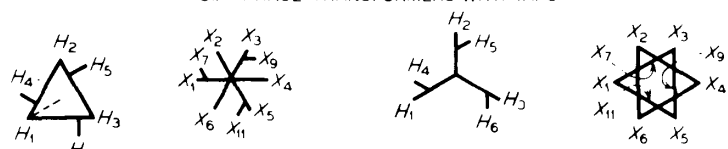
	ANGULAR DISPLACEMENT	DIAGRAM FOR CHECK MEASUREMENT	CHECK MEASUREMENTS
GROUP 1 ANGULAR DISPLACEMENT 0 DEGREES	 DELTA-DOUBLE DELTA		CONNECT H_1 TO X_1 TO X_4 MEASURE $H_2-X_3, H_1-H_2, H_2-X_5, H_2-X_6,$ $H_3-X_2, H_2-X_2, H_3-X_3$ VOLTAGE RELATIONS (1) $H_2-X_5 = H_3-X_3$ (4) $H_2-X_6 = H_3-X_2$ (2) $H_2-X_3 < H_1-H_2$ (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 diagrams for six-phase transformer connections

6.3.2.2 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. For the purpose of designation in Figure 7, zigzag windings are arbitrarily defined as windings whose line-end section is rotated 60 degrees 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 or wye for the test for phasor diagram.

6.3.2.4 Phase relation with ratio bridge

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

6.3.3 Phase-sequence test

The following method does not disclose the angular displacement of the transformer. 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 should be excited three-phase at a low voltage suitable for the indicator, and the direction of rotation of the 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, have to be connected temporarily in delta or wye for this test also. 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.

6.3.3.1 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 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.

7.1.1 Transformers with taps

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

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

7.1.2 Voltage and frequency requirements

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 preferably be used, although when convenient, three-phase power may be used.

7.1.4 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 will then result 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 to each other and of proper value (1.73 times the diametric voltages if connected in wye), the ratio is correct.

7.1.5 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

See Clause 9 of IEEE Std C57.12.01-1998.

7.3 Ratio test methods

7.3.1 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 will 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% 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 7.3.2.

7.3.2 Comparison method

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

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

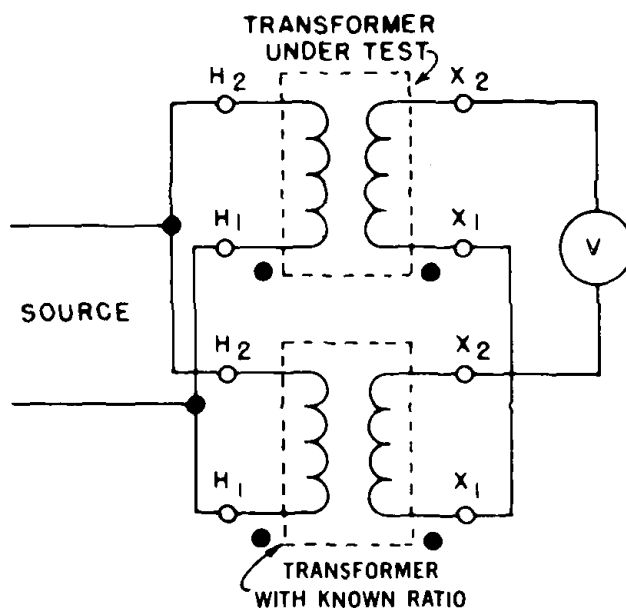


Figure 9—Voltmeter arranged to read the difference between the two secondary voltages

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.

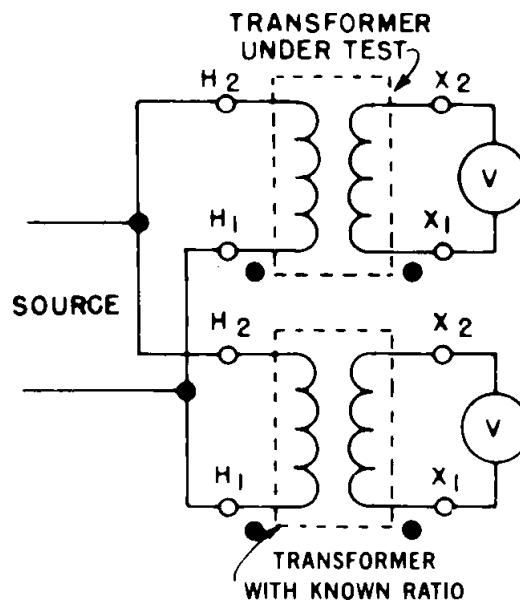


Figure 10—Voltmeters arranged to read the two secondary voltages

7.3.3 Ratio bridge

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

NOTES:

- 1—Measurement of the ratio using circuits of this type has also (in the past) been described as *ratio by resistance potentiometer*.
- 2—More accurate results can be obtained using a ratio bridge that provides phase-angle correction.
- 3—The ratio bridge can also be used to test polarity, phase relation, and phase sequence.

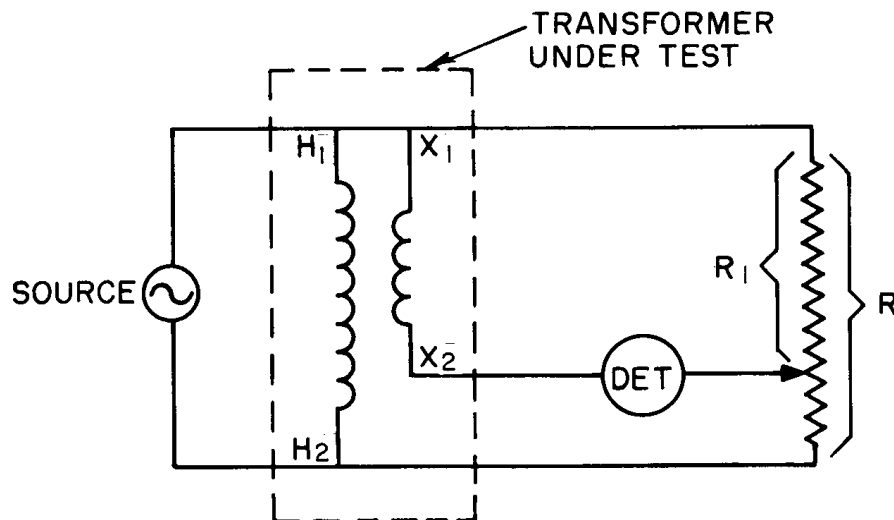


Figure 11—Basic circuit of ratio bridge

8. No-load losses and excitation current

8.1 General

No-load (excitation) losses are those losses that are incident to the excitation of the transformer. No-load (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 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, core joints, etc.

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 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 for the case where 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.

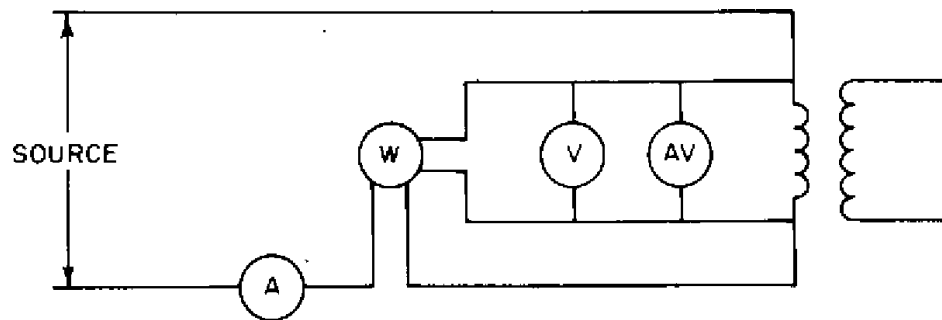


Figure 12—Connections for no-load loss test of a single-phase transformer without instrument transformers

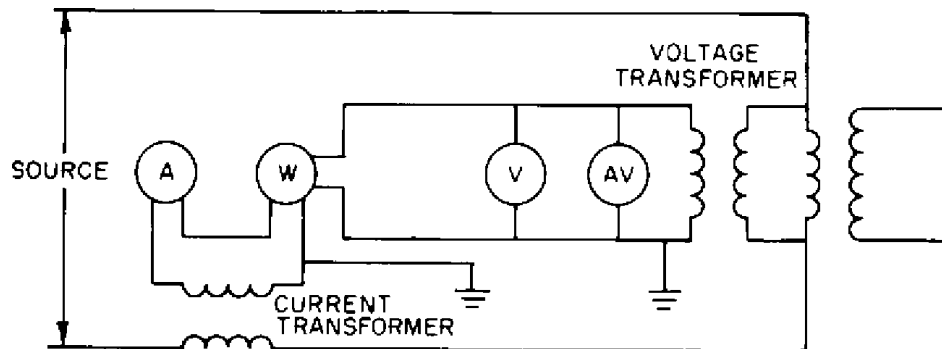


Figure 13—Connections for no-load loss test of a single-phase transformer with instrument transformers

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.