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NEMA STANDARDS PUBLICATION

NEMA TP 2

STANDARD TEST METHOD FOR MEASURING THE ENERGY CONSUMPTION OF DISTRIBUTION TRANSFORMERS

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NEMA Standards Publication No. TP 2-1998

Standard Test Method for Measuring the Energy Consumption of Distribution Transformers

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Foreword

This foreword is for information only and is not part of the standard. The purpose of this document is to provide a standardized means for losses measurement of distribution transformers to achieve energy efficiency levels as outlined in NEMA publication TP 1, *Guide for Determining Energy Efficiency for Distribution Transformers.*

The test accuracies, test methods, and test sets are referenced from existing industry standards. This document compiles the data obtained from the referenced standards into a single source. In some instances, this standard amplifies existing information or provides additional information pertaining to those references.

The referenced standards include the standards in Section 1, Referenced Standards.

Some changes were made in the test set wiring diagrams so as to conform to the recommendations of NIST 1204. A ground was added to the test sets so as to establish a firm ground for potential measurements and for safety reasons.

Transformer testing using statistical samples was added in Section 8.3. The concept was taken from NIST Technical Note 1422 and modified for transformers. A tolerance of 6 percent was used instead of 20 percent for motors.

This Standards Publication was developed by the Transformer Products Section. Section approval of the standard does not necessarily imply that all section members voted for its approval or participated in its development. At the time it was approved, the Section was composed of the following members:

ABB Power T & D Company—Jefferson City, MO

Acme Electric Corporation—Lumberton, NC

Cooper Power Systems—Waukesha, WI

Eaton Corp., Cutler-Hammer—Pittsburgh, PA

General Electric—Hickory, NC

Hammond Mfg. Co.—Guelph, Ontario

Kentucky Assn. Elec. Cooperatives, Inc.—Louisville, KY

Magnetran Inc.—Voorhees, NJ

Niagara Transformer Corporation—Buffalo, NY

North American Transformer—Milipitas, CA

Olsun Electrics Corporation—Richmond, IL

Pauwels Transformers—Washington, MO

PDI—Sandston, VA

R.E. Uptegraff Mfg. Company—Scottsdale, PA

Siemans Energy & Automation—Jackson, MS

SMIT Transformers, Inc.—Ladson, SC

Southern Transformer Company—East Point, GA

Square D Company—Lexington, KY

Vantran Electric Corporation—Waco, TX

Virginia Transformer Corporation—Roanoke, VA

Waukesha Electric Company—Goldsboro, NC

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Section 1
GENERAL

1.1 SCOPE

This standard is intended for use as a basis for determining the energy efficiency performance of the equipment covered and to assist in the proper selection of such equipment.

This standard covers single-phase and three-phase dry-type and liquid-immersed distribution transformers (transformers for transferring electrical energy from a primary distribution circuit to a secondary distribution circuit or within a secondary distribution circuit) as defined in the following table:

Table 1

Transformer Type	No. Phases	Rating Range
Liquid-immersed	Single phase	10 - 833 kVA
	Three Phase	15 - 2500 kVA
Dry-type	Single Phase	15 - 833 kVA
	Three Phase	15 - 2500 kVA

This standard addresses the test procedures for determining the efficiency performance of the transformers covered in NEMA Publication TP 1.

NOTE—Includes all products at 1.2kV and below.

Products excepted from this standard include:

a. Liquid-filled transformers below 10 kVA
b. Dry-type transformers below 15 kVA
c. Transformers connected to converter circuits
d. All rectifier transformers and transformers designed for high harmonics
e. Autotransformers
f. Non-distribution transformers, such as UPS transformers
g. Special impedance and harmonic transformers
h. Regulating transformers
i. Sealed and non-ventilated transformers
j. Retrofit transformers
k. Machine tool transformers
l. Welding transformers
m. Transformers with tap ranges greater than 15 percent
n. Transformers with frequency other than 60 Hz
o. Grounding transformers
p. Testing transformers

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1.2 REFERENCED STANDARDS

Transformers shall meet the requirements for fluid-filled and dry-type transformers as contained in the latest revision of the following standards:

American National Standards Institute, Inc
11 West 42nd Street
New York, NY 10036

ANSI/IEEE C57.12.00-1993	*IEEE Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers*
C57.12.01-1989	*IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers including those with Solid Cast and/or Resin-Encapsulated Windings*
C57.12.90-1993	*IEEE Standard Test Code for Liquid-Immersed Distribution, Power and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers*
C57.12.91-1979	*IEEE Standard for Test Code for Dry-Type Distribution and Power Transformers*

Institute of Electrical and Electronic Engineers
445 Hoes Hane
Piscataway, New Jersey 08855

PC57.12.33	*IEEE Guide for Evaluation of Losses in Distribution Transformers*

National Electrical Manufacturers Association
1300 North 17th Street
Arlington, VA 22209

TP 1	*Guide for Determining Energy Efficiency for Distribution Transformers*
TR 1-1993	*Transformers, Regulators and Reactors*
ST 20-1992	*Dry-Type Transformers for General Applications*

International Standards Organization
1, rue de Verambe
CH-1211 Geneva 20
Switzerland

ISO 9002:1994(e) Section 4.11.1	*Quality Systems-Model for Quality Assurance in Production, Installation and Servicing*

National Institute of Standards and Technology
Gaithersburg MD 20899-0001

NIST Technical Note 1204	*Calibration of Test Systems for Measuring Power Losses of Transformers*

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NIST
Technical Note 1422 *Electric Motor Efficiency Testing Under the New Part 431 of Chapter II of Title 10, Code of Federal Regulations: Enforcement Testing*

1.3 DEFINITIONS

no-load loss: 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 current in parallel windings. These losses change with the excitation voltage.

excitation current (no-load current): 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.

load loss: The load losses of a transformer are those losses incident to a specified load carried by the transformer. Load losses include I^2R loss in the windings due to load current and stray losses due to eddy currents induced by leakage flux in the windings, core clamps, magnetic shields, tank walls, and other conducting parts. Stray losses may also be caused by circulating currents in parallel windings or strands.

total loss: Total losses of a transformer shall be the sum of the no-load losses and the load losses determined for rated voltage, current, and frequency. The load-loss component shall be based on a reference temperature equal to the rated average temperature rise plus 20 degrees C or other specified temperature, such as that specified in NEMA Standard TP 1.

efficiency: The ratio of the useful power output to the total input power.

ambient temperature: Ambient temperature is considered to be at 20 degrees C (±10 degrees) for the purpose of measuring no-load loss (NL).

phase angle: The phase angle is the angle measured between the potential vector and current vector of an alternating current circuit.

phase angle error: The phase angle displacement voltage and current phasors, or both, introduced by the components of the test equipment. Phase angle error, if significant, can introduce errors in measured transformer losses.

phase angle correction: The adjustment (correction) of measurement data to negate the effects of phase angle error.

reference temperature: The temperature, specified in standards, to which the transformer losses shall be corrected and reported.

temperature correction: The adjustment (correction) of measurement data obtained with the transformer under test at a temperature that is different from the reference temperature to values that would have been obtained with the transformer under reference temperature.

test voltage, current, and frequency: The voltage, current, and frequency of the electrical power supplied to the transformer under test.

waveform correction: The adjustment (correction) of measurements data obtained with a test voltage that is non-sinusoidal (distorted) to values that would have been obtained with sinusoidal voltage.

tolerances on measured losses: Measured values of electrical power, voltages, currents, resistances, and temperature are used in the calculations of reported data. To ensure sufficient accuracy in the

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measured and calculated data, the test system accuracy for each measurement shall fall within the limits specified in Table 1.

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Section 2
ACCURACY REQUIREMENTS

Table 2
MEASUREMENT ACCURACY REQUIREMENTS

Quantity Measured	Test System Accuracy
Losses	± 3 percent
Voltage	± 0.5 percent
Current	± 0.5 percent
Resistance	± 0.5 percent
Frequency	± 0.5 percent
Temperature	± 1.0 degree C

NOTE—Equipment and methods for loss measurement shall be of sufficient accuracy that measurement error will be limited to the values shown in Table 2.

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Section 3
RESISTANCE MEASUREMENTS

Resistance measurements are of fundamental importance for the calculation of load losses as shown in 3.3. The I^2R calculation is dependent on the accurate value of the winding resistance.

3.1 DETERMINATION OF COLD TEMPERATURE RESISTANCE

The cold temperature of the winding, Tm, shall be determined. Cold resistance measurements shall not be made on a transformer when it is located in a room in which the temperature is fluctuating rapidly.

3.2 RESISTANCE MEASUREMENT METHODS

Two methods are used to measure resistance: the bridge method and the voltmeter-ammeter method using either indicating instruments or digital instruments. The choice is dependent upon the resistance to be measured test current as shown below and in Sections 3.2.1 and 3.2.2.

Table 3

Test Current	Bridge Resistance	Volt-Ammeter	Resistance Meter
< 10 Ohms	•	*	
10 to 100 Ohms	*	•	*
>100 Ohms	*		*

3.2.1 Bridge Method

Bridge methods (high accuracy digital instrumentation) are generally preferred because of their accuracy and convenience, since they may be employed for the measurement of resistance up to 10,000 Ohms. They should be used in cases where the rated current of the transformer winding to be measured is less than one Ampere or the test current is less than .15 Ampere.

3.2.2 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 windings is 1 Ampere or more or the test current is greater than .15 Ampere. Digital voltmeters and digital ammeters of appropriate accuracy are commonly used in connection with transformer winding resistance measurements.

3.3 RESISTANCE MEASUREMENT

Measurement is made with direct current, and simultaneous readings of current and voltage are taken using the connections in Figure 1. The required resistance is calculated from the readings in accordance with Ohm's law.

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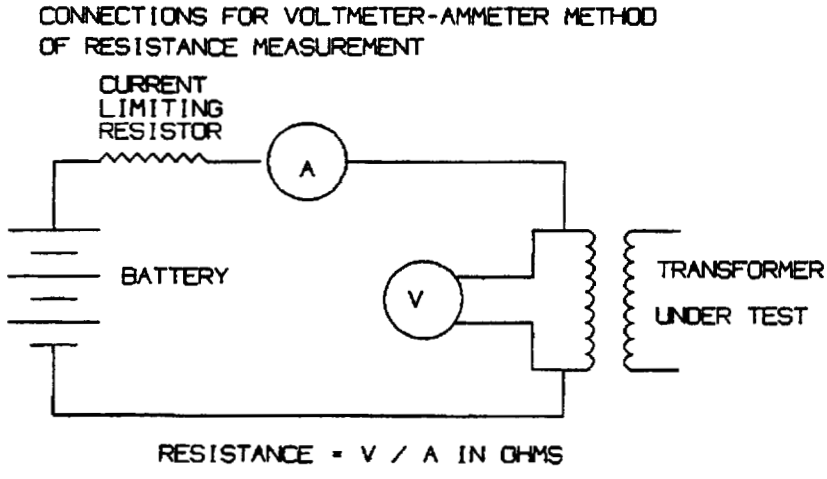


Figure 1

3.4 MEASUREMENT ERROR REDUCTION

a. The measuring instruments shall have such ranges as will give reasonably large indication, preferably larger than the 50 percent scale.

b. The polarity of the core magnetization shall be kept constant during the resistance readings.

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

3.5 RESISTANCE TEST SETUP

The voltmeter shall be independent of the current leads and shall be connected as closely as possible to the winding to be measured. This is to avoid including in the reading the resistance of current carrying leads and their contacts.

To protect the voltmeter from injury by off-scale deflections, the voltmeter should be disconnected from the circuit before the current is switched off. To protect test personnel from "inductive kick," the current should be switched off by a suitable insulated switch.

If the drop of voltage is less than 1 volt, a potentiometer or millivolt meter shall be used.

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3.5.1 Steady State of Current

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

The current used shall not exceed 15 percent 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.

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

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Section 4
LOSS MEASUREMENT

4.1 TEST SETS

The same test set may be used for both the no-load loss and load loss measurements provided the envelope of the test set encompasses the test requirements of both tests. The test set shall be calibrated to National Standards to meet the tolerance requirements in Table 2. In addition, the wattmeter, current measuring system, and potential measuring system must be calibrated separately if the overall test set calibration is outside the tolerance as shown in Table 2 or the individual phase angle error exceeds the values specified in Section 4.1.4

4.1.1 Three Phase Test Set without Instrument Transformers

A three phase test set without instrument transformers is shown in Figure 2.

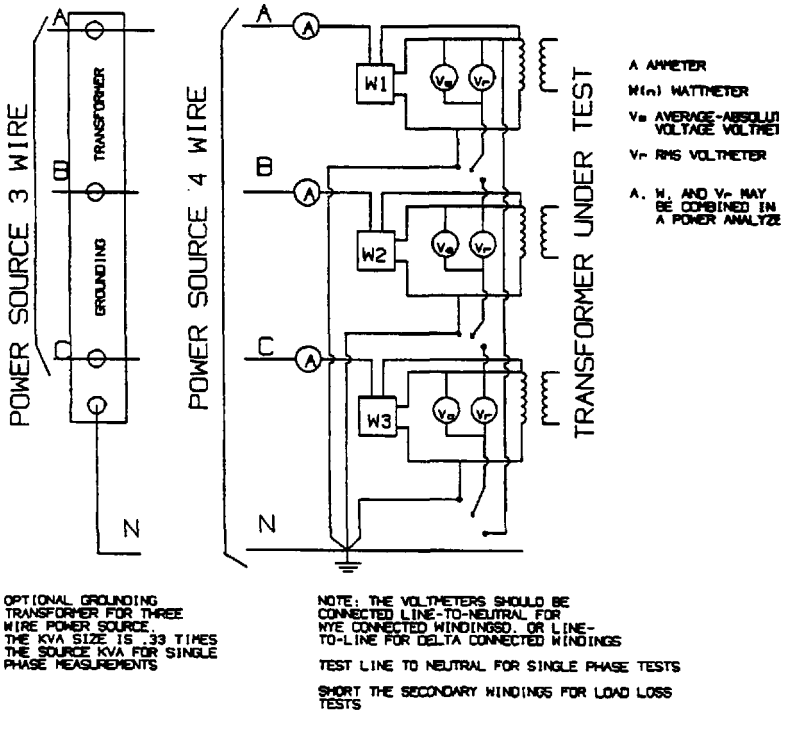


Figure 2
TEST SET CONNECTIONS FOR NO-LOAD LOSS AND A LOAD LOSS TEST WITHOUT INSTRUMENT TRANSFORMERS

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A single phase test may be made using a single phase test set or one phase of a three phase test set if there is a source neutral or a grounding transformer rated 33 percent of the source kVA.

Some power analyzers having voltage, current, and power measurement capabilities and have built in scaling resistors for voltage measurements and current shunts suitable for voltage, current, and power measurements without instrument transformers. A separate average-voltage voltmeter may be used with a power analyzer so that simultaneous average-voltage and rms voltage readings can be made.

4.1.2 Three Phase Test Set with Instrument Transformers

A three phase test set with instrument transformers is shown in Figure 3.

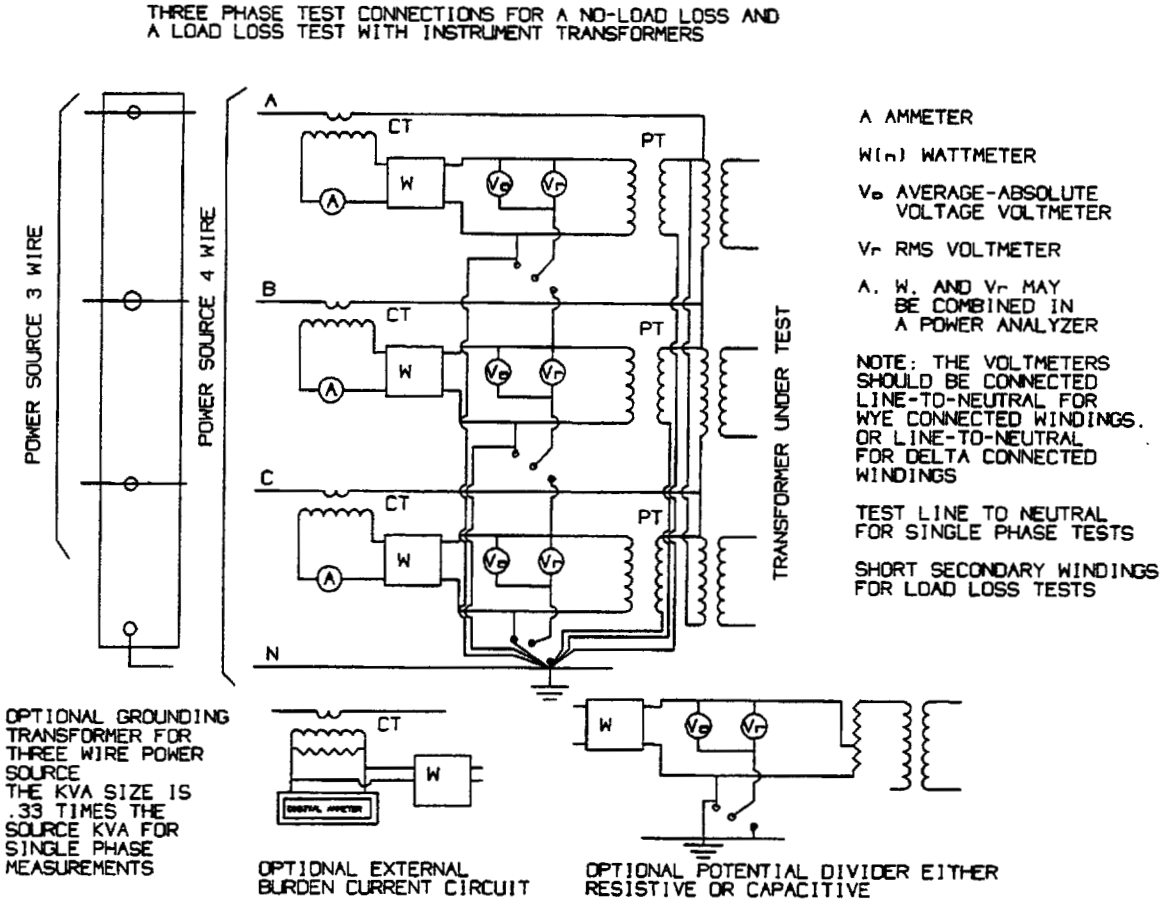


Figure 3

Instrument transformers are required for voltage and current values exceeding the inputs of the test measuring instruments. As indicated in the Figures, the voltmeter or voltage transformer is placed closer to the load and the ammeter and current circuit of wattmeter are placed closer to the power source.

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4.1.3 Test Set Neutrals

A four-wire, three phase test set shall be used in making measurements. A neutral deriving transformer may be used to derive a neutral and ground for those test sets without a source neutral.

4.1.4 Phase Angle Error Correction

The loss measurements for the load loss test must be corrected for phase angle errors of the wattmeter, voltage measuring circuit, and current measuring circuit. Each element of the test set must be calibrated in place to determine the phase angle errors. For instance, the current measuring circuit must be calibrated in place or as connected in the test set (see the test set calibration guide). No correction is necessary if the test set system has been calibrated to meet the tolerance in Section 2.1 of this standard or the total phase angle error is less than the following:

PF = Pm/VA(* 1.732 if three phase) (1)

loss PF >.03 and < .1 and the total phase angle error is less than 220 microradians 1 minute

loss PF >.1 and the total phase angle error is less than 870 microradians 3 minutes.

The corrected loss measurement is:

Pc = Pm - VmAm Cos(Wd - Vd + Cd) (2)

Where:

PF = per unit power factor
V = applied voltage volts
A = current in amperes
Pc = corrected loss measurement
Pm = Loss as measured
Vm = rms voltage of applied voltage
Am = rms current of the test
Wd = wattmeter phase angle error (all phase angle errors in microradians)
Vd = potential circuit phase angle error
Cd = current circuit phase angle error

4.2 NO-LOAD LOSSES

4.2.1 General

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-loads losses also vary with the 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 in manufacturing, variation in gap structure, core joints, etc.

The temperature of the core has a small effect on the no-load loss. No-load loss temperature correction is not necessary if the core temperature or liquid temperature is 20 degrees C ± 10 degrees C.

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4.2.2 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. The average voltmeter method is the most accurate method of 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 readings of both voltmeters are employed to correct the no-load losses to a sine-wave basis, using equation 3 in accordance with 4.2.2.1.

4.2.2.1 Waveform Correction of No-load Losses

The eddy-current loss 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 and the eddy-current loss in the test will be related to the correct eddy-current loss at rated voltage by the equations. The no-load losses of the transformer corrected to the sine-wave basis shall be determined from the measured value by means of the following equation:

$$P=\frac{Pm}{P1+kP2} \qquad (3)$$

Where:

P = excitation loss at voltage Ea, corrected to a sine wave basis
Pm = excitation loss measured in test
P1 = per unit hysteresis loss, referred to Pm
P2 = per unit eddy loss, referred to Pm
$k=(Er/Ea)^2$
Er = test voltage measured by rms voltmeter
Ea = test voltage measured by average-voltage voltmeter

The actual per-unit values of hystersis and eddy-current losses should be used, if available.

NOTE—If actual values are not available, it is suggested that these two loss components be assumed equal in value, assigning each a value of .5 per unit.

For three-phase transformers, the three wattmeter method shall be used, Figures 2 or 3. Each potential circuit is connected from one line to the three phase neutral except for wye connected windings as noted in 4.2.2.2.

The total no-load loss is P1 + P2 + P3 - where P(n) is the corrected wattmeter reading of the individual phase.

4.2.2.2 Voltmeter Connections

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

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4.2.2.3 Energized Windings

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

4.2.2.4 Voltage and Frequency

The operation 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 +/- 0.5 percent 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 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.

4.3 LOAD LOSSES

4.3.1 General

The load losses of a transformer are those losses incident to a specified load carried by the transformer. Load losses include I2R loss in the windings due to load current and stray losses due to eddy currents induced by leakage flux in the windings, core clamps, magnetic shields, tank walls, and other conducting parts. Stray losses may also be caused by circulating currents in parallel windings or strands. Load losses are measured by applying a short circuit across either the high-voltage winding or the low-voltage winding, and applying sufficient voltage across the other winding to cause a specified current to flow in the windings. The power loss within the transformer under these conditions equals the load losses of the transformer at the temperature of test for the specified load current.

The impedance voltage of a transformer is the voltage required to circulate rated current through one of two specified windings when the other winding is short circuited, with the windings connected as for rated voltage operation. Impedance voltage is usually expressed in per unit, or percent, of the rated voltage of the winding across which the voltage is applied and measured. The measured voltage is the impedance voltage at the temperature of the test, and the power loss dissipated within the transformer is equal to the load losses at the temperature of test and at rated load. The impedance voltage and the load losses are corrected to a reference temperature using the formulas specified in this standard.

4.3.2 Factors Affecting the Values of Load Losses and Impedance Voltage

The magnitude of the load losses and the impedance voltage will vary depending on the position of the tap changer, if any, in various windings. These changes are due to the change in the magnitude of load current and associated leakage-flux linkages as well as to changes in stray flux and accompanying stray losses. In addition, several other factors affect the values of load losses and impedance voltage of a transformer. Consideration of these factors, in part, explains variations in values of load losses and impedance voltage for the same transformer under different test conditions as well as variations between the values of load losses and impedance voltage of different transformers of the same design. The test should be conducted at the rated current and voltage of the nominal tap position. These factors are discussed below.

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4.3.2.1 Design

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

4.3.2.2 Process

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

4.3.2.3 Temperature

Load losses are also a function of temperature. The I^2R component of the losses increases with temperature, while the stray loss component decreases with temperature. Procedures for correcting the load losses to the standard reference temperature are described in 4.3.4.2.

4.3.2.4 Measurements

At low power factors, such as those encountered while measuring the load losses and impedance voltage of higher kVA transformers, judicious selection of measuring method and test system components is essential for accurate and repeatable results. The phase-angle errors in the instrument transformers, measuring instruments, and accessories affect the load-loss test results. Procedures for correcting the load losses for metering phase-angle errors are described in 4.3.4.1.

4.3.3 Tests for Measuring Load Losses and Impedance Voltage

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

a. The temperature of the winding shall be determined in accordance with section 4.3.4.2.

b. The conductors used to short-circuit the low-voltage, high-current windings of a transformer shall have a cross section area equal to or greater than the corresponding transformer leads.

c. The frequency of the test source used for measuring the load losses and impedance voltage shall be within ± .5 percent of the nominal value.

d. The maximum value of correction to the measured load losses due to test system phase-angle error is limited to ± 5 percent of measured losses. If more than 5 percent correction is required, test methods and/or test apparatus should be improved for an adequate determination of load losses.

4.3.3.1 Wattmeter-voltmeter-ammeter Method

The connections and apparatus needed for the determination of load losses and impedance voltage of a three phase transformer are shown in Figure 2 for test sets without instrument transformers and Figure 3 for test sets with instrument transformers.

For three-phase transformers, three-phase power measurements utilizing two wattmeters are possible but can result in very large errors at low power factors encountered in tests of transformers. The two wattmeter method should not be used for loss tests on three-phase transformers. Also, line-to-line impedance loss measurements of single phase transformers should not be used.

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4.3.4 Calculation of Load Losses and Impedance Voltage from Test Data

Load losses and impedance voltage measurements vary with temperature and, in general, must be corrected to a reference temperature. In addition, load loss measurement values must be corrected to metering phase-angle error, if significant.

4.3.4.1 Correction of Load Loss Measurements due to Metering Phase-angle Errors

The loss measurements for the load loss test must be corrected for phase angle errors of the wattmeter, voltage measuring circuit, and current measuring circuit. The correction shall be calculated in accordance with Section 4.1.4

4.3.4.2 Temperature Correction for Load Losses

The I^2R component of the load loss increases with the temperature. The stray-loss component diminishes with the temperature. Therefore, when it is desired to convert the load loss from one temperature, such as the temperature of the windings during the test, to another temperature, such as the reference temperature, the two components of the load loss are converted separately. Thus,

$$Pr = Prc\left(\frac{Tk + T}{Tk + Tm}\right) \quad (4)$$

$$Ps = Psc\left(\frac{Tk + Tm}{Tk + T}\right) \quad (5)$$

$$P = Pr + Ps \quad (6)$$

Where:

P = load losses at specified temperature T
Pr and Ps = temperature-corrected resistance and stray losses, respectively, at specified temperature T
Tm = winding temperature at the time of measurement of the resistance. See 3.1
Prc and Psc = Calculated resistance and stray losses, respectively at temperature Tm.
Tk = 234.5 for copper and 225 for aluminum

NOTE—225 applies for pure or EC grade aluminum. Tk may be as high as 230 for other grades of aluminum.

4.3.4.3 Load Loss Correction

For the purpose of this NEMA test standard, the load losses of dry-type transformers shall be corrected to 50 percent of the rated load for medium-voltage transformers, 35 percent of the rated load for low-voltage transformers, and to the reference temperature of 75 degrees C.

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Section 5
MEASUREMENTS AND CALCULATIONS

5.1 MEASURE LOSSES

Measure the no-load and load losses of a transformer according to the test methods in Section 4 of this standard.

5.2 CALCULATE LOAD LOSSES OF LIQUID FILLED TRANSFORMERS

Calculate the load losses of liquid-immersed transformers based on operation at 50 percent of the rated output power.

5.2.1 Correct No-load Losses to Sine Wave Basis

Correct the measured no-load loss data for liquid-immersed transformers to sine wave basis according to clause 4.2.2.1.

5.2.2 Correct Load Loss for Phase Angle Error

Correct the measured load loss data of liquid-immersed transformers for phase angle errors in measuring instruments, if significant, according to clause 4.1.4.

5.2.3 Correct Losses to Reference Temperature

Correct the no-load and load loss values as obtained from Section 4 to reference temperature of 55 degrees C and the no-load loss value to 20°C (if ambient is outside 20 ± 10°C range) and add the two to obtain the total loss based on operation at 50 percent of the rated input power.

5.3 CALCULATE LOSSES OF DRY TYPE TRANSFORMERS

Calculate the losses of dry-type transformers based on operation at 50 percent or 35 percent of the rated output power, as appropriate.

5.3.1 Correct No-load Loss to Sine Wave Basis

Correct the measured no-load loss data of dry-type transformers to a sine wave basis according to clause 4.2.

5.3.2 Correct Losses for Phase Angle Error

Correct the measured load loss data of dry-type transformers for phase angle errors in measuring instruments, if significant, according to clause 4.1.4.

5.3.3 Correct losses to reference temperature

Correct the no-load and load loss values as obtained from Section 4 to the reference temperature of 75 degrees C. Add the temperature-corrected no-load and load loss values to obtain the total losses based on operation at 50 percent or 35 percent of the rated output power, as appropriate.

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5.4 CALCULATE EFFICIENCY

Calculate the efficiency in percent of transformers operating at 50 percent or 35 percent of the rated output power, as appropriate, by using the equation:

$$E_{50(35)} = 100 [P_{50(35)} /(P_{50(35)} + L_{50(35)})], \quad (7)$$

where $E_{50(35)}$ is the efficiency of the transformer in percent when operating at 50 percent (35 percent) of the rated output power, $P_{50(35)}$ is the output power in kVA at 50 percent or 35 percent of the rated (nameplate) value, and $L_{50(35)}$ is the total loss power of the transformer in kW at 50 percent or 35 percent of the rated output power.

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Section 6
TEST EQUIPMENT CALIBRATION AND CERTIFICATION

Test equipment and measuring instruments shall be maintained and calibrated, calibration records maintained, and other test and measurement quality assurance procedures performed according to the following sections. The calibration of the test set shall confirm the accuracy of the test set to that specified in Section 2, Table 2.

6.1 TEST EQUIPMENT

The manufacturer shall control, calibrate, and maintain measuring and test equipment, whether owned by the manufacturer, on loan, or provided by the purchaser, to demonstrate the conformance of the transformer to the specified efficiency. Equipment shall be used in a manner which assures that measurement uncertainty is known and is consistent with the required measurement capability.

6.2 CALIBRATION AND CERTIFICATION

The manufacturer shall:

a. Identify the measurements to be made, the accuracy required, and select the appropriate measurement and test equipment;

b. Identify, check, and calibrate, if needed, all measuring and test equipment systems or devices that affect test accuracy at prescribed intervals, or prior to use, against certified equipment having a known valid relationship to nationally recognized standards—where no such standards exist, the basis used for calibration shall be documented;

c. Establish, document, and maintain calibration procedures, including details of equipment type, identification number, location, frequency of checks, check method, acceptance criteria, and action to be taken when results are unsatisfactory;

d. Ensure that the measuring and test equipment is capable of the accuracy and precision necessary taking into account the voltage, current, and power factor of the transformer under test;

e. Identify measuring and test equipment with a suitable indicator or approved identification record to show the calibration status;

f. Maintain calibration records for measuring and test equipment;

g. Assess and document the validity of previous test results when measuring and test equipment is found to be out of calibration;

h. Ensure that the environmental conditions are suitable for the calibrations, measurements, and tests being carried out;

i. Ensure that the handling, preservation, and storage of measuring and test equipment is such that the accuracy and fitness for use is maintained;

j. Safeguard measuring and test facilities, including both test hardware and test software, from adjustments which would invalidate the calibration setting.

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Section 7
DEMONSTRATION OF COMPLIANCE

7.1 GENERAL

This Section provides a methodology for proving compliance in achieving the specified efficiency levels. It specifies monthly sampling over a 180 day period for the cases where 100 percent of the units are not tested. This standard requires that no individual transformer shall be considered acceptable if its measured losses exceed the allowance by more than 8 percent.

For a transformer population of a specific kVA rating, compliance with the energy efficiency standards as defined in Section 4 of NEMA TP 1 shall be demonstrated through measurements of no-load and load losses according to the procedures described in this standard. A transformer model is defined as all transformers of the same kVA rating and type as described in the efficiency tables of NEMA TP 1.

According to the IEEE Standards C57.12.00 and C57.12.01 the loss tolerance for an individual unit as related to guarantee is defined as follows:

	Limit Beyond Guarantee
No Load Loss	10 percent max.
Total Loss at 100 percent Load	6 percent max.

At 100 percent load, the load loss is normally four times the no-load loss, suggesting that a load loss variability of approximately 5 percent is allowed. The sum of this allowance and the 10 percent variability for the no-load loss yields the total loss variability of 6 percent.

Since TP 1 tables reflect loss measurements at 35 percent or 50 percent of rated load where no-load loss is equal to load losses, the 6 percent loss tolerance cannot be used and therefore a new total loss tolerance of 8 percent shall be applicable at these measurement points. This is consistent with the IEEE Standards C57.12.00 and C57.12.01.

7.2 NUMBER OF UNITS TO BE TESTED

NEMA TP 1 requires that the overall efficiency of the entire population of transformers meet the specified efficiency standards. This intent is satisfied if the mean efficiency of the entire population satisfies this requirement. The compliance of a group of transformers shall be demonstrated by testing all or randomly drawn samples of these transformers.

7.2.1 Compliance Demonstration Through Test on All Transformers

Manufacturers may choose to test all units of various kVA ratings manufactured during a production period of 180 days to demonstrate compliance with the efficiency standard NEMA TP 1. The intent of this standard is satisfied if the Total Measure kVA Input (TMI) of this batch of transformers is equal to or less than the Total Allowed kVA Input (TAI) calculated based on the measured and specified efficiency levels specified in TP 1. Each individual unit from this production batch must meet or exceed the minimum acceptable efficiency level calculated as follows:

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Minimum Acceptable Efficiency level = (SEL/ (108 - 0.08 * SEL)) • 100

Where:

SEL = The standard percent efficiency level from NEMA Standard TP 1.

NOTE—The Minimum Acceptable Efficiency level calculation is based on an 8 percent tolerance on total loss at the load levels considered for the Efficiency levels specified in NEMA TP 1 (i.e., no individual unit shall be considered acceptable if its measured losses exceed the allowance by more than 8 percent).

To demonstrate compliance with the Efficiency standard, proceed as follows:

Step 1. Calculate the Total Allowed kVA Input:

$$TAI = \sum L_i * kVA_i / \eta_i$$

Where:

i = 1,2,3,4, ...

kVA_i = kVA ratings of various transformers included in a production batch manufactured in 180 days

η_i = Specified Efficiency Level in TP 1 for transformer rating kVA_i

L_i = Per unit load at which the efficiency is specified per TP1

Step 2. Calculate the Total Measured kVA Input:

$$TMI = \sum L_i * kVA_i / \eta_{mi}$$

Where:

i = 1,2,3,4, ...

η_{mi} = Measured Efficiency Level for the transformer

L_i = Per unit load at which the efficiency is specified per TP1

Step 3. If TMI is equal to or less than TAI, the compliance of the production batch has been demonstrated.

7.2.2 Compliance Demonstration through Tests on a Statistically Valid Sample

The manufacturer may choose to demonstrate the compliance of a plurality of units by a random sampling of the units of each kVA rating produced in a period of 180 days. Statistically valid numbers of units but not less than 5 shall be drawn on a monthly basis from the units of each kVA rating produced during this period for testing. This will assure the randomness of the samples (30 units minimum).

All the units drawn in 180 day period shall be tested for computing the mean efficiency of each kVA rating. None of the individual units in a sample shall be considered acceptable if its measured losses exceed the allowance by more than 8 percent.

It is the responsibility of the manufacturer to assure through adequate quality control procedures and / or random testing that the conformance of various kVA rating transformers is maintained.

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Table 5

Sample size n	t at 95 percent confidence level	Sample size n	t at 95 percent confidence level
2	6.314	11	1.812
3	2.920	12	1.796
4	2.353	13	1.782
5	2.132	14	1.771
6	2.015	15	1.761
7	1.943	16	1.753
8	1.895	17	1.746
9	1.860	18	1.740
10	1.833	19	1.734
		20	1.729

For a random sample to be statistically valid, a minimum number of units 'n' in the sample must be tested to assure that the standard deviation of the test results is no more than the standard deviation S of the population with 95 percent confidence. The minimum sample size shall be determined as follows:

$$n = (t * S * K)^2$$

Where:

$$K = \frac{108 - 0.08 * SEL}{SEL\,(8 - 0.08 * SEL)}$$

and

t Statistic is determined from Table 5 corresponding to sample size of n at 95 percent confidence level.

To demonstrate compliance with this standard, proceed as follows:

Step 1. Choose a sample size of n_1 units (5 min.)

Step 2. Compute the mean X_1 and standard deviation S_1 as follows:

$$X_1 = \frac{1}{n_1} * \sum Xi$$

$$S_1 = \sqrt{\frac{\sum (X_1 - X_i)^2}{n_1 - 1}}$$

Where:

X_1 = The average efficiency of the first sample
Xi = The efficiency of the unit i
n_1 = The number of units in the first set of samples (the subscript refers to the sample number)
S_1 = The computed sample standard deviation of the first sample

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Step 3. Calculate the minimum sample size n as follows:

$$n = (t_1 * S_1 * K)^2$$

Where:

t_1 Statistic is chosen from Table 5 corresponding to the sample size n_1.

Step 4. If $n \leq n_1$, the sample size is adequate to yield the acceptable standard deviation. Proceed with Step 6. Otherwise, test additional units and increase the sample size to n_2 such that:

$$n_2 \geq n$$

Where:

n_2 is the total number of units tested.

Step 5. Repeat Steps 2 and 3 until each sample size for each kVA rating produced is larger than the minimum sample size n.

Step 6. Calculate the average efficiency η_{mi} of all the samples tested in 180 days for each rating kVA_i manufactured within this period.

Step 7. Calculate the Total Allowed kVA Input:

$$TAI = \sum N_i * L_i * kVA_i / \eta_i$$

Where:

i = 1,2,3,4, ...

kVA_i = kVA ratings of various transformers included in a production batch manufactured in 180 days

η_i = Specified Efficiency Level in TP 1 for transformer rating kVA_i

L_i = Per unit load at which the efficiency is specified per TP 1

N_i = Total number of units produced with rating kVA_i

Step 8. Calculate the Total Measured kVA Input:

$$TMI = \sum N_i * L_i * kVA_i / \eta_{mi}$$

Where:

i = 1,2,3,4, ...

kVA_i = kVA ratings of various transformers included in a production batch manufactured in 180 days

η_{mi} = Measured Efficiency Level for transformers rated kVA_i.

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L_i = Per unit load at which the efficiency is specified per TP 1

N_i = Total number of units produced with rating kVA_i

Step 9. If TMI is equal to or less than TAI, the compliance of the production batch has been demonstrated.

7.3 COMPLIANCE VERIFICATION

7.3.1 A customer may choose to verify the efficiency through tests on a transformer if it was tested to demonstrate compliance as described in Section 7.2, above.

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