

**NEMA Standards Publication TP 2-2005**

*Standard Test Method for Measuring the Energy Consumption  
of Distribution Transformers*

*Published by:*

**National Electrical Manufacturers Association**

1300 North 17th Street, Suite 1752

Rosslyn, Virginia 22209

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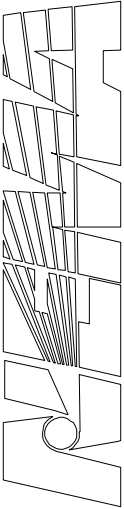
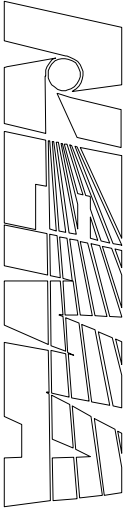
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## Foreword

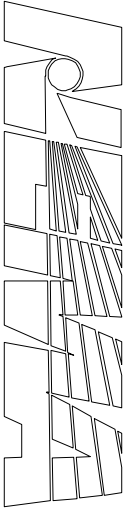
This foreword is for information only and is not part of the standard. The purpose of this document is to provide a standardized means for losses measurement of distribution transformers to achieve energy efficiency levels as outlined in NEMA publication TP 1, *Guide for Determining Energy Efficiency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

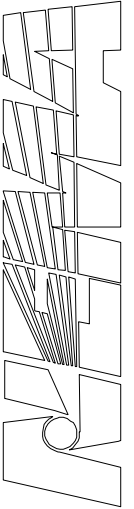
The referenced standards include the standards in Section 1, Referenced Standards.

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, Inc.—Jefferson City, MO  
Acme Electric Corporation—Lumberton, NC  
Cooper Power Systems—Waukesha, WI  
Eaton Electrical—Pittsburgh, PA  
Federal Pacific—Bristol, VA  
General Electric—Hickory, NC  
Hammond Mfg. Co.—Guelph, Ontario  
Kentucky Assn. Elec. Cooperatives, Inc.—Louisville, KY  
MGM Transformer Company—Commerce, CA  
Niagara Transformer Corporation—Buffalo, NY  
Pauwels Transformers—Washington, MO  
Power Paragon—Anaheim, CA  
Siemens Energy & Automation—Jackson, MS  
Square D Company—Lexington, KY  
Vantran Electric Corporation—Waco, TX



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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 at 60Hz for the North American system (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 1-1**

Transformer Type	Number 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.

Products excepted from this standard include:

- a. Autotransformers
- b. Drive (Isolation) transformer
- c. Grounding transformers
- d. Machine tool (Control) transformers
- e. Non-ventilated transformers
- f. Rectifier transformers
- g. Regulating transformers
- h. Sealed transformers
- i. Special impedance transformers
- j. Testing transformers
- k. Transformers with tap ranges greater than 15 percent
- l. Uninterruptible Power Supply (UPS) transformers
- m. Welding transformers
- n. Mining transformers
- o. K rated transformer, when tested with  $K > 1$  (see Section 4.2.1)

NOTE—This standard does apply to K rated transformer when tested with  $K=1$ .

## 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<br>C57.12.00-2000 | <i>IEEE Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers</i>  |
| C57.12.01-1998              | <i>IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers including those with Solid Cast and/or Resin-Encapsulated Windings</i>                      |
| C57.12.90-1999              | <i>IEEE Standard Test Code for Liquid-Immersed Distribution, Power and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers</i> |
| C57.12.91-2001              | <i>IEEE Standard for Test Code for Dry-Type Distribution and Power Transformers</i>  |

### **Institute of Electrical and Electronic Engineers**

445 Hoes Lane  
Piscataway, New Jersey 08855

- |            |   |
|------------|---|
| PC57.12.33 | <i>IEEE Guide for Evaluation of Losses in Distribution Transformers</i> |
|------------|---|

### **National Electrical Manufacturers Association**

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- |            |  |
|------------|--|
| TP 1-2002  | <i>Guide for Determining Energy Efficiency for Distribution Transformers</i> |
| TR 1-1993  | <i>Transformers, Regulators and Reactors</i>                                 |
| ST 20-1992 | <i>Dry-Type Transformers for General Applications</i>                        |

### **International Standards Organization**

1, rue de Verambe  
CH-1211 Geneva 20  
Switzerland

- |                                    |  |
|------------------------------------|--|
| ISO 9002:1994(e)<br>Section 4.11.1 | <i>Quality Systems-Model for Quality Assurance in Production, Installation and Servicing</i> |
|------------------------------------|--|

### **National Institute of Standards and Technology**

Gaithersburg, Maryland 20899-0001

- |                             |   |
|-----------------------------|---|
| NIST<br>Technical Note 1204 | <i>Calibration of Test Systems for Measuring Power Losses of Transformers</i> |
|-----------------------------|---|

### 1.3 DEFINITIONS

**ambient temperature:** The temperature of the medium such as air, water, or earth into which the heat of the equipment is dissipated.

NOTES—(A) For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate neighborhood of the equipment.  
(B) For air- or gas-cooled equipment with forced ventilation or secondary water cooling, the ambient air temperature is taken as that of the ingoing air or cooling gas.  
(C) For self-ventilated enclosed (including oil-immersed) equipment considered as a complete unit, the ambient temperature is the average temperature of the air outside of the enclosure in the immediate neighborhood of the equipment.

NOTE—Ambient temperature is considered to be at 20°C ( $\pm 10^\circ$ ) for the purpose of measuring no-load loss (NL).

**autotransformer:** A transformer that:

- (a) Has one physical winding that consists of a series winding part and a common winding part;
- (b) Has no isolation between its primary and secondary circuits; and
- (c) During step down operation, has a primary voltage that is equal to the total of the series and common winding voltages, and a secondary voltage that is equal to the common winding voltage.

**basic model:** A group of distribution transformers manufactured by a single manufacturer, that have the same insulation type (i.e., liquid immersed or dry type), have the same number of phases (i.e., single or three), have the same standard kVA rating, and do not have any differentiating electrical, physical or functional features that affect energy consumption.

**distribution transformer:** A transformer with a primary voltage of equal to or less than 35 kV, a secondary voltage equal to or less than 600 V, a frequency of 55-65 Hz, and a capacity of 10 kVA to 2500 kVA for liquid immersed units and 15 kVA to 2500 kVA for dry type units.

**drive (isolation) transformer:** A transformer that:

- (a) Isolates an electric motor from the line;
- (b) Accommodates the added loads of drive created harmonics; and
- (c) Is designed to withstand the additional mechanical stresses resulting from an alternating current adjustable frequency motor drive or a direct current motor drive.

**dry-type distribution transformer:** A distribution transformer in which the core and coil assembly is immersed in a gaseous or dry compound insulating medium.

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

**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.

**grounding transformer:** A three phase transformer intended primarily to provide a neutral point for system-grounding purposes, either by means of:

- (a) A grounded wye primary winding and a delta secondary winding; or
- (b) An autotransformer with a zig zag winding arrangement.

**instrument transformer:** A transformer which is intended to reproduce in its secondary circuit, in a definite and known proportion, the current or voltage of its primary circuit, with the phase relations and waveform substantially preserved.

**k factor transformer:** A transformer that is designed to tolerate the additional eddy current losses resulting from harmonics drawn by non linear loads.

**liquid-immersed distribution transformer:** A distribution transformer in which the core and coil assembly is immersed in an insulating liquid.

**load loss:** The load losses of a transformer are those losses incident to the carrying of a specified load by the transformer. Load losses include  $I^2R$  loss in the windings due to load and eddy currents; stray losses due to leakage fluxes in the windings, core clamps, and other parts, and the loss due to circulating currents (if any) in parallel windings, or in parallel winding strands.

**low-voltage distribution transformer:** A dry-type distribution transformer with a rated primary voltage of 600 V or less.

**machine tool (control) transformer:** A transformer that is equipped with a fuse or other over current protection device, and is generally used for the operation of a solenoid, contactor, relay, portable tool, or localized lighting.

**medium-voltage distribution transformer:** A dry-type distribution transformer with rated primary voltage between 601 V and 35 kV.

**mining transformer:** Any transformer installed:

- underground in a mine,
- inside equipment for use in mines, or
- as a component of equipment used for underground digging, tunneling, or dredging operations.

The nameplate shall identify transformer for such use.

**no-load (excitation) 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 circulating current in parallel windings. These losses change with the excitation voltage.

**non-ventilated transformer:** A transformer constructed so as to prevent external air circulation through the coils of the transformer while operating at zero gauge pressure.

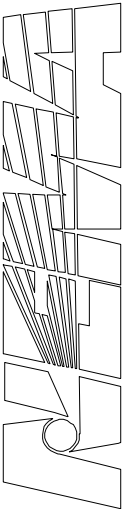
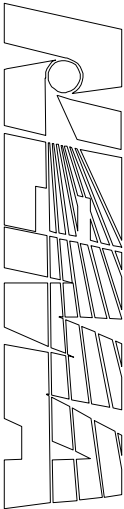
**phase angle:** The angle between two phasors, where the two phasors represent progressions of periodic waves of either:

- (1) Two voltages;
- (2) Two currents; or
- (3) A voltage and a current of an alternating current circuit.

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

**phase angle error:** The incorrect displacement of the phase angle introduced by the components of the test equipment.

NOTE—Phase angle error, if significant, can introduce errors in measured transformer losses.



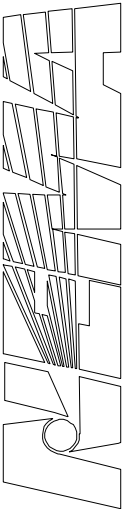
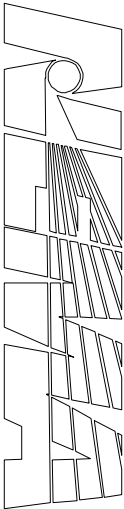
**rectifier transformer:** A transformer that operates at the fundamental frequency of an alternating current system and that is designed to have one or more output windings connected to a rectifier.

**reference temperature:** 20°C for no-load loss, 55°C for liquid-immersed distribution transformers at 50% load, and 75°C for both low-voltage and medium-voltage dry-type distribution transformers, at 35% load and 50% load, respectively. It is the temperature at which the transformer losses must be determined, and to which such losses must be corrected if testing is done at a different point. (These temperatures are specified in the test method in Sections 3 and 4.)

**regulating transformer:** A transformer that varies the voltage, the phase angle, or both voltage and phase angle, of an output circuit and compensates for fluctuation of load and input voltage, phase angle or both voltage and phase angle.

**sealed transformer:** A transformer designed to remain hermetically sealed under specified conditions of temperature and pressure.

**special impedance transformer:** Any transformer built to operate at an impedance outside of the normal impedance range for that transformer's kVA rating. The normal impedance range for each kVA rating for liquid-immersed and dry-type transformers is shown in Tables 1-2 and 1-3, respectively.



**Table 1-2  
NORMAL IMPEDANCE RANGES FOR LIQUID-IMMERSED TRANSFORMERS**

Single-Phase Transformers		Three-Phase Transformers	
KVA	Impedance (%)	kVA	Impedance (%)
10	1.0-4.5	15	1.0-4.5
15	1.0-4.5	30	1.0-4.5
25	1.0-4.5	45	1.0-4.5
37.5	1.0-4.5	75	1.0-5.0
50	1.5-4.5	112.5	1.2-6.0
75	1.5-4.5	150	1.2-6.0
100	1.5-4.5	225	1.2-6.0
167	1.5-4.5	300	1.2-6.0
250	1.5-6.0	500	1.5-7.0
333	1.5-6.0	750	5.0-7.5
500	1.5-7.0	1000	5.0-7.5
667	5.0-7.5	1500	5.0-7.5
833	5.0-7.5	2000	5.0-7.5
		2500	5.0-7.5

**Table 1-3  
NORMAL IMPEDANCE RANGES FOR DRY-TYPE TRANSFORMERS**

Single-Phase Transformers		Three-Phase Transformers	
KVA	Impedance (%)	kVA	Impedance (%)
15	1.5-6.0	15	1.5-6.0
25	1.5-6.0	30	1.5-6.0
37.5	1.5-6.0	45	1.5-6.0
50	1.5-6.0	75	1.5-6.0
75	2.0-7.0	112.5	1.5-6.0
100	2.0-7.0	150	1.5-6.0
167	2.5-8.0	225	3.0-7.0
250	3.5-8.0	300	3.0-7.0
333	3.5-8.0	500	4.5-8.0
500	3.5-8.0	750	5.0-8.0
667	5.0-8.0	1000	5.0-8.0
833	5.0-8.0	1500	5.0-8.0
		2000	5.0-8.0
		2500	5.0-8.0

**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 current:** The current of the electrical power supplied to the transformer under test.

**testing transformer:** A transformer used in a circuit to produce a specific voltage or current for the purpose of testing electrical equipment.

**test frequency:** The frequency of the electrical power supplied to the transformer under test.

**test voltage:** The voltage of the electrical power supplied to the transformer under test.

**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 measured and calculated data, the test system accuracy for each measurement shall fall within the limits specified in Table 4.

**total loss:** Total losses of a transformer shall be the sum of the no-load losses and the load losses, excluding losses due to accessories.

NOTE—The load-loss component shall be based on a reference temperature equal to the rated average temperature rise plus 20°C or other specified temperature, such as that specified in NEMA Standard TP 1.

**transformer:** A static electric device consisting of a winding or two or more coupled windings, with a magnetic core, for introducing mutual coupling between electric circuits.

**transformer with tap range greater than 15%:** A transformer with a tap range in the primary winding greater than the range accomplished with six, 2.5% taps, 3 above and 3 below the rated primary voltage (e.g., 6 times 2.5% = 15%).

**uninterruptible power supply transformer:** A transformer that supplies power to an uninterruptible power system, which in turn supplies power to loads that are sensitive to power failure, power sags, over voltage, switching transients, line noise, and other power quality factors.

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

**welding transformer:** A transformer designed for use in arc welding equipment or resistance welding equipment.

## Section 2 ACCURACY REQUIREMENTS

### 2.1 GENERAL CONSIDERATIONS

Equipment and methods for loss measurement shall be of sufficient accuracy that measurement error will be limited to the values shown in Table 2-1.

**Table 2-1  
MEASUREMENT ACCURACY REQUIREMENTS**

<b>Quantity Measured</b>	<b>Test System Accuracy</b>
Losses	$\pm 3\%$
Voltage	$\pm 0.5\%$
Current	$\pm 0.5\%$
Resistance	$\pm 0.5\%$
Frequency	$\pm 0.5\%$
Temperature	$\pm 1.0^\circ \text{C}$

## Section 3 RESISTANCE MEASUREMENTS

Resistance measurements are of fundamental importance for the calculation of load losses as shown in 4.5. The  $I^2R$  calculation is dependent on the accurate value of the winding resistance.

### 3.1 GENERAL CONSIDERATIONS

Measure or establish the winding temperature at the time of the winding resistance measurement.

Measure the direct current resistance ( $R_{dc}$ ) of transformer windings by one of the methods outlined in section 3.3. The methods of section 3.5 must be used to correct load losses to the applicable reference temperature from the temperature at which they are measured.

### 3.2 TEMPERATURE DETERMINATION OF WINDINGS AND PRE-CONDITIONS FOR RESISTANCE MEASUREMENT

Make temperature measurements in protected areas where the air temperature is stable and there are no drafts. Determine the winding temperature ( $T_{dc}$ ) for liquid-immersed and dry-type distribution transformers by the methods described in sections 3.2.1 and 3.2.2, respectively.

#### 3.2.1 Liquid-Immersed Distribution Transformers

Record the winding temperature ( $T_{dc}$ ) of liquid-immersed transformers as the average of top and bottom thermocouples or other temperature sensing devices applied to the outside of the transformer tank. The top sensor should be located at the level of the oil and the bottom sensor should be near the tank bottom or at the lower radiator header if applicable.

Make this determination under either of the following conditions:

- (a) The windings have been under insulating liquid with no excitation and no current in the windings for four hours before the dc resistance is measured; or
- (b) The temperature of the insulating liquid has stabilized, and the difference between the top and bottom temperature does not exceed 5°C.

#### 3.2.2 Dry Type Distribution Transformers

Record the winding temperature ( $T_{dc}$ ) of ventilated dry type transformers as the average of readings of four or more thermometers, thermocouples, or other suitable temperature sensors inserted within the coils. Sensing points of the measuring devices must be placed as close as possible to the winding conductors. Other suitable methods are described in NEMA ST20 or IEEE/ANSI C57.12.90 and C57.12.91

For sealed units such as epoxy coated or epoxy encapsulated distribution transformers, the temperature of the windings must be recorded as either:

- (1) The average of four or more temperature sensors located on the enclosure and cover as close to different parts of the winding assemblies as possible; or
- (2) After allowing a stabilizing interval with no excitation and no current in the windings for at least 24 hours, the ambient temperature of the test area.

The following conditions must be met immediately before taking cold-resistance measurements:

- (a) All internal temperatures measured by the internal temperature sensors must not differ from the test area ambient temperature by more than 2°C.
- (b) Enclosure surface temperatures for sealed units must not differ from the test area ambient temperature by more than 2°C.
- (c) Test area ambient temperature should not have changed by more than 3°C for 3 hours before the test.
- (d) Neither voltage nor current has been applied to the unit under test for 24 hours. In addition, the period since application of voltage or current must exceed 24 hours by any added amount of time necessary for the temperature of the transformer windings to stabilize at the level of the ambient temperature. However, this added amount of time need not exceed 24 hours.

### 3.3 RESISTANCE MEASUREMENT METHODS

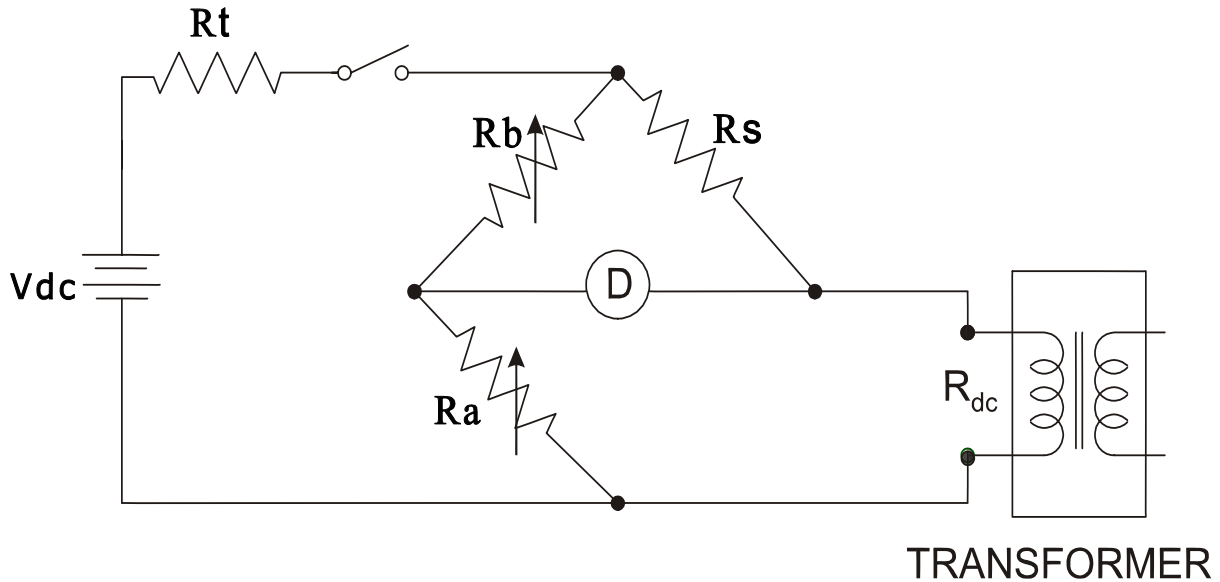
Make resistance measurements using either the resistance bridge method, the voltmeter-ammeter method, or a resistance meter. In each instance when this Uniform Test Method is used to test more than one unit of a basic model to determine the efficiency of that basic model, the resistance of the units being tested may be determined from making resistance measurements on only one of the units.

#### 3.3.1 Resistance Bridge Methods

If the resistance bridge method is selected, use either the Wheatstone or Kelvin bridge circuit (or the equivalent of either).

##### 3.3.1.1 Wheatstone Bridge

This bridge is best suited for measuring resistances larger than ten ohms. A schematic diagram of a Wheatstone bridge with a representative transformer under test is shown in Figure 3-1.



**Figure 3-1  
WHEATSTONE BRIDGE**

where:

$R_{dc}$  is the resistance of the transformer winding being measured,

$R_s$  is a standard resistor having the resistance  $R_s$ ,

$R_a, R_b$  are two precision resistors with resistance values  $R_a$  and  $R_b$ , respectively; at least one resistor must have a provision for resistance adjustment,

$R_t$  is a resistor for reducing the time constant of the circuit,

D is a null detector, which may be either a micro ammeter or microvoltmeter or equivalent instrument for observing that no signal is present when the bridge is balanced, and

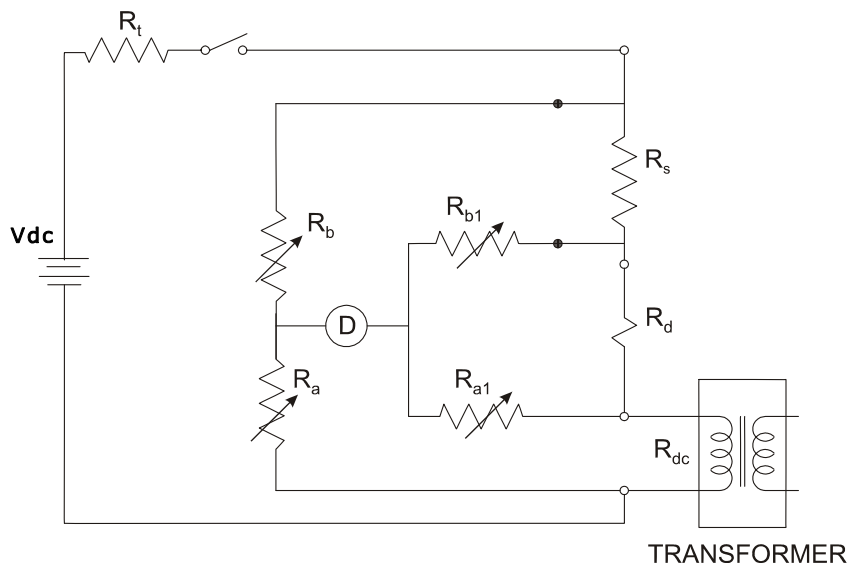
$V_{dc}$  is a source of dc voltage for supplying the power to the Wheatstone Bridge.

In the measurement process, turn on the source ( $V_{dc}$ ), and adjust the resistance ratio ( $R_a/R_b$ ) to produce zero signal at the detector (D). Determine the winding resistance by using equation 3-1 as follows:

$$R_{dc} = R_s (R_a/R_b) \quad (3-1)$$

### 3.3.1.2 Kelvin Bridge

This bridge separates the resistance of the connecting conductors to the transformer winding being measured from the resistance of the winding, and therefore is best suited for measuring resistances of ten ohms and smaller. A schematic diagram of a Kelvin bridge with a representative transformer under test is shown in Figure 3-2.



**Figure 3-2  
KELVIN BRIDGE**

The Kelvin Bridge has seven of the same type of components as in the Wheatstone Bridge. It has two more resistors than the Wheatstone bridge,  $R_{a1}$  and  $R_{b1}$ . At least one of these resistors must have adjustable resistance. In the measurement process, the source is turned on, two resistance ratios ( $R_a/R_b$ ) and ( $R_{a1}/R_{b1}$ ) are adjusted to be equal, and then the two ratios are adjusted together to balance the bridge producing zero signal at the detector. Determine the winding resistance by using equation 3-2 as follows:

$$R_{dc} = R_s (R_a/R_b) \quad (3-2),$$

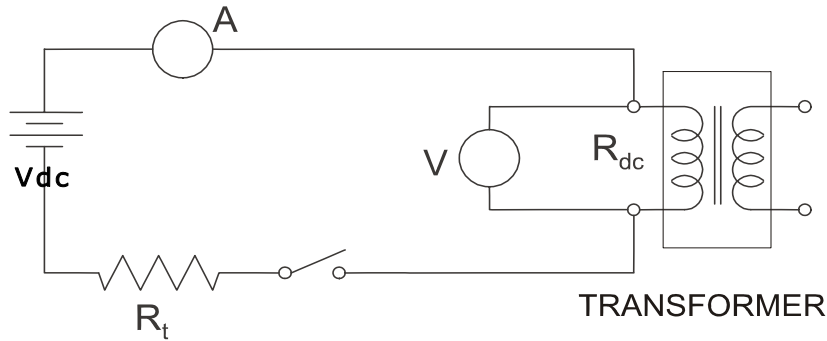
as with the Wheatstone bridge, with an additional condition that:

$$(R_a/R_b) = (R_{a1}/R_{b1}) \quad (3-3)$$

The Kelvin bridge provides two sets of leads, current-carrying and voltage-sensing, to the transformer terminals and the standard resistor, thus eliminating voltage drops from the measurement in the current-carrying leads as represented by  $R_d$ .

### 3.3.2 Voltmeter-Ammeter Method

Employ the voltmeter ammeter method only if the rated current of the winding is greater than one ampere and the test current is limited to 15% of the winding current. Connect the transformer winding under test to the circuit shown in Figure 3-3.



**Figure 3-3**  
**VOLTMETER-AMMETER METHOD**

where:

A is an ammeter or a voltmeter-shunt combination for measuring the current ( $I_{m_{dc}}$ ) in the transformer winding,

V is a voltmeter with sensitivity in the millivolt range for measuring the voltage ( $V_{m_{dc}}$ ) applied to the transformer winding,

$R_{dc}$  is the resistance of the transformer winding being measured,

$R_t$  is a resistor for reducing the time constant of the circuit, and

$V_{dc}$  is a source of dc voltage for supplying power to the measuring circuit.

To perform the measurement, turn on the source to produce current no larger than 15% of the rated current for the winding. Wait until the current and voltage readings have stabilized and then take simultaneous readings of voltage and current. Determine the winding resistance  $R_{dc}$  by using equation 3-4 as follows:

$$R_{dc} = (V_{m_{dc}} / I_{m_{dc}}) \quad (3-4)$$

where:

$V_{m_{dc}}$  is the voltage measured by the voltmeter V, and

$I_{m_{dc}}$  is the current measured by the ammeter A.

As shown in Figure 3.3, separate current and voltage leads must be brought to the transformer terminals. (This eliminates the errors due to lead and contact resistance.)

### 3.3.3 Resistance Meters

Resistance meters may be based on voltmeter-ammeter, or resistance bridge, or some other operating principle. A particular meter may be used to measure a transformer's winding resistance only if the meter's specifications for resistance range, current range, and ability to measure highly inductive resistors cover the characteristics of the transformer being tested. Also the meter's specifications for accuracy must meet the applicable criteria of Table 2-1 in Section 2.

### 3.4 PRECAUTIONS IN MEASURING WINDING RESISTANCE

#### 3.4.1 Required actions

The following guidelines must be observed when making resistance measurements:

- (a) Use separate current and voltage leads when measuring small (< 10 ohms) resistance.
- (b) Use null detectors in bridge circuits, and measuring instruments in voltmeter-ammeter circuits, that have sensitivity and resolution sufficient to enable observation of at least 0.1% change in the measured resistance.
- (c) Maintain the dc test current at or below 15% of the rated winding current.
- (d) Use a higher source voltage, as required, to compensate for inclusion of a stabilizing resistor  $R_t$  (see section 3.4.2).
- (e) Disconnect the null detector (if a bridge circuit is used) and voltmeter from the circuit before the current is switched off, and switch off current by a suitable insulated switch.

#### 3.4.2 Guideline for Time Constant

The following guideline is suggested for the tester as a means to facilitate the measurement of resistance in accordance with the accuracy requirements of Section 2:

The accurate reading of resistance  $R_{dc}$  may be facilitated by shortening the time constant. This is done by introducing a resistor  $R_t$  in series with the winding under test in both the bridge and voltmeter ammeter circuits as shown in Figures 3.1 to 3.3. The relationship for the time constant is:

$$T_c = (L_{tc} / R_{tc}) \quad (3-5)$$

where:

$T_c$  is the time constant in seconds,

$L_{tc}$  is the total magnetizing and leakage inductance of the winding under test, in henries, and

$R_{tc}$  is the total resistance in ohms, consisting of  $R_t$  in series with the winding resistance  $R_{dc}$ .

Because  $R_{tc}$  is in the denominator of the expression for the time constant, increasing the size of resistor  $R_{tc}$  will decrease the time constant. If the time constant in a given test circuit is too high for the resistance readings to be stable, then a higher resistance can be substituted for the existing  $R_{tc}$ , and successive replacements can be made until adequate stability is reached.

### 3.5 CONVERSION OF RESISTANCE MEASUREMENTS

Resistance measurements must be corrected, from the temperature at which the winding resistance measurements were made, to the reference temperature. As specified in these test procedures, the reference temperature for liquid immersed transformers loaded at 50% of the rated load is 55°C. For medium voltage, dry type transformers loaded at 50% of the rated load, and for low-voltage, dry-type transformers loaded at 35% of the rated load, the reference temperature is 75°C.

Correct measurement temperatures to the reference temperature using equation 3-6 as follows:

$$R_{ts} = R_{dc} [(T_s + T_k) / (T_{dc} + T_k)] \quad (3-6)$$

where:

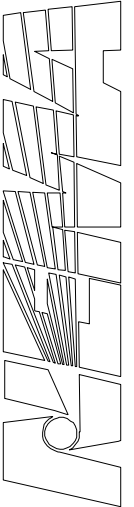
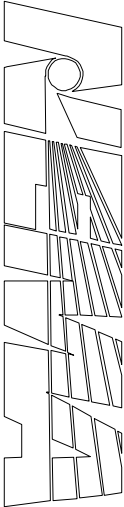
$R_{ts}$  is the resistance at the reference temperature,  $T_s$ ,

$R_{dc}$  is the measured resistance at temperature,  $T_{dc}$ ,

$T_s$  is the reference temperature in °C,

$T_{dc}$  is the temperature at which resistance was measured in °C, and

$T_k$  is 234.5°C for copper or 225°C for aluminum.



## Section 4 LOSS MEASUREMENT

### 4.1 GENERAL CONSIDERATIONS

The efficiency of a transformer is computed from the total transformer losses, which are determined from the measured value of the no-load loss and load loss power components. Each of these two power loss components is measured separately using functionally identical test sets. The measured quantities will need correction for instrumentation losses and may need corrections for known phase angle errors in measuring equipment and for the wave form distortion in the test voltage. Any power loss not measured at the applicable reference temperature must be adjusted to that reference temperature. The measured load loss must also be adjusted to a specified output loading level if not measured at the specified output loading level.

### 4.2 MEASUREMENT OF POWER LOSSES

#### 4.2.1 No-Load Loss

Measure the no-load loss and apply corrections as described in section 4.4, using the appropriate test set as described in section 4.3.

#### 4.2.2 Load Loss

Measure the load loss and apply corrections as described in section 4.5, using the appropriate test set as described in section 4.3. For K rated transformers above K=1, measure the losses at K=1. At this rating, transformers must meet the efficiency in NEMA Publication TP 1.

### 4.3 TEST SETS

The same test set may be used for both the no-load loss and load loss measurements provided the range of the test set encompasses the test requirements of both tests. Calibrate the test set to national standards to meet the tolerances in Table 2-1 in Section 2. In addition, the wattmeter, current measuring system and voltage measuring system must be calibrated separately if the overall test set calibration is outside the tolerance as specified in Section 2 or the individual phase angle error exceeds the values specified in section 4.5.3.

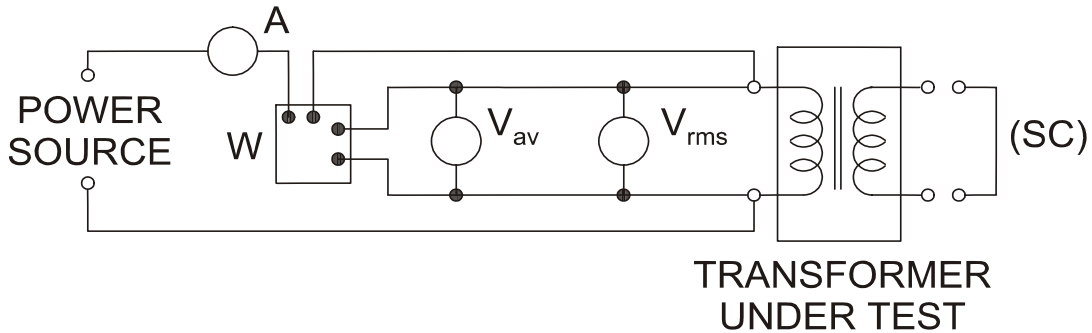
A test set based on the wattmeter-voltmeter-ammeter principle may be used to measure the power loss and the applied voltage and current of a transformer where the transformer's test current and voltage are within the measurement capability of the measuring instruments. Current and voltage transformers, known collectively as instrument transformers, or other scaling devices such as resistive or capacitive dividers for voltage, may be used in the above circumstance, and must be used in place of an instrument to measure current or voltage where the current or voltage of the transformer under test exceeds the measurement capability of such instrument. Thus, a test set may include a combination of measuring instruments and instrument transformers (or other scaling devices), so long as the current or voltage of the transformer under test does not exceed the measurement capability of any of the instruments.

#### 4.3.1 Single-Phase Test Sets

Use these for testing single phase distribution transformers, other than as shown in 4.3.3.

#### 4.3.1.1 Without Instrument Transformers

A single-phase test set without an instrument transformer is shown in Figure 4-1.



**Figure 4-1**  
**SINGLE-PHASE TEST SET WITHOUT INSTRUMENT TRANSFORMERS**

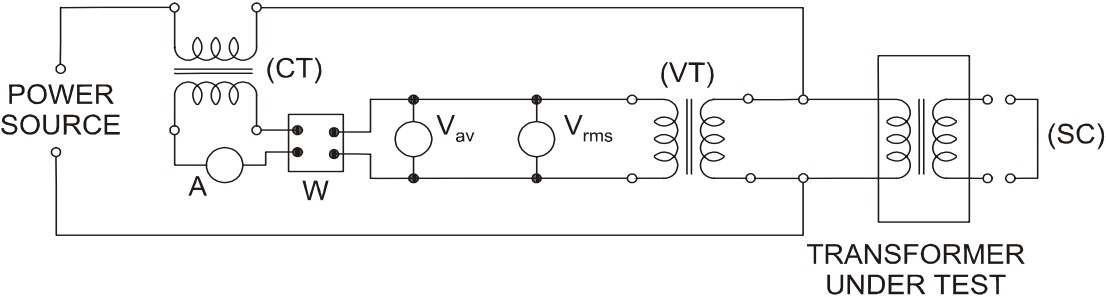
Where:

- W is a wattmeter used to measure  $P_{nm}$  and  $P_{lm}$ , the no-load and load loss power, respectively,
- $V_{rms}$  is a true root-mean-square (rms) voltmeter used to measure  $V_{r(nm)}$  and  $V_{lm}$ , the rms test voltages in no-load and load loss measurements, respectively,
- $V_{av}$  is an average sensing voltmeter, calibrated to indicate rms voltage for sinusoidal waveforms and used to measure  $V_{a(nm)}$ , the average voltage in no-load loss measurements. The no-load loss determination is based on a sine-wave voltage. The average-voltmeter method is the most accurate method for correcting the measured no-load losses to a sine-wave basis and is recommended,
- A is an rms ammeter used to measure test current, especially  $I_{lm}$ , the load loss current, and
- (SC) is a conductor for providing a short-circuit across the output windings for the load loss measurements.

Either the primary or the secondary winding can be connected to the test set. However, more compatible voltage and current levels for the measuring instruments are available if for no-load loss measurements the secondary (low voltage) winding is connected to the test set, and for load loss measurements the primary winding is connected to the test set. Use the average-sensing voltmeter,  $V_{av}$ , only in no-load loss measurements.

**4.3.1.2 With Instrument Transformers**

A single-phase test set with instrument transformers is shown in Figure 4-2. This circuit has the same four measuring instruments as that in Figure 4-1. The current and voltage transformers, designated as (CT) and (VT), respectively, are added.



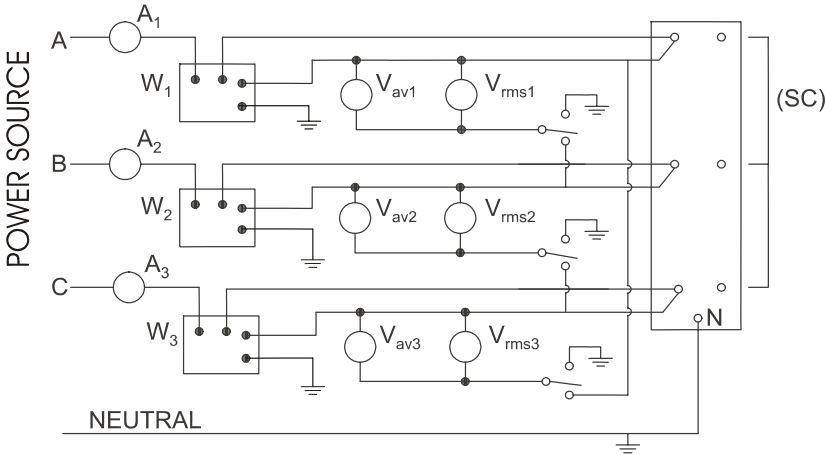
**Figure 4-2**  
**SINGLE-PHASE TEST SET WITH INSTRUMENT TRANSFORMERS**

**4.3.2 Three-Phase Test Sets**

Use these for testing three-phase distribution transformers, other than as shown in 4.3.3.

**4.3.2.1 Without Instrument Transformers**

A three-phase test set without instrument transformers is shown in Figure 4-3. This test set is essentially the same circuit shown in Figure 4-1 repeated three times, and the instruments are individual devices as shown. As an alternative, the entire instrumentation system of a three-phase test set without transformers may consist of a multi-function analyzer.



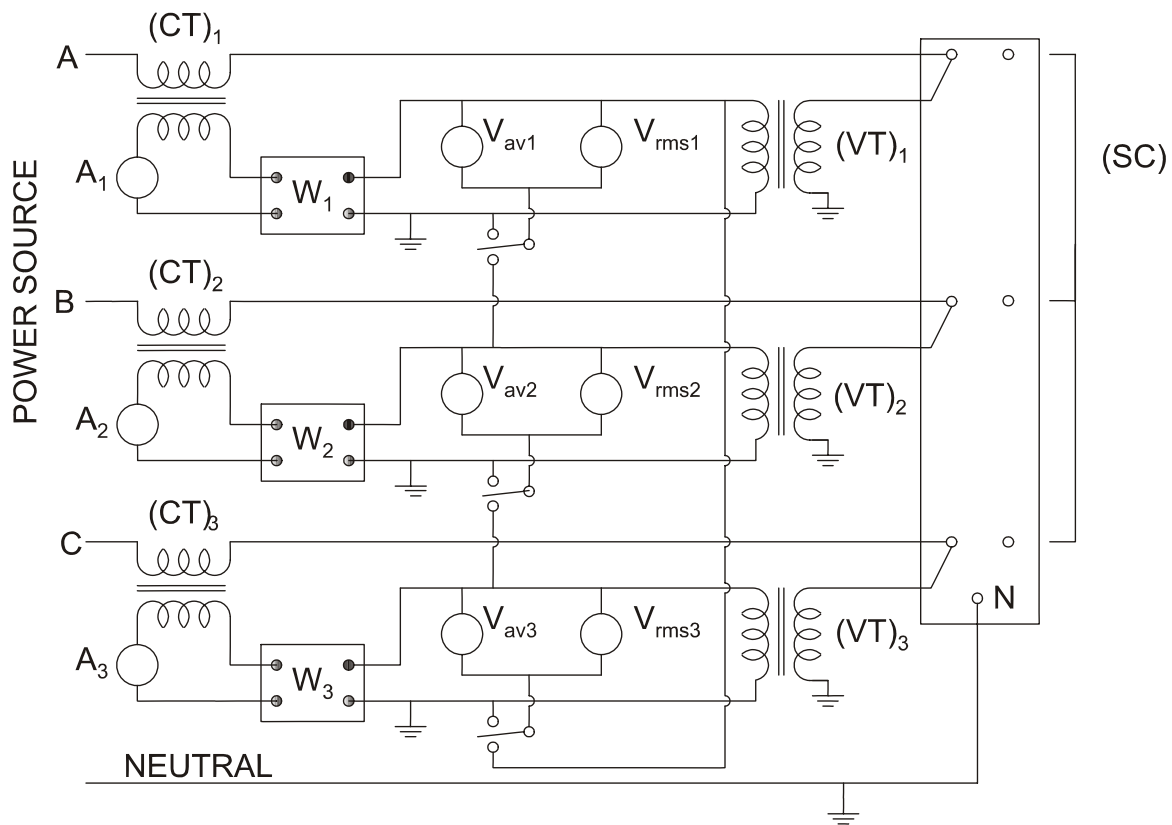
**Figure 4-3**  
**THREE-PHASE TEST SET WITHOUT INSTRUMENT TRANSFORMERS**

Either group of windings, the primary or the secondary, can be connected in wye or delta configuration. If both groups of windings are connected in the wye configuration for the no-load test, the neutral of the winding connected to the test set must be connected to the neutral of the source to provide a return path for the neutral current.

In the no-load loss measurement, the voltage on the winding must be measured. Therefore a provision must be made to switch the voltmeters for line-to-neutral measurements for wye-connected windings and for line-to-line measurements for delta-connected windings.

#### 4.3.2.2 With Instrument Transformers

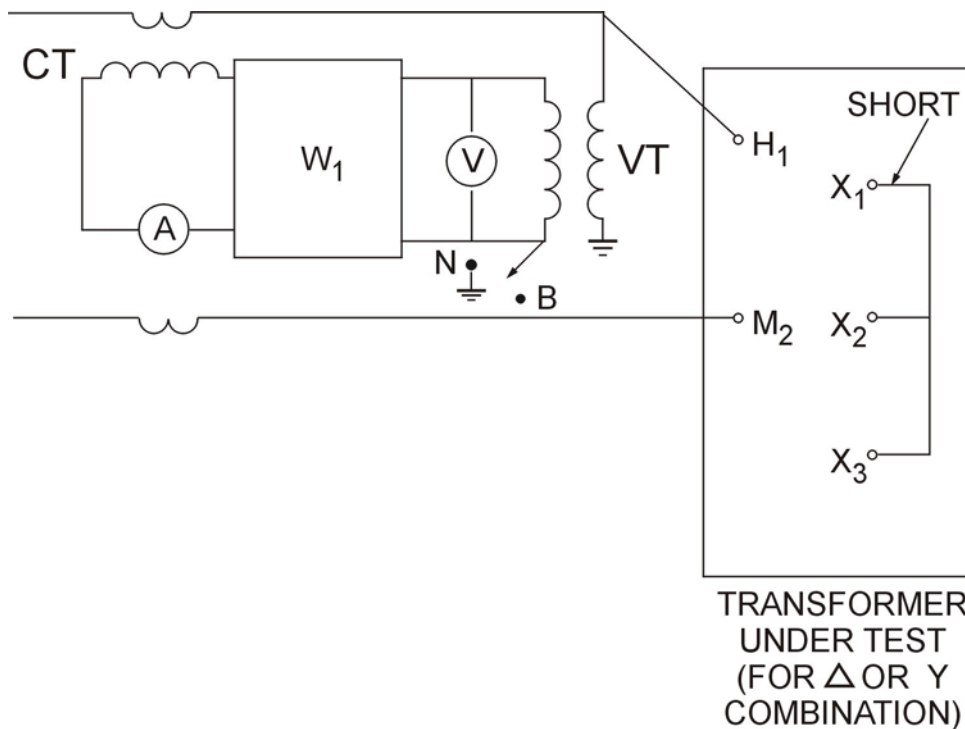
A three-phase test set with instrument transformers is shown in Figure 4-4. This test set is essentially the same circuit shown in Figure 4-2 repeated three times. Provision must be made to switch the voltmeters for line-to-neutral and line-to-line measurements as in section 4.3.2.1. The voltage sensors ("coils") of the wattmeters must always be connected in the line-to-neutral configuration.



**Figure 4-4**  
**THREE-PHASE TEST SET WITH INSTRUMENT TRANSFORMERS**

#### 4.3.3 Test of three-phase transformer with single-phase voltage

To determine the load losses and impedance voltage of a three-phase transformer with single-phase voltage, the setup, as schematically shown in Figure 4-5 is recommended.



**Figure 4-5**  
**TEST OF THREE-PHASE TRANSFORMER WITH SINGLE-PHASE VOLTAGE**

The three line leads of one winding are short-circuited, and single-phase voltage at rated frequency is applied to two terminals of the other winding. The applied voltage is adjusted to circulate rated line current.

Three successive readings are taken on the three pairs of leads; for example, H<sub>1</sub> and H<sub>2</sub>, H<sub>2</sub> and H<sub>3</sub>, H<sub>3</sub> and H<sub>1</sub>. Then

$$\text{Measured load losses (watts)} = 1.5 \left( \frac{P_{12} + P_{23} + P_{31}}{3} \right)$$

$$\text{Measured impedance voltage} = 0.866 \left( \frac{E_{12} + E_{23} + E_{31}}{3} \right)$$

where

P and E are individual readings of measured load losses and impedance voltage, respectively, as indicated by subscripts.

The stray loss component shall be obtained by subtracting the I<sup>2</sup>R losses from the measured load losses of the transformer. Let R<sub>1</sub> be the resistance measured between two high-voltage terminals and R<sub>2</sub> that between two low-voltage terminals; let I<sub>1</sub> and I<sub>2</sub> be the respective rated line currents. Then, the total I<sup>2</sup>R loss of all three phases will be

$$\text{Total I}^2\text{R (watts)} = 1.5 (I_1^2 R_1 + I_2^2 R_2)$$

This formula applies equally well to wye- or delta-connected windings.

Temperature correction shall be made as in 4.5.3.3.

#### 4.3.4 Test Set Neutrals

A four-wire, three-wattmeter test circuit must be used in making measurements. For delta-wound transformers, a neutral deriving transformer must be used to obtain neutral and ground for the test.

### 4.4 NO-LOAD LOSSES: MEASUREMENT AND CALCULATIONS

#### 4.4.1 General Considerations

Make measurement corrections:

- (1) For instrumentation losses;
- (2) When the waveform of the applied voltage is non-sinusoidal; and
- (3) When the core temperature or liquid temperature is outside the  $20^{\circ}\text{C} \pm 10^{\circ}\text{C}$  range.

#### 4.4.2 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 must be based on a sine-wave voltage corrected to the reference temperature. Connect either of the transformer windings, primary or secondary, to the appropriate test set of Figures 4-1 to 4-4, giving consideration to precaution (b) below. Leave the unconnected winding(s) open circuited. Apply the rated voltage at rated frequency, as measured by the average-sensing voltmeter, to the transformer. Take the readings of the wattmeter(s) and the average-sensing and true rms voltmeters. Observe the precautions (a), (b), and (c) below:

- (a) Voltmeter connections. When correcting to a sine-wave basis using the average-voltmeter method, the voltmeter connections must be such that the waveform applied to the voltmeters is the same as the waveform across the energized windings.
- (b) Energized windings. Either the high voltage or the low voltage winding of the transformer under test may be energized. Energize not less than 25 percent of the winding.
- (c) Voltage and frequency. The no-load loss test must be 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.

Adjust the voltage to the specified value as indicated by the average-sensing voltmeter. Record the values of rms voltage, rms current, electrical power, and average voltage as close to simultaneously as possible. For a three-phase transformer, take all of the readings on one phase before proceeding to the next, and record the average of the three rms voltmeter readings as the rms voltage value.

NOTE—When the tester uses a power supply that is not synchronized with an electric utility grid, such as a dc/ac motor-generator set, check the frequency and maintain it within  $\pm 0.5$  percent of the rated frequency of the transformer under test. A power source that is directly connected to, or synchronized with, an electric utility grid need not be monitored for frequency.

### 4.4.3 Corrections

#### 4.4.3.1 Correction for Instrumentation Losses

Determine the losses attributable to the voltmeters, ammeter, and wattmeter, and to the instrument transformers if they are used, and deduct these losses from the measurement of total no-load losses.

#### 4.4.3.2 Correction for Non-Sinusoidal Applied Voltage

The measured value of no-load loss must be corrected to a sinusoidal voltage, except when waveform distortion in the test voltage causes the magnitude of the correction to be less than 1%. In such a case, no correction is required.

To make a correction where the distortion requires a correction of 5% or less, use equation 4-1. If the distortion requires a correction to be greater than 5%, improve the test voltage and re-test. Repeat until the distortion requires a correction of 5% or less.

Determine the no-load losses of the transformer corrected for sine-wave basis from the measured value by using equation 4-1 as follows:

$$P_{ncl} = \frac{P_{nm}}{P_1 + kP_2} \quad (4-1)$$

where:

$P_{ncl}$  is the no-load loss corrected to a sine-wave basis at the temperature ( $T_{nm}$ ) at which no-load loss is measured,

$P_{nm}$  is the measured no-load loss at temperature  $T_{nm}$ ,

$P_1$  is the per unit hysteresis loss,

$P_2$  is the per unit eddy-current loss,

$$P_1 + P_2 = 1,$$

$$k = \left( \frac{V_{r(nm)}}{V_{a(nm)}} \right)^2,$$

$V_{r(nm)}$  is the test voltage measured by rms voltmeter, and

$V_{a(nm)}$  is the test voltage measured by average-voltage voltmeter.

The two loss components ( $P_1$  and  $P_2$ ) are assumed equal in value, each assigned a value of 0.5 per unit, unless the actual measurement-based values of hysteresis and eddy-current losses are available (in per unit form), in which case the actual measurements apply.

#### 4.4.3.3 Correction of No-Load Loss to Reference Temperature

After correcting the measured no-load loss for waveform distortion, correct the loss to the reference temperature of 20°C. If the no-load loss measurements were made between 10°C and 30°C, this correction is not required. If the correction to reference temperature is applied, then the core temperature

of the transformer during no-load loss measurement ( $T_{nm}$ ) must be determined within  $\pm 10^{\circ}\text{C}$  of the true average core temperature. Correct the no-load loss to the reference temperature by using equation 4-2 as follows:

$$P_{nc} = P_{ncl} [(1 + 0.00065(T_{nm} - T_{nr}))] \quad (4-2)$$

where:

$P_{nc}$  is the no-load losses corrected for waveform distortion and then to the reference temperature of  $20^{\circ}\text{C}$ ,

$P_{ncl}$  is the no-load losses, corrected for waveform distortion, at temperature  $T_{nm}$ ,

$T_{nm}$  is the core temperature during the measurement of no-load losses, and

$T_{nr}$  is the reference temperature,  $20^{\circ}\text{C}$ .

## 4.5 LOAD LOSSES: MEASUREMENT AND CALCULATIONS

### 4.5.1 General Considerations

The load losses of a transformer are those losses incident to a specified load carried by the transformer. Load losses consist of ohmic loss in the windings due to the load current and stray losses due to the eddy currents induced by the leakage flux in the windings, core clamps, magnetic shields, tank walls, and other conducting parts. The ohmic loss of a transformer varies directly with temperature, whereas the stray losses vary inversely with temperature.

For a transformer with a tap changer, the test must be conducted at the rated current and voltage of the nominal tap position.

### 4.5.2 Tests for Measuring Load Losses

Connect the transformer with either the high-voltage or low-voltage windings to the appropriate test set. Then short-circuit the winding that was not connected to the test set. Apply a voltage at the rated frequency (of the transformer under test) to the connected windings to produce the rated current in the transformer. Take the readings of the wattmeter(s), the ammeters(s), and rms voltmeter(s).

Regardless of the test set selected, the following preparatory requirements must be satisfied for accurate test results:

- (a) Determine the temperature of the windings using the applicable method in section 3.2.1 or section 3.2.2.
- (b) The conductors used to short-circuit the windings must have a cross-sectional area equal to, or greater than, the corresponding transformer leads.
- (c) When the tester uses a power supply that is not synchronized with an electric utility grid, such as a dc/ac motor-generator set, follow the provisions of the NOTE in section 4.4.2.

### 4.5.3 Corrections

#### 4.5.3.1 Correction for Instrumentation Losses

Determine the losses attributable to the voltmeters, ammeter, wattmeter and short-circuiting conductor (SC), and to the instrument transformers if they are used, and deduct these losses from the measurement of total load losses.

#### 4.5.3.2 Correction for Phase Angle Errors

Corrections for phase angle errors are not required if the instrumentation is calibrated over the entire range of power factors and phase angle errors. Otherwise, determine whether to correct for phase angle errors from the magnitude of the normalized per unit correction,  $\beta_n$ , obtained by using equation 4-3 as follows:

$$\beta_n = \frac{V_{lm} I_{lm} (\beta_w - \beta_v + \beta_c) \sin \phi}{P_{lm}} \quad (4-3)$$

The correction must be applied if  $\beta_n$  is outside the limits of  $\pm 0.01$ . If  $\beta_n$  is within the limits of  $\pm 0.01$ , the correction is permitted but not required.

If the correction for phase angle errors is to be applied, first examine the total system phase angle ( $\beta_w - \beta_v + \beta_c$ ). Where the total system phase angle is equal to or less than  $\pm 12$  milliradians ( $\pm 41$  minutes), use either equation 4-4 or 4-5 to correct the measured load loss power for phase angle errors, and where the total system phase angle exceeds  $\pm 12$  milliradians ( $\pm 41$  minutes) use equation 4-5, as follows:

$$P_{lc1} = P_{lm} - V_{lm} I_{lm} (\beta_w - \beta_v + \beta_c) \sin \phi \quad (4-4)$$

$$P_{lc1} = V_{lm} I_{lm} \cos (\Phi + \beta_w - \beta_v + \beta_c) \quad (4-5)$$

The symbols in this section (4.5.3.2) have the following meanings:

$P_{lc1}$  is the corrected wattmeter reading for phase angle errors,

$P_{lm}$  is the actual wattmeter reading,

$V_{lm}$  is the measured voltage at the transformer winding,

$I_{lm}$  is the measured rms current in the transformer winding,

$PF = \frac{P_{lm}}{V_{lm} I_{lm}}$  is the measured power factor of the load loss impedance,

$\phi = \cos^{-1} \frac{P_{lm}}{V_{lm} I_{lm}}$  is the measured phase angle between  $V_{lm}$  and  $I_{lm}$ ,

$\beta_w$  is the phase angle error (in radians) of the wattmeter; the error is positive if the phase angle between the voltage and current phasors as sensed by the wattmeter is

smaller than the true phase angle, thus effectively increasing the measured power,

$\beta_v$  is the phase angle error (in radians) of the voltage transformer; the error is positive if the secondary voltage leads the primary voltage, and

$\beta_c$  is the phase angle error (in radians) of the current transformer; the error is positive if the secondary current leads the primary current.

The instrumentation phase angle errors used in the correction equations must be specific for the test conditions involved.

#### 4.5.3.3 Temperature Correction of Load Loss

When the measurement of load loss is made at a temperature  $T_{lm}$  that is different from the reference temperature, use the procedure summarized in the equations 4-6 to 4-10 to correct the measured load loss to the reference temperature.

Calculate the ohmic loss ( $P_e$ ) by using equation 4-6 as follows:

$$\begin{aligned}
 P_e &= P_{e(p)} + P_{e(s)} \\
 &= I_{lm(p)}^2 R_{dc(p)} TC_{(p)} + I_{lm(s)}^2 R_{dc(s)} TC_{(s)} \\
 &= I_{lm(p)}^2 \left[ R_{dc(p)} TC_{(p)} + \left[ \frac{N_1}{N_2} \right]^2 R_{dc(s)} TC_{(s)} \right]
 \end{aligned}
 \tag{4-6}$$

Obtain the stray loss by subtracting the calculated ohmic loss from the measured load loss, by using equation 4-7 as follows:

$$P = P_{lcl} - P_e \tag{4-7}$$

Correct the ohmic and stray losses to thereference temperature for the load loss by using equations 4-8 and 4-9, respectively, as follows:

$$\begin{aligned}
 P_{er} &= P_{e(p)} \frac{T_{k(p)} + T_{lr}}{T_{k(p)} + T_{lm}} + P_{e(s)} \frac{T_{k(s)} + T_{lr}}{T_{k(s)} + T_{lm}} \\
 &= I_{lm(p)}^2 \left[ R_{dc(p)} \frac{T_{k(p)} + T_{lr}}{T_{k(p)} + T_{dc}} + \left[ \frac{N_1}{N_2} \right]^2 R_{dc(s)} \frac{T_{k(s)} + T_{lr}}{T_{k(s)} + T_{dc}} \right]
 \end{aligned}
 \tag{4-8}$$

$$P_{sr} = (P_{lcl} - P_e) \frac{T_k + T_{lr}}{T_k + T_{lm}} \tag{4-9}$$

Add the ohmic and stray losses, corrected to the reference temperature, to give the load loss,  $P_{lc2}$ , at the reference temperature, by using equation (4-10) as follows:

$$\begin{aligned}
 P_{lc2} &= P_{er} + P_{sr} \\
 &= I_{lm(p)}^2 \left[ R_{dc(p)} \frac{T_{k(p)} + T_{lr}}{T_{k(p)} + T_{dc}} + \left[ \frac{N_1}{N_2} \right]^2 R_{dc(s)} \frac{T_{k(s)} + T_{lr}}{T_{k(s)} + T_{dc}} \right] \\
 &\quad + \left[ P_{lc1} - I_{lm(p)}^2 \left[ R_{dc(p)} TC_{(p)} + \left[ \frac{N_1}{N_2} \right]^2 R_{dc(s)} TC_{(s)} \right] \right] \frac{T_k + T_{lm}}{T_k + T_{lr}}
 \end{aligned}
 \tag{4-10}$$

The symbols in this section (4.5.3.3) have the following meanings:

$I_{lm(p)}$  is the primary current in amperes,

$I_{lm(s)}$  is the secondary current in amperes,

$P_e$  is the ohmic loss in the transformer in watts at the temperature  $T_{lm}$ ,

$P_{e(p)}$  is the ohmic loss in watts in the primary winding at the temperature  $T_{lm}$ ,

$P_{e(s)}$  is the ohmic loss in watts in the secondary winding at the temperature  $T_{lm}$ ,

$P_{er}$  is the ohmic loss in watts corrected to the reference temperature,

$P_{lc1}$  is the measured load loss in watts, corrected for phase angle error, at the temperature  $T_{lm}$ ,

$P_{lc2}$  is the load loss at the reference temperature,

$P_s$  is the stray loss in watts at the temperature  $T_{lm}$ ,

$P_{sr}$  is the stray loss in watts corrected to the reference temperature,

$R_{dc(p)}$  is the measured dc primary winding resistance in ohms,

$R_{dc(s)}$  is the measured dc secondary winding resistance in ohms,

$TC_{(p)} = \frac{T_{k(p)} + T_{lm}}{T_{k(p)} + T_{dc}}$  is the temperature correction factor for the primary winding

$TC_{(s)} = \frac{T_{k(s)} + T_{lm}}{T_{k(s)} + T_{dc}}$  is the temperature correction factor for the secondary winding

$T_k$  is the critical temperature in degrees Celsius for the material of the transformer windings. Where copper is used in both primary and secondary windings,  $T_k$  is 234.5°C; where aluminum is used in both primary and secondary windings,  $T_k$  is 225°C,

$T_{k(p)}$  is the critical temperature in degrees Celsius for the material of the primary winding: 234.5°C if copper and 225 °C if aluminum,

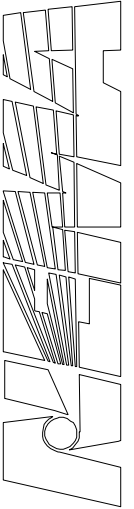
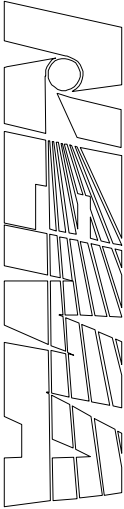
$T_{k(s)}$  is the critical temperature in degrees Celsius for the material of the secondary winding: 234.5°C if copper and 225°C if aluminum,

$T_{lm}$  is the temperature in degrees Celsius at which the load loss is measured,

$T_{lr}$  is the reference temperature for the load loss in degrees Celsius,

$T_{dc}$  is the temperature in degrees Celsius at which the resistance values are measured, and

$N1/N2$  is the ratio of the number of turns in the primary winding ( $N1$ ) to the number of turns in the secondary winding ( $N2$ ); for a primary winding with taps,  $N1$  is the number of turns used when the voltage applied to the primary winding is the rated primary voltage.



## Section 5 DETERMINING THE EFFICIENCY VALUE OF THE TRANSFORMER

This section presents the equations to use in determining the efficiency value of the transformer at the required reference conditions and at the specified loading level. The details of measurements are described in sections 3 and 4.

### 5.1 OUTPUT LOADING LEVEL ADJUSTMENT

If the output loading level for energy efficiency is different from the level at which the load loss power measurements were made, then adjust the corrected load loss power,  $P_{lc2}$ , by using equation 5-1 as follows:

$$P_{lc} = P_{lc2} \left[ \frac{P_{os}}{P_{or}} \right] = P_{lc2} L^2 \tag{5-1}$$

Where:

$P_{lc}$  is the load loss power adjusted to the specified energy efficiency load level,

$P_{lc2}$  is as calculated in section 4.5.3.3,

$P_{or}$  is the rated transformer output power (name plate),

$P_{os}$  is the specified energy efficiency load level, where  $P_{os} = P_{or} L^2$ , and

$L$  is the per unit load level, e.g., if the load level is 50 percent then “ $L$ ” will be 0.5.

### 5.2 TOTAL LOSS POWER CALCULATION

Calculate the corrected total loss power by using equation 5-2 as follows:

$$P_{ts} = P_{nc} + P_{lc} \tag{5-2}$$

Where:

$P_{ts}$  is the corrected total loss power adjusted for the transformer output loading specified by the standard,

$P_{nc}$  is as calculated in section 4.4.3.3, and

$P_{lc}$  is as calculated in section 5.1.

### 5.3 ENERGY EFFICIENCY CALCULATION

Calculate efficiency ( $\eta$ ) at specified energy efficiency load level,  $P_{os}$ , by using equation 5-3 as follows:

$$\eta = \frac{P_{os}}{P_{os} + P_{ts}} \quad (5-3)$$

Where:

$P_{os}$  is as described and calculated in section 5.1, and

$P_{ts}$  is as described and calculated in section 5.2.

### 5.4 SIGNIFICANT FIGURES IN POWER LOSS AND EFFICIENCY DATA

In measured and calculated data, retain enough significant figures to provide at least 1 percent resolution in power loss data and 0.01 percent resolution in efficiency data.

## 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 2-2.

### 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.

## Section 7 MANUFACTURER'S DETERMINATION OF EFFICIENCY FOR DISTRIBUTION TRANSFORMERS

### 7.1 METHODS USED TO DETERMINE EFFICIENCY

#### 7.1.1 General Requirements

A manufacturer must determine the efficiency of each basic model of distribution transformer in one of the two following ways:

1. Testing in accordance with the procedures in the previous sections of this standard and paragraph 7.2.2 of this section,

Or

2. Application of an alternative efficiency determination method (AEDM) that meets the requirements of paragraphs 7.1.2 and 7.1.3 of this section.

A manufacturer may use an AEDM to determine the efficiency of one or more untested basic models only if it determines the efficiency of at least five of its other basic models (selected in accordance with paragraph 7.2.1 of this section) through actual testing.

#### 7.1.2 Alternative Efficiency Determination Method

A manufacturer may apply an AEDM to a basic model only if:

- The AEDM has been derived from a mathematical model that represents the electrical characteristics of that basic model;
- The AEDM is based on engineering and statistical analysis, computer simulation or modeling, or other analytic evaluation of performance data; and
- In applying the AEDM to distribution transformers, the manufacturer uses the AEDM only for one or more of its basic models in one of the following groups of distribution transformers: low-voltage dry type transformers, medium-voltage dry type transformers, and liquid immersed transformers.

#### 7.1.3 Substantiation of an Alternative Efficiency Determination Method

Before using an AEDM, the manufacturer must substantiate the AEDM's accuracy and reliability as follows:

- (i) Apply the AEDM to at least five of the manufacturer's basic models that have been selected for testing in accordance with paragraph 7.2.1 of this section, and calculate the power loss for each of these basic models;

(ii) Test at least five units of each of these basic models in accordance with the applicable test procedure and paragraph 7.2.2 of this section, and determine the power loss for each of these basic models;

(iii) The predicted total power loss for each of these basic models, calculated by applying the AEDM pursuant to paragraph 7.1.3(i) of this section, must be within  $\pm 5\%$  of the mean total power loss determined from the testing of that basic model pursuant to paragraph 7.1.3(ii) of this section; and

(iv) Calculate for each of these basic models the percentage that its power loss calculated pursuant to paragraph 7.1.3(i) is of its power loss determined from testing pursuant to paragraph 7.1.3(ii), compute the average of these percentages, and that calculated average power loss, expressed as a percentage of the average power loss determined from testing, must be no less than 97% and no greater than 103%.

#### **7.1.4 Subsequent Verification of an AEDM**

(i) Each manufacturer shall periodically (at a minimum every 12 months) select basic models representative of those to which it has applied an AEDM, and for each basic model selected shall either:

(A) Subject a sample of at least five units to testing in accordance with the applicable test procedure and paragraph 7.2.2 of this section by an independent testing laboratory; or

(B) Have an independent state registered professional engineer, who is qualified to perform an evaluation of distribution transformer efficiency in a highly competent manner and who is not an employee of the manufacturer, review the manufacturer's representations and certify that the results of the AEDM accurately represent the total power loss and efficiency of the basic model.

Verification of the AEDM shall be required in the case that design software used as an AEDM has been updated. Prior data may be used to re-verify the AEDM

(ii) Each manufacturer that has used an AEDM under this section shall have available for inspection by the Department of Energy records showing: the method or methods used; the mathematical model, the engineering or statistical analysis, computer simulation or modeling, and other analytic evaluation of performance data on which the AEDM is based; complete test data, product information, and related information that the manufacturer has generated or acquired pursuant to paragraphs 7.1.3 and 7.1.4(i) of this section; and the calculations used to determine the efficiency and total power losses of each basic model to which the AEDM was applied.

(iii) If requested by the Department, the manufacturer shall conduct simulations to predict the performance of particular basic models of distribution transformers specified by the Department, analyses of previous simulations conducted by the manufacturer, sample testing of basic models selected by the Department, or a combination of the foregoing.

## **7.2 ADDITIONAL TESTING REQUIREMENTS**

### **7.2.1 Selection of Basic Models for Testing If An AEDM is to be Applied**

(i) A manufacturer must select basic models for testing in accordance with the following criteria:

(A) Two of the basic models must be among the five basic models with the highest unit volumes of production by the manufacturer in the prior year, or during the prior 12-calendar-month period beginning in 2003,<sup>1</sup> whichever is later;

(B) No two basic models should have the same combination of power and voltage ratings; and

(C) At least one basic model should be single-phase and at least one should be three-phase.

(ii) In any instance where it is impossible for a manufacturer to select basic models for testing in accordance with all of these criteria, the criteria shall be given priority in the order in which they are listed. Within the limits imposed by the criteria, basic models shall be selected randomly.

### 7.2.2 Selection of Units for Testing Within a Basic Model

For each basic model a manufacturer selects for testing, it shall select a sample of units at random and test them. The sample shall be comprised of production units of the basic model, or units that are representative of such production units. The sample size shall be not fewer than five units, except that when the manufacturer would produce fewer than five units of a basic model over a reasonable period of time (approximately 180 days), then it must test each unit. However, a manufacturer may not use a basic model with a sample size of fewer than five units to substantiate or verify an AEDM pursuant to paragraphs 7.1.3 or 7.1.4 of this section. In a test of compliance with a represented efficiency:

The average efficiency of the sample,  $\bar{X}$ , which is defined by

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i$$

where  $X_i$  is the measured efficiency of unit  $i$  and  $n$  is the number of units tested, must satisfy the condition:

$$\bar{X} \geq \frac{100}{1 + \left(1 + \frac{.12}{\sqrt{n}}\right) \left(\frac{100}{RE} - 1\right)}$$

where RE is the represented efficiency.

<sup>1</sup> When identifying these five basic models, any basic model that does not comply with Federal energy conservation standards for distribution transformers that may be in effect shall be excluded from consideration.