

APPENDIX A TO SUBPART K OF PART 431—UNIFORM TEST METHOD FOR MEASURING THE ENERGY CONSUMPTION OF DISTRIBUTION TRANSFORMERS

1.0 DEFINITIONS.

The definitions contained in §§431.2 and 431.192 are applicable to this appendix A.

2.0 ACCURACY REQUIREMENTS.

(a) Equipment and methods for loss measurement shall be sufficiently accurate that measurement error will be limited to the values shown in Table 2.1.

TABLE 2.1—TEST SYSTEM ACCURACY REQUIREMENTS FOR EACH MEASURED QUANTITY

Measured quantity	Test system accuracy
Power Losses .....	±3.0%
Voltage .....	±0.5%
Current .....	±0.5%
Resistance .....	±0.5%
Temperature .....	±1.0 °C

(b) Only instrument transformers meeting the 0.3 metering accuracy class, or better, may be used under this test method.

3.0 RESISTANCE MEASUREMENTS

3.1 General Considerations

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

(b) 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. Observe precautions while taking measurements, such as those in section 3.4, in order to maintain measurement uncertainty limits specified in Table 2.1.

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.

3.2.1.1 Methods

Record the winding temperature ( $T_{dc}$ ) of liquid-immersed transformers as the average of either of the following:

(a) The measurements from two temperature sensing devices (for example, thermocouples) applied to the outside of the

transformer tank and thermally insulated from the surrounding environment, with one located at the level of the oil and the other located near the tank bottom or at the lower radiator header if applicable; or

(b) The measurements from two temperature sensing devices immersed in the transformer liquid, with one located directly above the winding and other located directly below the winding.

3.2.1.2 Conditions

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 dry-type transformers as either of the following:

(a) For ventilated dry-type units, use the average of readings of four or more thermometers, thermocouples, or other suitable temperature sensors inserted within the coils. Place the sensing points of the measuring devices as close as possible to the winding conductors. For sealed units, such as epoxy-coated or epoxy-encapsulated units, use the average of four or more temperature sensors located on the enclosure and/or cover, as close to different parts of the winding assemblies as possible; or

(b) For both ventilated and sealed units, use the ambient temperature of the test area, under the following conditions:

(1) All internal temperatures measured by the internal temperature sensors must not differ from the test area ambient temperature by more than 2 °C.

(2) Enclosure surface temperatures for sealed units must not differ from the test area ambient temperature by more than 2 °C.

(3) Test area ambient temperature should not have changed by more than 3 °C for 3 hours before the test.

(4) Neither voltage nor current has been applied to the unit under test for 24 hours. In addition, increase this initial 24 hour period 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 additional 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

(a) 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.

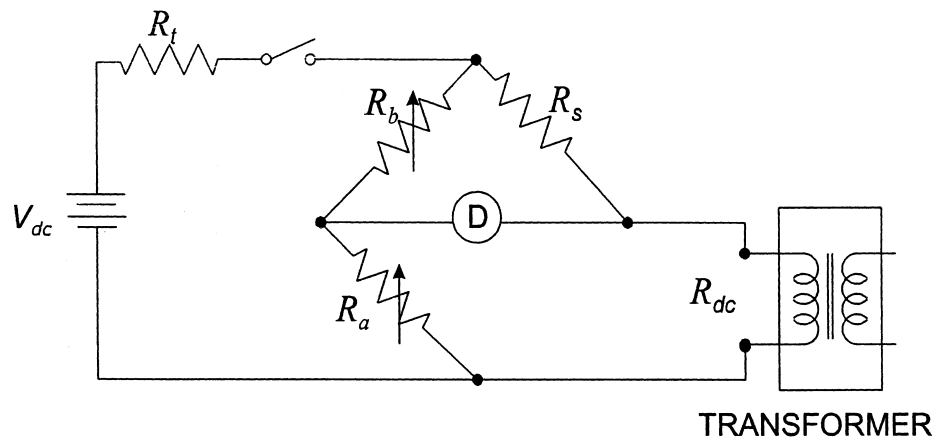


Figure 3.1 Wheatstone Bridge

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.

(b) 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

(a) 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.

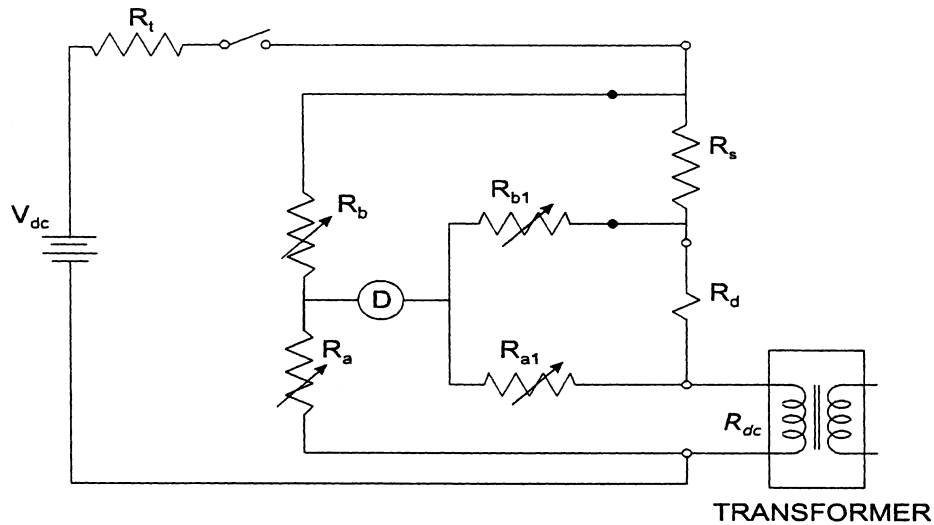


Figure 3.2 Kelvin Bridge

(b) 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:

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

(c) 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.

(a) 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 percent of the winding current. Connect the transformer winding under test to the circuit shown in Figure 3.3.

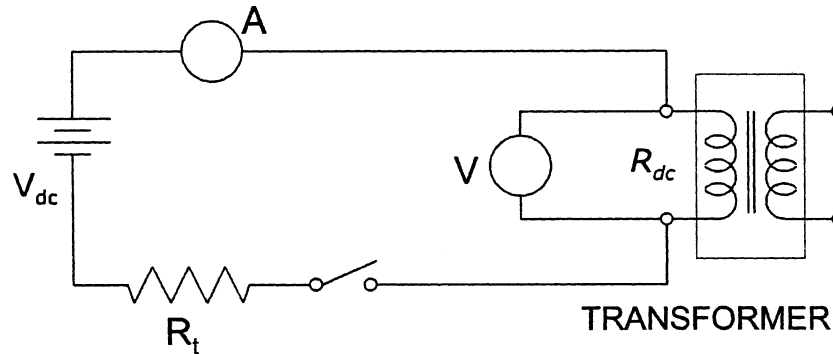


Figure 3.3 Voltmeter-Ammeter Method

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.

(b) To perform the measurement, turn on the source to produce current no larger than 15 percent 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.

(c) 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. Any meter used to measure a transformer's winding resistance must have specifications for resistance range, current range, and ability to measure highly inductive resistors that

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 2.0.

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 percent change in the measured resistance.

(c) Maintain the dc test current at or below 15 percent of the rated winding current.

(d) Inclusion of a stabilizing resistor  $R_t$  (see section 3.4.2) will require higher source voltage.

(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.

(a) 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 2.0:

(b) 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,

$L_{lc}$  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  $R_{dc}$  and the resistance  $R_s$  of the standard resistor in the bridge circuit.

(c) Because  $R_{tc}$  is in the denominator of the expression for the time constant, increasing the resistance  $R_{tc}$  will decrease the time constant. If the time constant in a given test circuit is too long 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.

(a) 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 percent of the rated load is 55 °C. For medium-voltage, dry-type transformers loaded at 50 percent of the rated load, and for low-voltage, dry-type transformers loaded at 35 percent of the rated load, the reference temperature is 75 °C.

(b) Correct the measured resistance to the resistance at the reference temperature using equation 3-6 as follows:

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

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.

### 4.0 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 test sets that are identical, except that shorting straps are added for the load-loss test. The measured quantities will need correction for instrumentation losses and may need corrections for known phase angle errors in measuring equipment and for the

waveform 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. Test distribution transformers designed for harmonic currents using a sinusoidal waveform ( $k=1$ ).

#### 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.

#### 4.3 Test Sets.

(a) 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 2.0. 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 2.0 or the individual phase angle error exceeds the values specified in section 4.5.3.

(b) 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 together with instruments to measure current, voltage, or power where the current or voltage of the transformer under test exceeds the measurement capability of such instruments. 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.

##### 4.3.1.1 Without Instrument Transformers.

(a) A single-phase test set without an instrument transformer is shown in Figure 4.1.

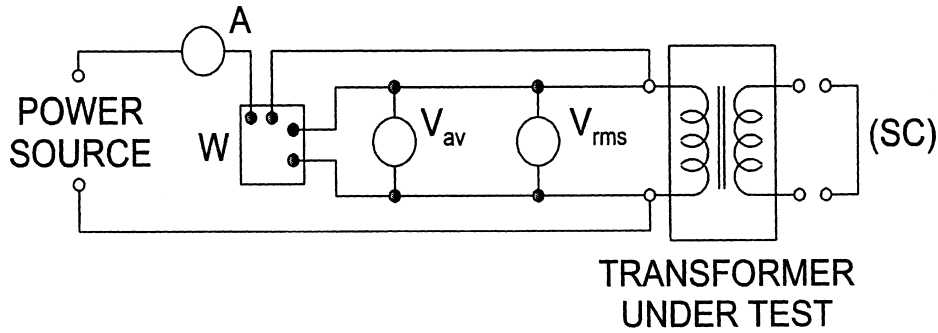


Figure 4.1 Single-Phase Test Set Without Instrument Transformers

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  $V_{l(m)}$ , 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,

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.

(b) 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.

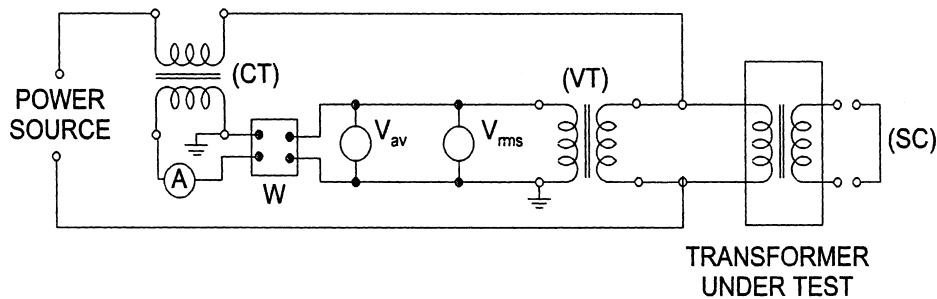


Figure 4.2 Single-Phase Test Set With Instrument Transformers

4.3.2 Three-Phase Test Sets.

Use these for testing three-phase distribution transformers. Use in a four-wire, three-wattmeter test circuit.

4.3.2.1 Without Instrument Transformers.

(a) 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 in-

strumentation system of a three-phase test set without transformers may consist of a multi-function analyzer.

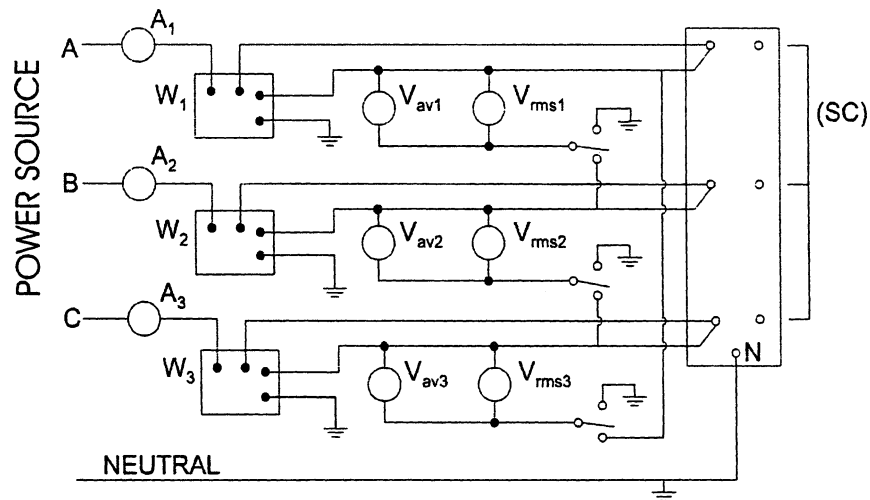


Figure 4.3 Three-Phase Test Set Without Instrument Transformers

(b) 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.

(c) 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.

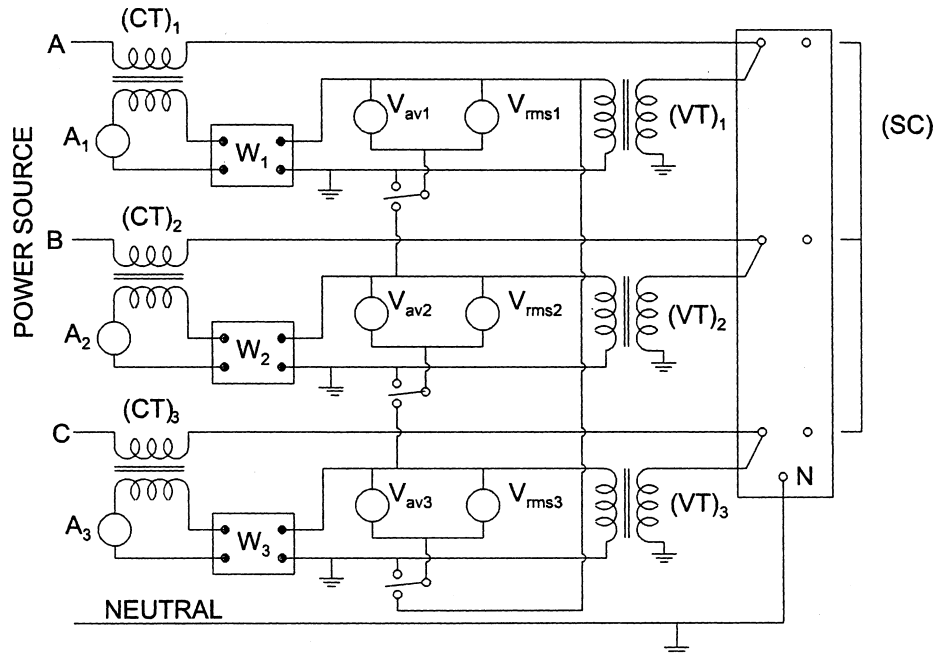


Figure 4.4 Three-Phase Test Set with Instrument Transformers

4.3.2.3 Test Set Neutrals.

If the power source in the test circuit is wye-connected, ground the neutral. If the power source in the test circuit is delta-connected, use a grounding transformer to obtain neutral and ground for the test.

4.4 No-Load Losses: Measurement and Calculations.

4.4.1 General Considerations.

Measurement corrections are permitted but not required for instrumentation losses and for losses from auxiliary devices. Measurement corrections are required:

- (a) When the waveform of the applied voltage is non-sinusoidal; and
- (b) When the core temperature or liquid temperature is outside the 20 °C ±10 °C range.

4.4.2 No-Load Loss Test.

(a) 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 section 4.4.2(a)(2). 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 following precautions:

- (1) 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.
- (2) Energized windings. Energize either the high voltage or the low voltage winding of the transformer under test.
- (3) 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.

(b) 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.

Measured losses attributable to the voltmeters and wattmeter voltage circuit, and to voltage transformers if they are used, may be deducted from the total no-load losses measured during testing.

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

(a) 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 percent. In such a case, no correction is required.

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

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

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

Where:

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

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

$P_1$  is the per unit hysteresis loss,

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

$P_1 + P_2 = 1$ ,

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

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

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

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

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

Where:

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

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

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

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

#### 4.5 Load Losses: Measurement and Calculations.

##### 4.5.1 General Considerations.

(a) 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.

(b) For a transformer with a tap changer, conduct the test at the rated current and rated-voltage tap position. For a transformer that has a configuration of windings which allows for more than one nominal rated voltage, determine its load losses either in the winding configuration in which the highest losses occur or in each winding configuration in which the transformer can operate.

##### 4.5.2 Tests for Measuring Load Losses.

(a) 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).

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

(1) Determine the temperature of the windings using the applicable method in section 3.2.1 or section 3.2.2.

(2) The conductors used to short-circuit the windings must have a cross-sectional

area equal to, or greater than, the corresponding transformer leads, or, if the tester uses a different method to short-circuit the windings, the losses in the short-circuiting conductor assembly must be less than 10 percent of the transformer's load losses.

(3) 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 Losses from Instrumentation and Auxiliary Devices.

4.5.3.1.1 Instrumentation Losses.

Measured losses attributable to the voltmeters, wattmeter voltage circuit and short-circuiting conductor (SC), and to the voltage transformers if they are used, may be deducted from the total load losses measured during testing.

4.5.3.1.2 Losses from Auxiliary Devices.

Measured losses attributable to auxiliary devices (e.g., circuit breakers, fuses, switches) installed in the transformer, if any, that are not part of the winding and core assembly, may be excluded from load losses measured during testing. To exclude these losses, either (1) measure transformer losses without the auxiliary devices by removing or bypassing them, or (2) measure transformer losses with the auxiliary devices connected,

determine the losses associated with the auxiliary devices, and deduct these losses from the load losses measured during testing.

4.5.3.2 Correction for Phase Angle Errors.

(a) 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:

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

(b) 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.

(c) 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:

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

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

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

- $P_{cl}$  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,

$$\phi = \cos^{-1} \frac{P_{lm}}{V_{lm} I_{lm}}$$

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.

(e) 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.

(a) 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. The symbols used in these equations are defined at the end of this section.

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

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

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

$$P_s = P_{lc1} - P_e \quad (4-7)$$

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

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

$$P_{sr} = (P_{lc1} - P_e) \frac{T_k + T_{lm}}{T_k + T_{lr}} \quad (4-9)$$

(e) 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:

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

(f) 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  $T_{lm}$ .

## Department of Energy

## Pt. 431, Subpt. K, App. A

$P_{e(s)}$  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,

$T_k$  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; where both copper and aluminum are used in the same transformer, the value of 229 °C is used for  $T_k$ ,

$T_{k(p)}$  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,

$T_r$  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

$N_1/N_2$  is the ratio of the number of turns in the primary winding ( $N_1$ ) to the number of turns in the secondary winding ( $N_2$ ); for a primary winding with taps,  $N_1$  is the number of turns used when the voltage applied to the primary winding is the rated primary voltage.

### 5.0 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 3.0 and 4.0. For a transformer that has a configuration of windings which allows for more than one nominal rated voltage, determine its efficiency either at the voltage at which the highest losses occur or at each voltage at which the transformer is rated to operate.

#### 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:

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

Where:

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

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

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

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

$$P_{ts} = P_{nc} + P_{lc} \quad (5-2)$$

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

$$\eta = 100 \left( \frac{P_{os}}{P_{os} + P_{ts}} \right) \quad (5-3)$$

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.

### 6.0 TEST EQUIPMENT CALIBRATION AND CERTIFICATION

Maintain and calibrate test equipment and measuring instruments, maintain calibration records, and perform other test and measurement quality assurance procedures according to the following sections. The calibration of the test set must confirm the accuracy of the test set to that specified in section 2.0, Table 2.1.

#### 6.1 Test Equipment.

The party performing the tests shall control, calibrate and maintain measuring and test equipment, whether or not it owns the

## § 431.201

equipment, has the equipment on loan, or the equipment is provided by another party. 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 party performing the tests must:

(a) Identify the measurements to be made, the accuracy required (section 2.0) and select the appropriate measurement and test equipment;

(b) At prescribed intervals, or prior to use, identify, check and calibrate, if needed, all measuring and test equipment systems or devices that affect test accuracy, against certified equipment having a known valid relationship to nationally recognized standards; where no such standards exist, the basis used for calibration must 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; and

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

[71 FR 24999, Apr. 27, 2006, as amended at 71 FR 60662, Oct. 16, 2006]

EFFECTIVE DATE NOTE: At 71 FR 24999, Apr. 27, 2006, appendix A to subpart K of part 431 was added, effective May 30, 2006, except for section 6.2(f) and section 6.2 (b) and (c) which contain information collection requirements and will not become effective until approval has been given by the Office of Management and Budget.

## 10 CFR Ch. II (1–1–14 Edition)

### Subpart L—Illuminated Exit Signs

SOURCE: 70 FR 60417, Oct. 18, 2005, unless otherwise noted.

#### § 431.201 Purpose and scope.

This subpart contains energy conservation requirements for illuminated exit signs, pursuant to Part B of Title III of the Energy Policy and Conservation Act, as amended, 42 U.S.C. 6291–6309.

#### § 431.202 Definitions concerning illuminated exit signs.

*Basic model* means all units of a given type of covered product (or class thereof) manufactured by one manufacturer, having the same primary energy source, and which have essentially identical electrical, physical, and functional (or hydraulic) characteristics that affect energy consumption, energy efficiency, water consumption, or water efficiency.

*Face* means an illuminated side of an illuminated exit sign.

*Illuminated exit sign* means a sign that—

(1) Is designed to be permanently fixed in place to identify an exit; and

(2) Consists of an electrically powered integral light source that—

(i) Illuminates the legend “EXIT” and any directional indicators; and

(ii) Provides contrast between the legend, any directional indicators, and the background.

*Input power demand* means the amount of power required to continuously illuminate an exit sign model, measured in watts (W). For exit sign models with rechargeable batteries, input power demand shall be measured with batteries at full charge.

[70 FR 60417, Oct. 18, 2005, as amended at 71 FR 71372, Dec. 8, 2006; 76 FR 12504, Mar. 7, 2011]

#### TEST PROCEDURES

#### § 431.203 Materials incorporated by reference.

(a) *General.* The Department incorporates by reference the following test procedures into subpart L of part 431. The Director of the Federal Register has approved the material listed in